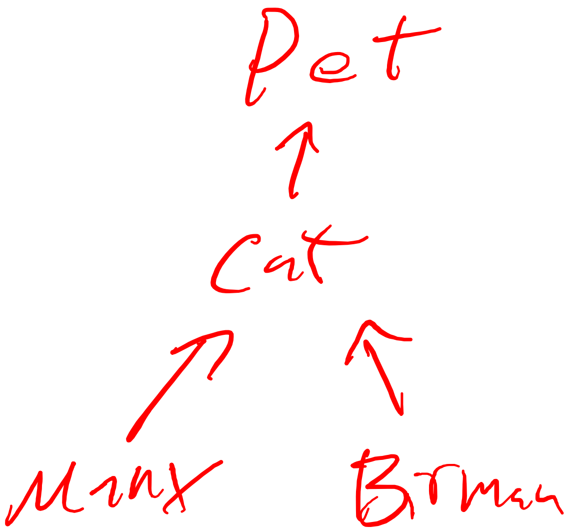
Warmup

Draw an **object diagram** depicting the state of the program's memory after executing the code to the right.

Assume the following subtype relationships:

- `Cat <: Pet`
- `Manx <: Cat`
- `Birman <: Cat`

```
Pet p = new Birman();
Cat c = (Cat)p;
p = new Manx();
Manx m = (Manx)p;
```



Warmup

What is the dynamic type of the object referenced by c?

```
Pet p = new Birman();
Cat c = (Cat)p;
p = new Manx();
Manx m = (Manx)p;
```

A. Pet

B. Cat

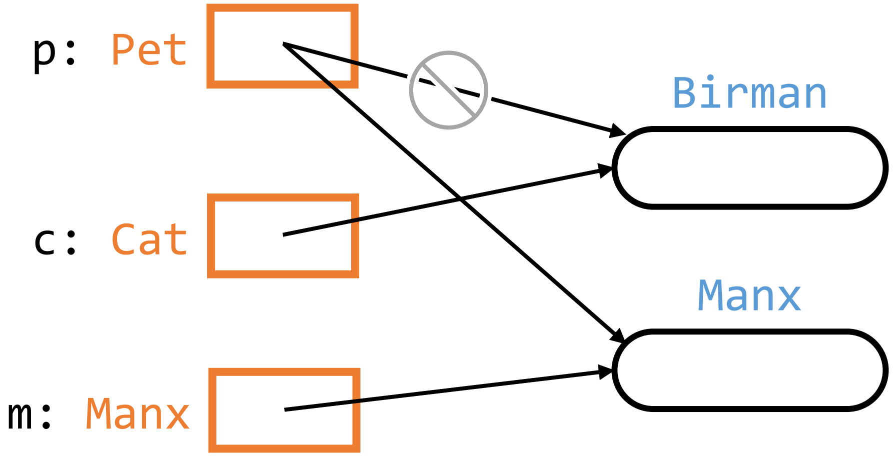
C. Birman

D. Manx

E. A ClassCastException would be thrown

Warmup (solution)

```
Pet p = new Birman();
Cat c = (Cat)p;
p = new Manx();
Manx m = (Manx)p;
```



CS 2110 Lecture 6

Inheritance, equality

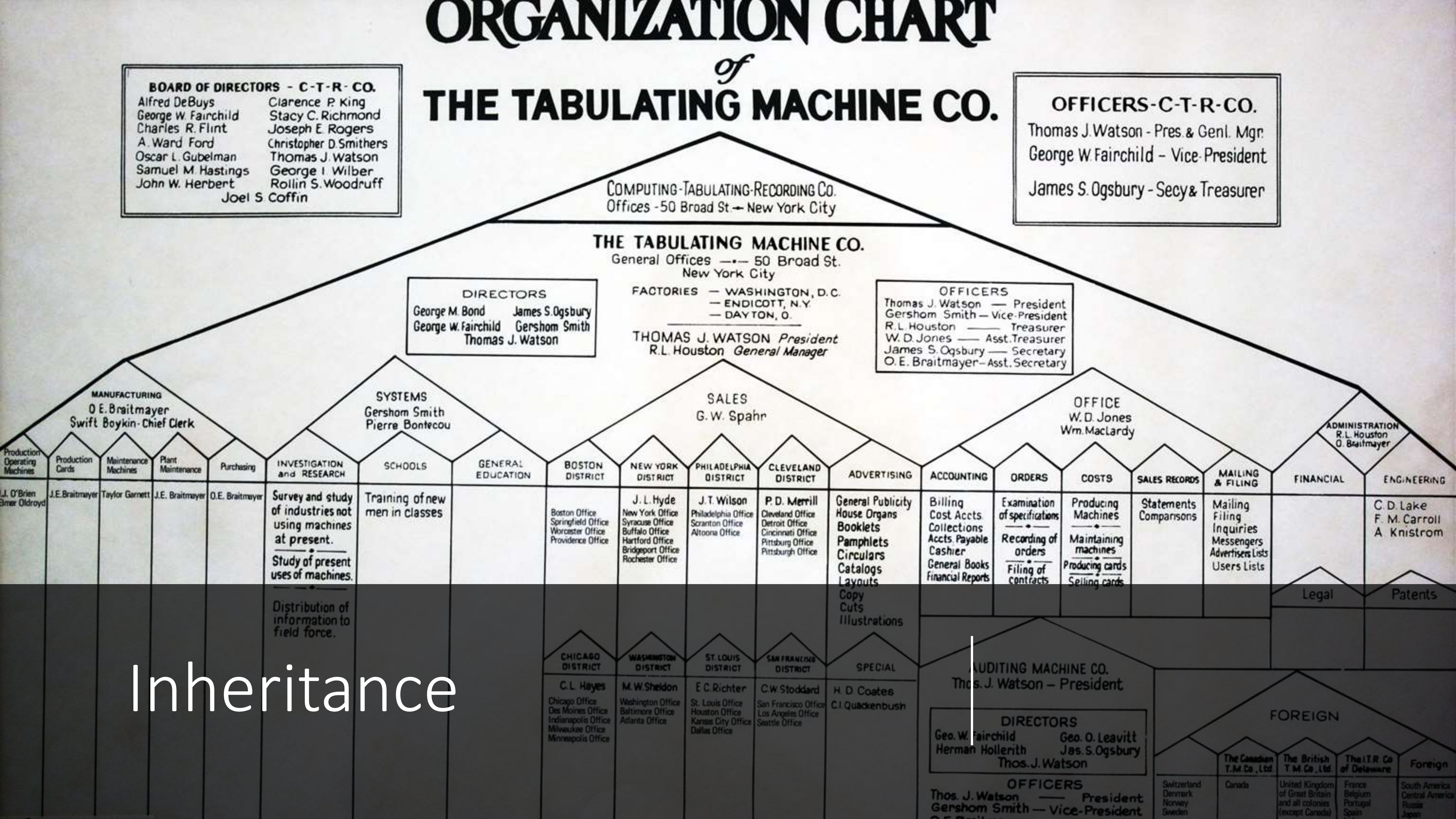
Coming up

A2 released

A1 grades incoming

Quiz 3

Inheritance



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Chess pieces revisited

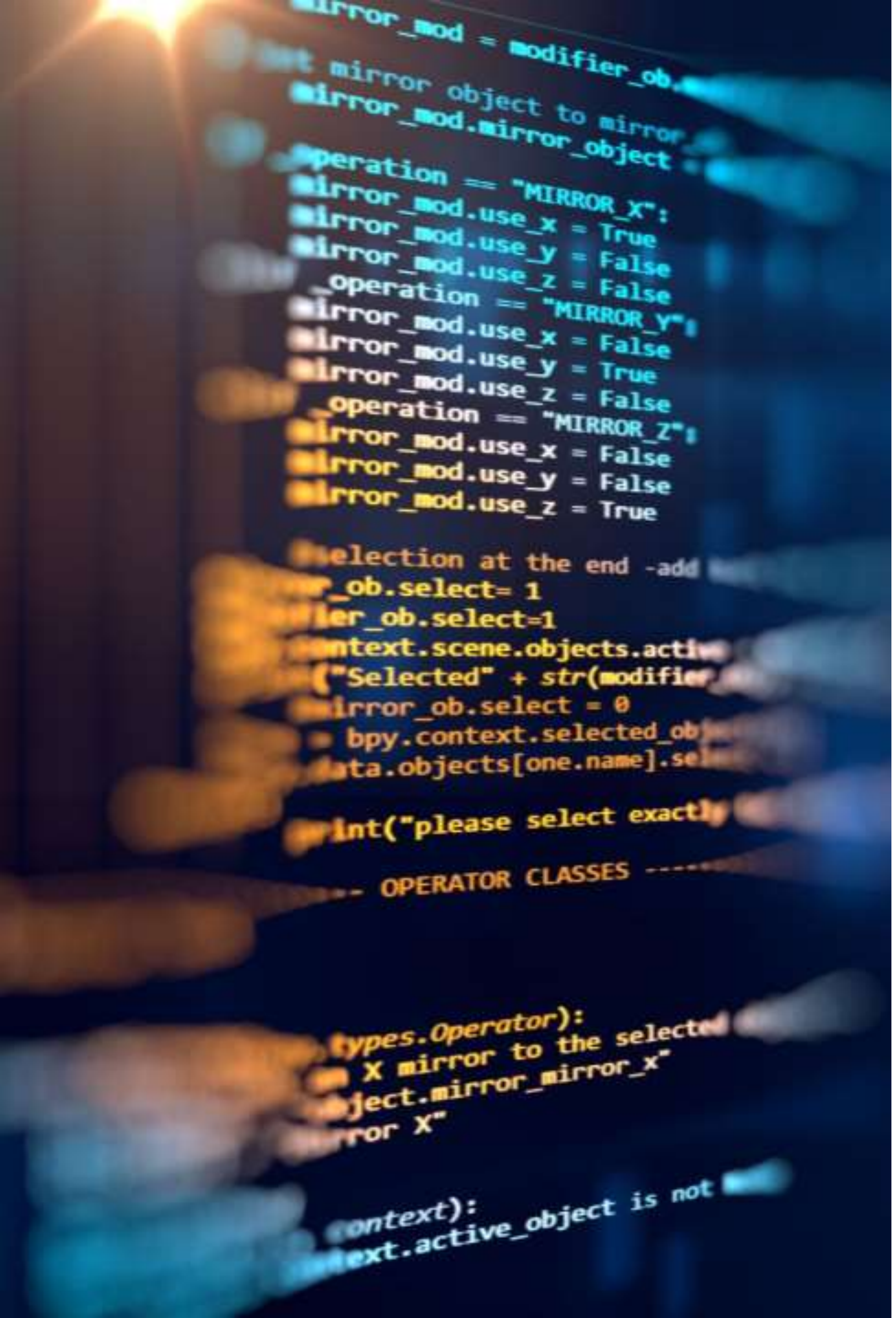
```
public class Knight
    implements Piece {
  private int row;
  private int col;
  private int player;
  public int player() {
    return player;
  }
  // ...
}
```

```
public class King
    implements Piece {
  private int row;
  private int col;
  private int player;
  private boolean hasMoved;
  public int player() {
    return player;
  }
  // ...
}
```

Chess pieces revisited

```java
public class Knight
    implements Piece {
  private int row;
  private int col;
  private int player;
  public int player() {
    return player;
  }
  // ...
}
```

```java
public class King
    implements Piece {
  private int row;
  private int col;
  private int player;
  private boolean hasMoved;
  public int player() {
    return player;
  }
  // ...
}
```



DRY principle: Don’t repeat yourself

- Duplicated code is not just tedious to write (or copy-paste) the first time
    - To fix a bug in duplicated code, must find all instances
    - Modifications that aren’t repeated everywhere lead to deviation in “common” behavior
- OOP languages can help you avoid duplication

Commonality beyond interfaces

- Interfaces guarantee *availability* of behaviors
- What if types have similar state? Identical behaviors?
  - Interfaces can't provide fields or method bodies that depend on fields
  - (they can provide method bodies that depend only on other methods)
- **Subclasses** allow a *derived class* to **inherit** fields and method bodies from a *parent class*
  - `class Derived extends Parent {…}`
  - Implies a *subtype* relationship: Derived <: Parent

Piece as a *superclass*

```java
public class Piece {
  private int row;
  private int col;
  private int player;

  public Piece(int row,
      int col, int player) {
    this.row = row;
    this.col = col;
    this.player = player;
}
```

```java
  public int player() {
    return player;
  }

  public boolean legalMove(
      int dstRow, int dstCol,
      Board board) { ??? }
}
```

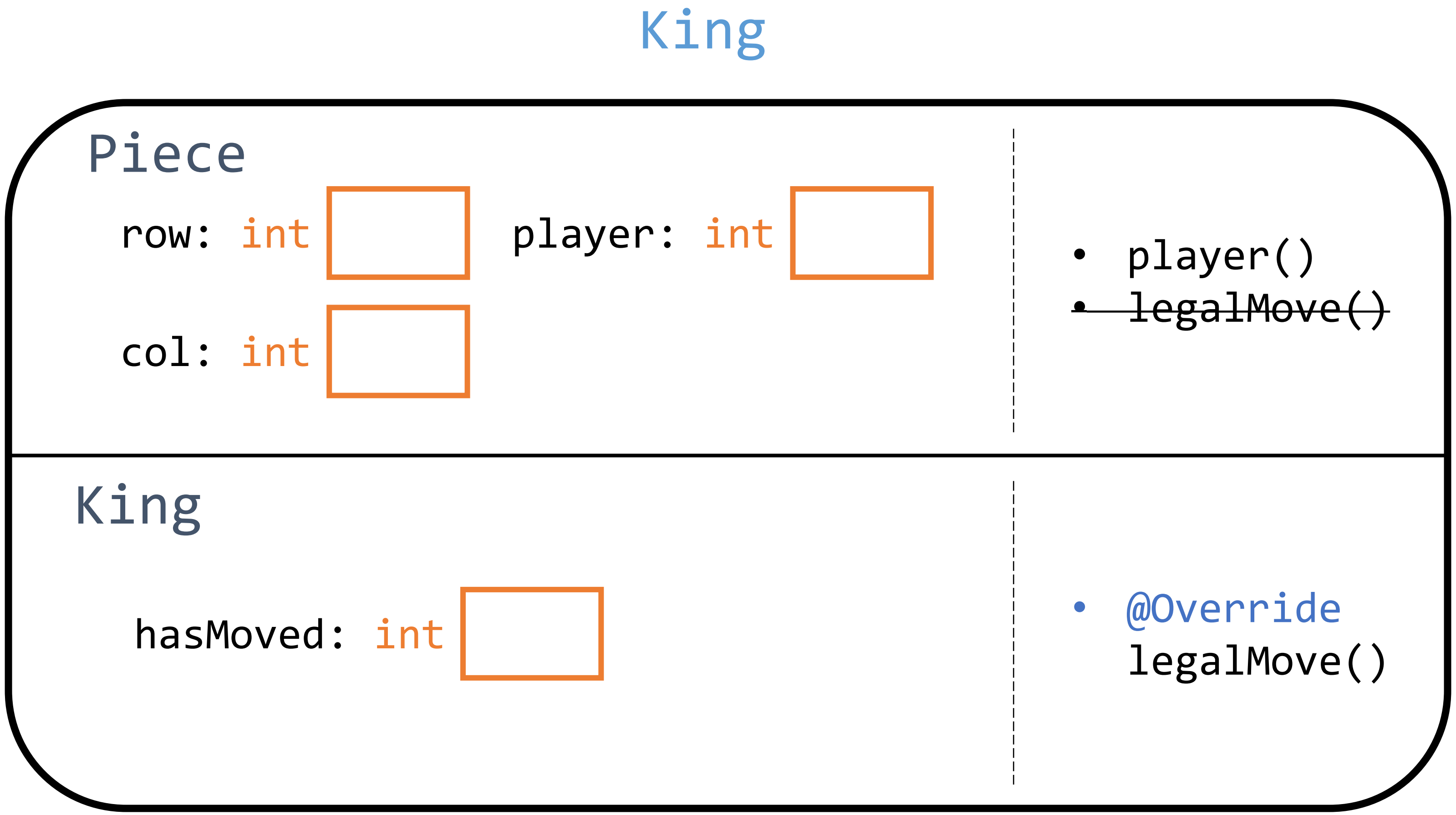
King as a subclass

```
public class King
    extends Piece {
 private boolean hasMoved;


 public King(int player) {
   super((player==1)?0:7,
         3, player);
   hasMoved = false;
 }
```

```
 @Override
  public boolean legalMove(
      int dstRow
      int dstCol,
      Board board) {…}
}
```

Object diagram showing inheritance



King

Piece

row: int

player: int

col: int

- player()
- ~~legalMove()~~

King

hasMoved: int

- @Override legalMove()

Parent section (above)

Derived section (below)

Accessibility

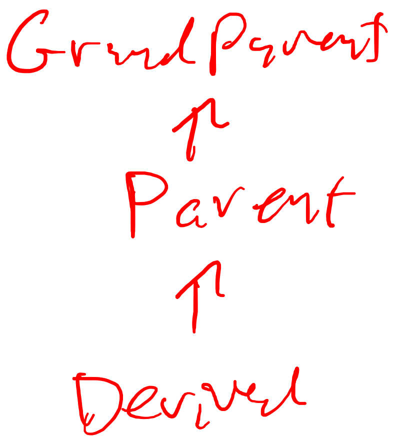
- Subclasses cannot see private members of parent class
  - Is this a concern?
- "Specialization interface": in what ways can subclasses tweak the behavior of a parent?
  - Another layer of **encapsulation**

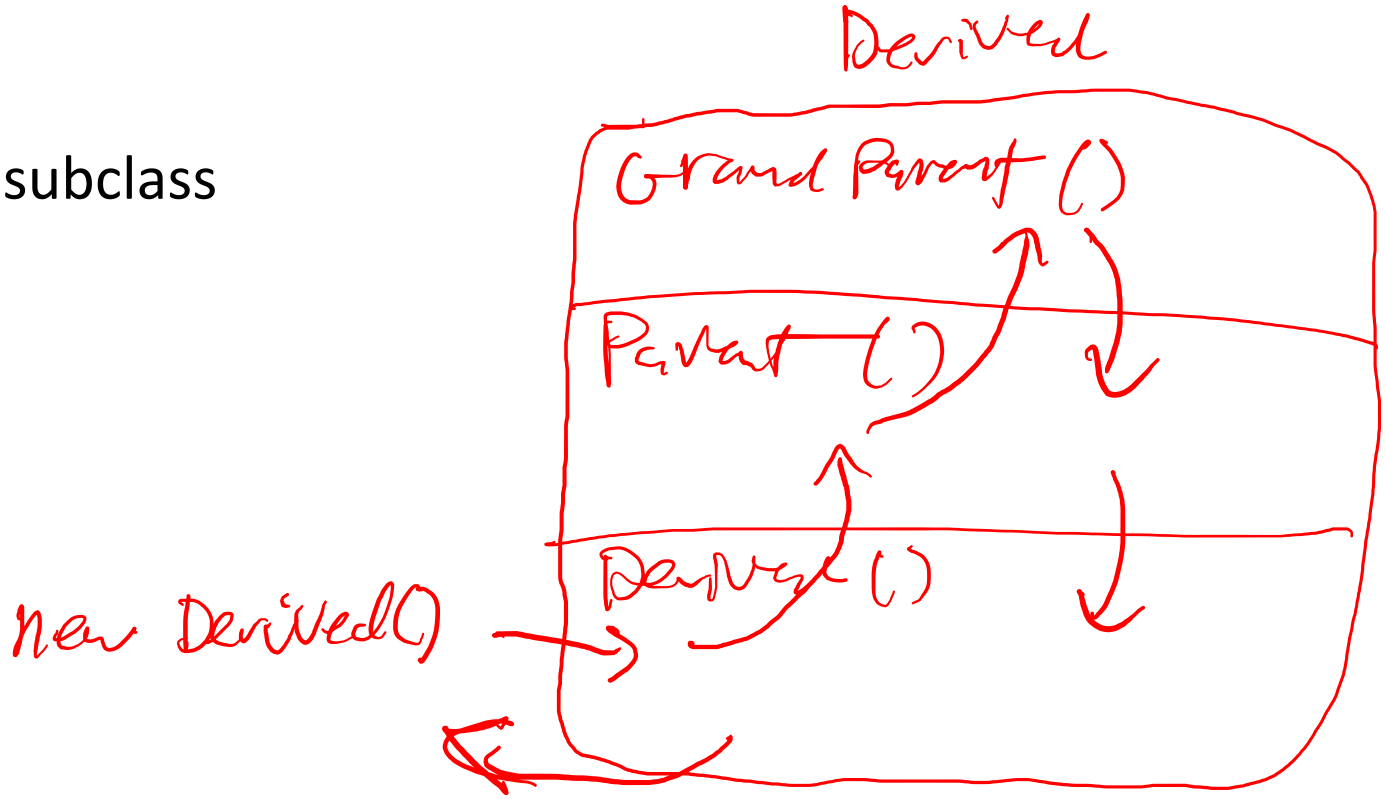
- `private` ("don't mess with my invariants")
  - Parent class has exclusive responsibility
- `protected` ("I'm trusting you")
  - Derived classes have rights and responsibilities
- `public`
  - The "client interface" is also usable by derived classes

Constructors

- Since some state *could* be private, subclass *must* call a parent class constructor
  - Invoked using `super()`
  - Must be *first* statement in subclass constructor

- Delegation order: fully construct superclass, then specialize



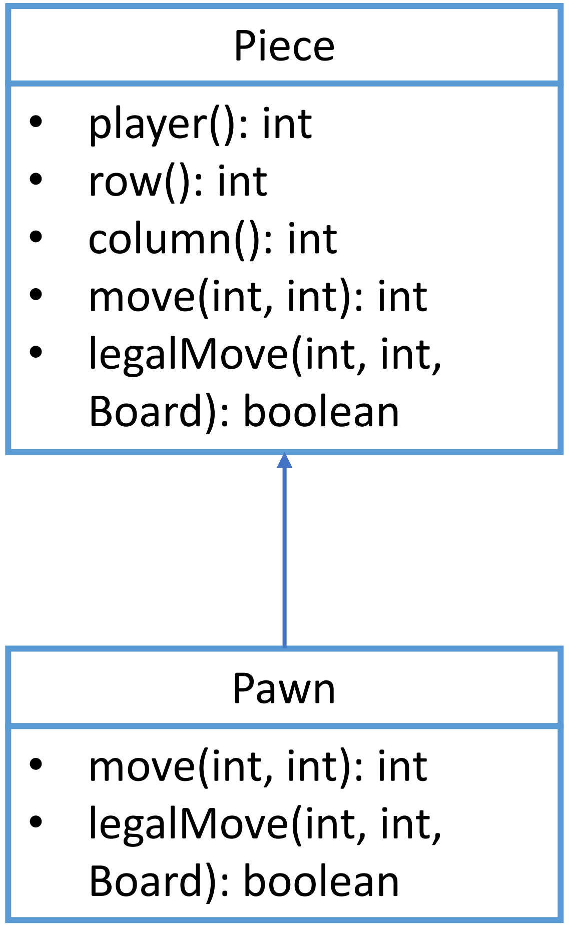


Overriding

- A subclass method with the same signature as a parent class method will **override** it
  - Whenever that method is invoked on the object, the *subclass* version will be executed
  - Consequence of **dynamic dispatch**

```
class Piece {
  boolean legalMove(
    int r, int c, Board b) {
    // IDK?
  }
}
class Pawn {
  @Override
  boolean legalMove(
    int r, int c, Board b) {
    // Pawn logic
  }
}
```

Dynamic dispatch illustrated



Piece

- player(): int
- row(): int
- column(): int
- move(int, int): int
- legalMove(int, int, Board): boolean

Pawn

- move(int, int): int
- legalMove(int, int, Board): boolean

```
Piece p = selectPiece();
// user selects a Pawn
p.move(newRow, newCol);
// which class’s move()
// code is run?
```

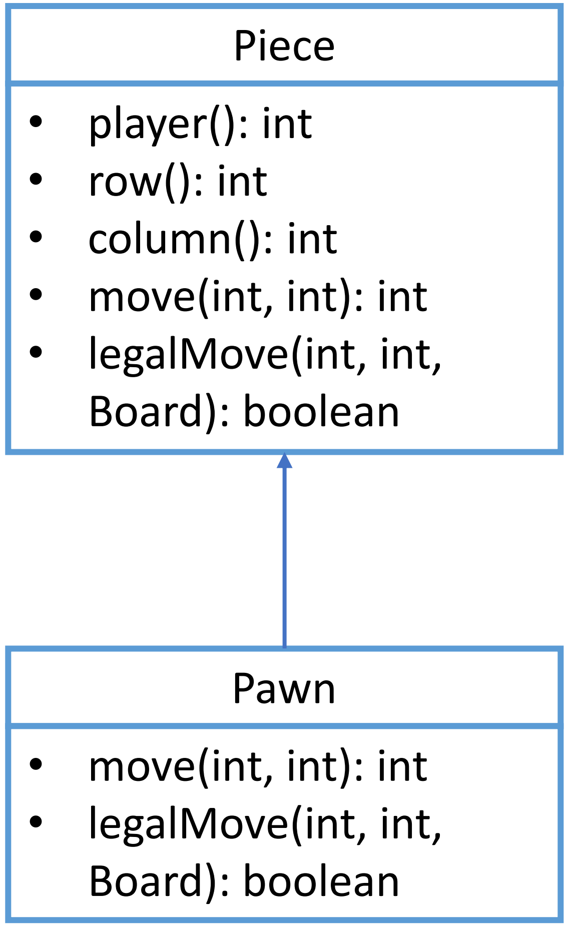
Overriding

- A subclass method with the same signature as a parent class method will **override** it
  - Whenever that method is invoked on the object, the *subclass* version will be executed
  - Consequence of **dynamic dispatch**
- Impossible for *client* to request a parent implementation
  - Only subclass impl could know about all the relevant invariants

- Subclass may delegate to its parent’s implementation

  -
    ```
    @Override
    public void move(int r,
        int c) {
      super.move(r, c);
      checkPromotion();
    }
    ```
- No way to prefer “grandparent’s” implementation

Bottom-up rule



Piece

- player(): int
- row(): int
- column(): int
- move(int, int): int
- legalMove(int, int, Board): boolean

Pawn

- move(int, int): int
- legalMove(int, int, Board): boolean

```
class Piece {
  boolean legalMove(…) {}
  void move(…) {
    if (legalMove(…)) {}
  }
}
class Pawn {
  @Override boolean legalMove(…) {}
  @Override void move(…) {
    super.move(…);
    checkPromotion();
  }
}
```

Checkpoint

```
class Parent {
  int foo(int x) { /* Parent impl */ }
  int bar(int x) {
    return foo(2*x + 1);
  }
}
class Derived extends Parent {
  int foo(int x) { /* Derived impl */ }
}
class Child extends Parent {
  int bar(int x) {
    return super.foo(x - 1);
  }
}
```

Which blocks of code are executed when the following client code is run?

```
Parent p = new Derived();
int ans = p.bar(42);
```

- A: `/* Parent impl */`
- B: `/* Derived impl */`
- C: Both Parent impl and Derived impl
- D: None of these
- E: Compile-time error

Checkpoint

```
class Parent {
  int foo(int x) { /* Parent impl */ }
  int bar(int x) {
    return foo(2*x + 1);
  }
}
class Derived extends Parent {
  int foo(int x) { /* Derived impl */ }
}
class Child extends Parent {
  int bar(int x) {
    return super.foo(x - 1);
  }
}
```

Which blocks of code are executed when the following client code is run?

```
Parent p = new Derived();
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```
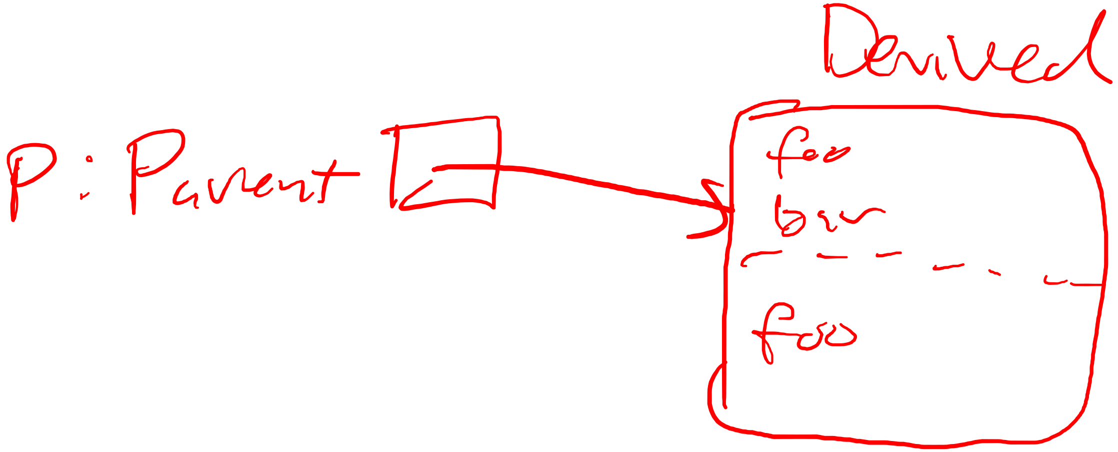



Abstract classes

- How should `Piece` implement `legalMove()` itself?
- Who should be allowed to construct a `Piece`?
    - Not a concern with `interface` – no method bodies, no constructor

- Abstract classes
    - Cannot be constructed on their own (must construct a subclass)
        - Even though they may define a constructor
    - May have abstract methods
        - Declarations only (like interfaces)
- Subclass must override all abstract methods, or be abstract itself

Piece as an abstract superclass

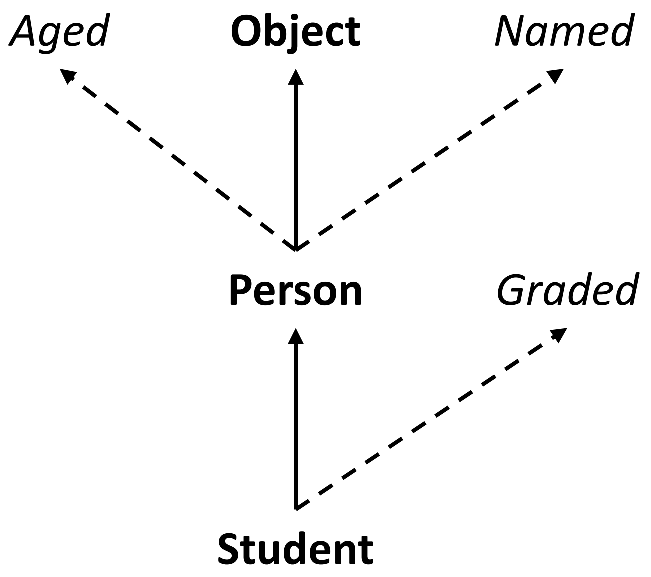
```
public abstract class Piece {
  protected int row;
  protected int col;
  private int player;

  protected Piece(int row,
      int col, int player) {
    this.row = row;
    this.col = col;
    this.player = player;
  }
```

```
  public int player() {
    return player;
  }

  public abstract boolean
      legalMove(int dstRow,
      int dstCol, Board board);
}
```

Class `Object`

Relationships

- Java only supports *single inheritance*
  - Only one superclass
  - Reserve for “is-a” relationship
- Classes may implement multiple interfaces
  - “Can-do” relationship
- Interfaces may extend (multiple) other interfaces



Relationships

- Don’t forget about **composition**
  - Reference an instance of another class in a field
  - “Has a” relationship
  - Often most flexible, maintainable kind of relationship

Object

- All classes are a subtype of Object
  - If no `extends` clause, then `Object` is the superclass
  - Interfaces implicitly must be implemented by an `Object`

- Object provides useful universal methods that you may want to override
  - `toString()`
  - `equals()`
  - `hashCode()`

toString() example: Point

```
public class Point {
  private double x;
  private double y;

  @Override
  public String toString() {
    return "(" + x + "," + y + ")";
  }
}
```

Equality

Referential equality (identity)

- Are two objects the same object?
- Test using ==
- Best avoided in most client code
  - Let classes define their own equivalence relations

Logical equality (state)

- Should two objects be considered equivalent (substitutable)?
- Test using `equals()`
  - Defaults to referential equality
  - May override `equals()` to define value equality
    - Danger if class is mutable

Equivalence relations

- Reflexive
  - You equal yourself
- Symmetric
  - If you equal someone, they equal you
- Transitive
  - If you equal someone and they equal someone else, you also equal that someone else

Overriding .equals()

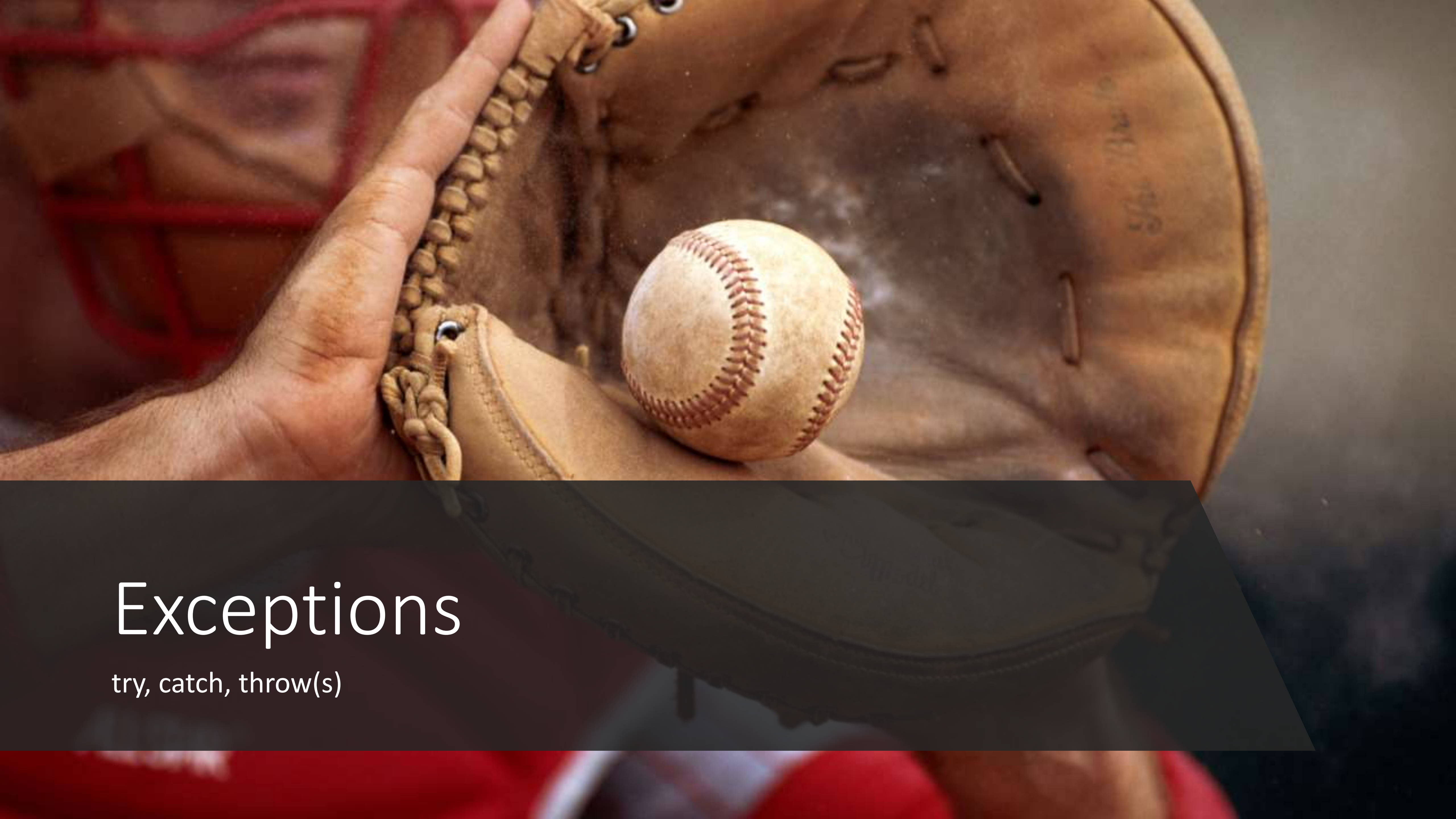
```
@Override
public boolean equals(Object other) {
    if (!(other instanceof Point)) {
        return false;
    }
    Point p = (Point) other;
    return x == p.x && y == p.y;
}
```

Warning: not **symmetric** if subclasses might be compared with superclasses

getClass()

- To look at the exact dynamic type of an object (rather than an upper bound), use getClass() (inherited from Object)
  - Reserve for special cases
- Stronger equals() template:

```
@Override
public boolean equals(Object obj) {
    if ((obj == null) || (getClass() != obj.getClass())) {
        return false;
    }
    MyClass objAsMC = (MyClass) obj;
    // Compare fields
}
```



Exceptions

try, catch, throw(s)