

# 7. Inheritance and Refactoring

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# Inheritance and Refactoring

## ***Source***

- > Wirfs-Brock & McKean, *Object Design — Roles, Responsibilities and Collaborations*, 2003.



# Roadmap

- > Uses of inheritance
  - conceptual hierarchy, polymorphism and code reuse
- > TicTacToe and Gomoku
  - interfaces and abstract classes
- > Iterative development
  - Quiet testing
- > Refactoring
  - iterative strategies for improving design
- > Top-down decomposition
  - decomposing algorithms to reduce complexity



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# What is Inheritance?

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*Inheritance* in object-oriented programming languages is a mechanism to:

- derive new subclasses* from existing classes
- where subclasses *inherit all the features* from their parent(s)
- and may *selectively override* the implementation of some features.

# Inheritance mechanisms

*OO languages realize inheritance in different ways:*

<i>self</i>	<i>dynamically access</i> subclass methods
<i>super</i>	<i>statically access</i> overridden, inherited methods
<i>multiple inheritance</i>	inherit features from <i>multiple superclasses</i>
<i>abstract classes</i>	<i>partially defined classes</i> (to inherit from only)
<i>mixins</i>	build classes from <i>partial sets of features</i>
<i>interfaces</i>	<i>specify</i> method argument and return types
<i>subtyping</i>	guarantees that subclass instances can be <i>substituted</i> for their parents

# The Board Game

Tic Tac Toe is a pretty dull game, but there are many other interesting games that can be played by *two players with a board and two colours of markers*.

## **Example:** Go-moku

*“A Japanese game played on a go board with players alternating and attempting to be first to place five counters in a row.”*

— Random House

We would like to implement a program that can be used to play several *different kinds of games using the same game-playing abstractions* (starting with TicTacToe and Go-moku).

# Inheritance is used for three orthogonal, but related purposes

## ***Conceptual hierarchy (domain modeling):***

- > Go-moku *is-a kind of* Board Game; Tic Tac Toe is-a kind of Board Game

## ***Polymorphism (design):***

- > Instances of Gomoku and TicTacToe can be *uniformly manipulated* as instances of BoardGame by a client program

## ***Software reuse (implementation):***

- > Gomoku and TicTacToe reuse the BoardGame *interface*
- > Gomoku and TicTacToe reuse and extend the BoardGame *representation* and the *implementations* of its operations



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# Class Diagrams

The TicTacToe class currently looks like this:

	<b>Key</b>
-	private feature
#	protected feature
+	public feature
<u>create( )</u>	static feature
<i>checkWinner( )</i>	abstract feature

<b>TicTacToe</b>
-gameState : char [3][3] -winner: Player -turn : Player -player : Player[2] -squaresLeft : int
+ <u>create</u> (Player, Player) +update( ) +move(char, char, char) +winner( ) : Player +notOver( ) : boolean +squaresLeft( ) : int -set(char, char, char) -get(char, char) : char -swapTurn( ) -checkWinner( ) -inRange(char col, char row) : boolean

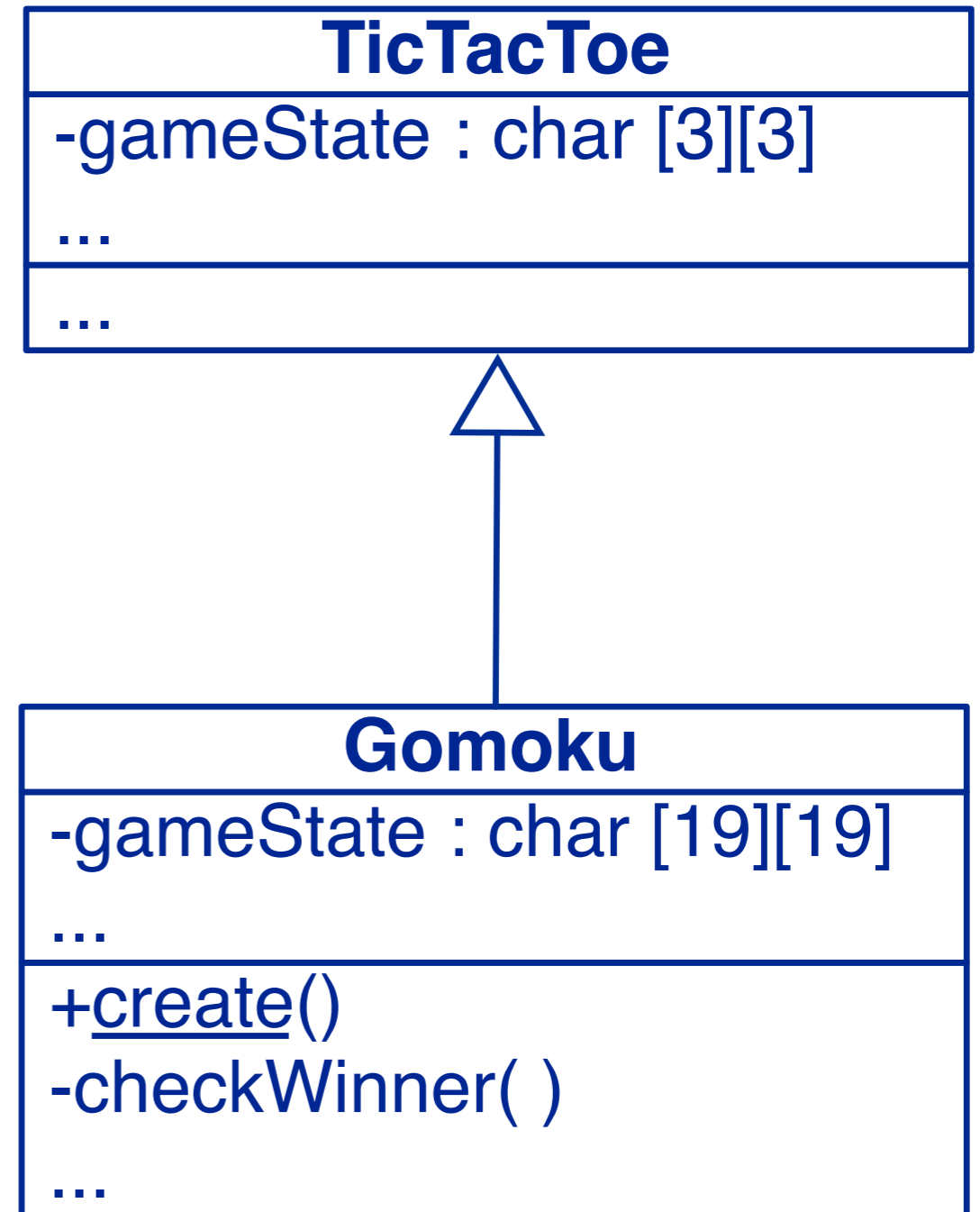
# A bad idea ...

*Why not simply use inheritance for incremental modification?*

Exploiting inheritance for code reuse without refactoring tends to lead to:

- > *duplicated code* (similar, but not reusable methods)
- > *conceptually unclear design* (arbitrary relationships between classes)

*Gomoku is not a kind of TicTacToe*

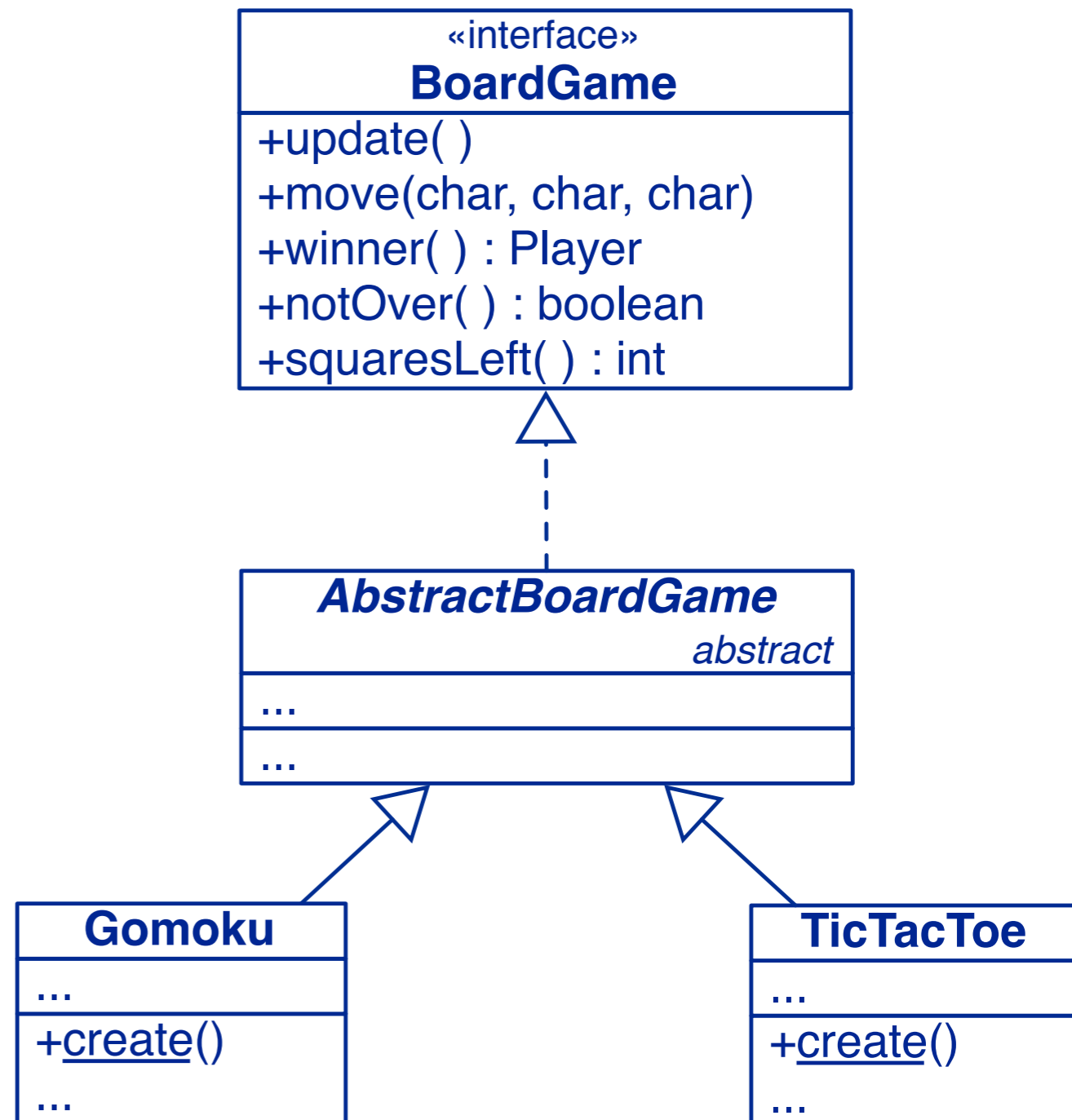


# Class Hierarchy

Both Go-moku and Tic Tac Toe are *kinds of Board games* (IS-A).

We would like to define a *common interface*, and factor the common functionality into a *shared parent class*.

Behaviour that is not shared will be implemented by the subclasses.



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# Iterative development strategy

We need to find out which TicTacToe functionality will:

- already work for both TicTacToe and Gomoku
- need to be adapted for Gomoku
- can be generalized to work for both

**Example:** set() and get() will not work for a 19×19 board!

Rather than attempting a “big bang” redesign, we will iteratively redesign our game:

- introduce a BoardGame interface that TicTacToe implements
- move all TicTacToe implementation to an AbstractBoardGame parent
- fix, refactor or make abstract the non-generic features
- introduce Gomoku as a concrete subclass of AbstractBoardGame

*After each iteration we run our regression tests to make sure nothing is broken!*

 When should you run your (regression) tests?

✓ *After every change to the system.*

## Version 3 (add interface)

*We specify the interface both subclasses should implement:*

```
public interface BoardGame {
    public void update() throws IOException;
    public void move(char col, char row, char mark);
    public Player currentPlayer();    // NB: new method
    public Player winner();
    public boolean notOver();
    public int squaresLeft();
}
```

Initially we focus only on *abstracting* from the current TicTacToe implementation

# Speaking to an Interface

Clients of TicTacToe and Gomoku should only depend on the BoardGame *interface*:

```
public class GameDriver {
    public static void main(String args[]) {
        Player X = new Player('X');
        Player O = new Player('O');
        playGame(new TicTacToe(X, O));
    }

    public static void playGame(BoardGame game) {
        ...
    }
}
```

*Speak to an interface, not an implementation.*



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# Quiet Testing

Our current TestDriver prints the state of the game after each move, making it hard to tell when a test has failed.

*Tests should be silent unless an error has occurred!*

```
public static void playGame(BoardGame game, boolean verbose) {  
    ...  
    if (verbose) {  
        System.out.println();  
        System.out.println(game);  
    ...  
}
```

*NB: we must shift all responsibility for printing to playGame().*

## Quiet Testing (2)

A more flexible approach is to let the *client* supply the `PrintStream`:

```
public static void playGame(BoardGame game, PrintStream out) {
    try {
        do { // all printing must move here ...
            out.println();
            out.println(game);
            out.print("Player "
                + game.currentPlayer().mark() + " moves: ");
            ...
        }
    }
}
```

*The TestDriver can simply send the output to a Null stream:*

```
playGame(game, System.out);
playGame(game, new PrintStream(new NullOutputStream()));
```

# NullOutputStream

*A Null Object implements an interface with null methods:*

```
public class NullOutputStream extends OutputStream {  
    public NullOutputStream() { super(); }  
  
    // Null implementation of inherited abstract method  
    public void write(int b) throws IOException { }  
}
```

Null Objects are useful for eliminating flags and switches.

# TicTacToe adaptations

In order to pass responsibility for printing to the GameDriver, a BoardGame must provide a method to *export the current Player*:

```
public class TicTacToe implements BoardGame {  
    ...  
    public Player currentPlayer() {  
        return player[turn];  
    }  
}
```

*Now we run our regression tests and (after fixing any bugs) continue.*

## Version 4 — add abstract class

AbstractBoardGame will provide common variables and methods for TicTacToe and Gomoku.

```
public abstract class AbstractBoardGame implements BoardGame {  
    static final int X = 0;  
    static final int O = 1;  
    ...  
}
```

In a first step we include the entire TicTacToe implementation ...

 When should a class be declared abstract?

✓ *Declare a class abstract if it is intended to be subclassed, but not instantiated.*

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# Refactoring

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Refactoring is a process of moving methods and instance variables from one class to another to improve the design, specifically to:

- reassign responsibilities
- eliminate duplicated code
- reduce coupling: interaction between classes
- increase cohesion: interaction within classes



# Refactoring strategies

We have adopted one possible refactoring strategy, first moving everything except the constructor from TicTacToe to AbstractBoardGame, and changing all private features to protected. TicTacToe inherits everything:

```
public class TicTacToe extends AbstractBoardGame {
    public TicTacToe(Player playerX, Player playerO)
    {
        super(playerX, playerO);
    }
}
```

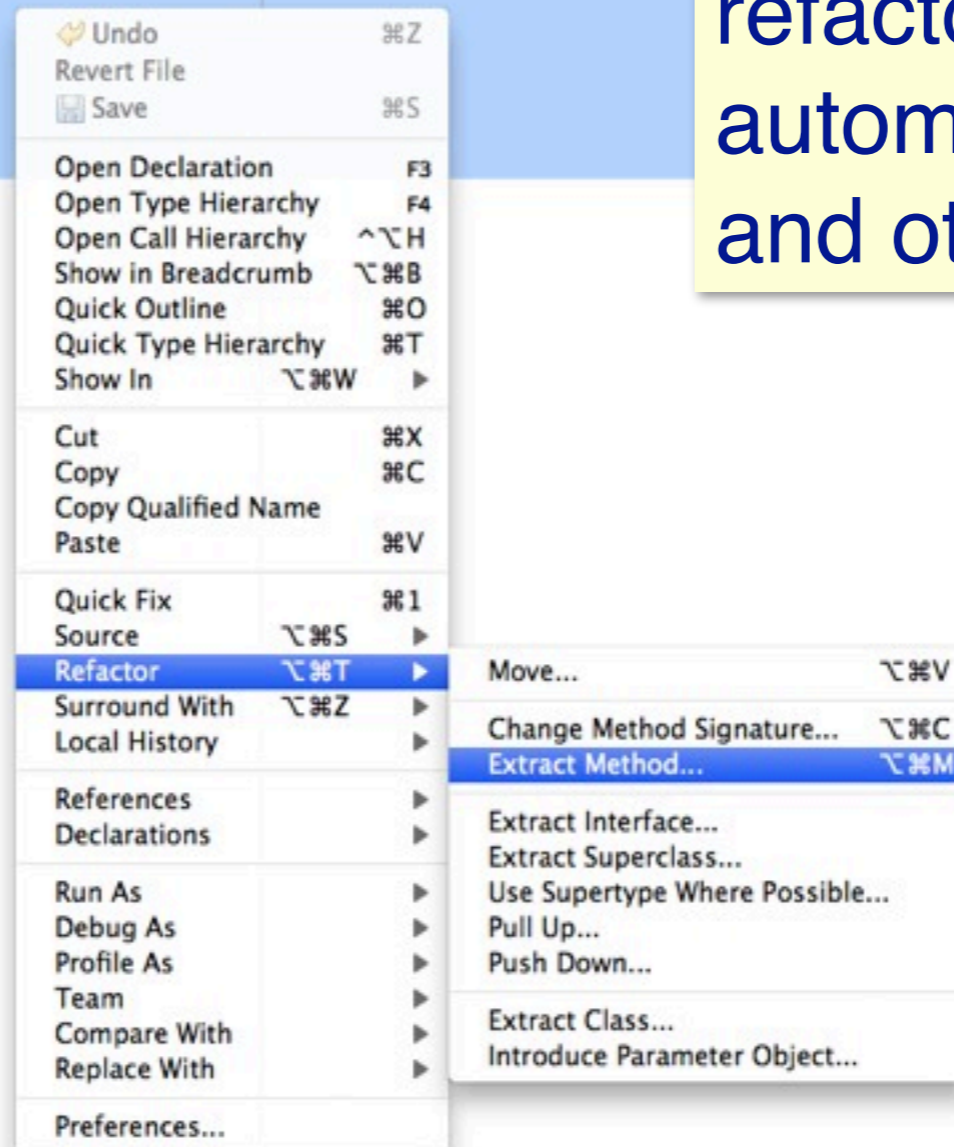
*We could equally have started with an empty AbstractBoardGame and gradually moved shared code there.*

# Refactoring support in Eclipse

Many common refactorings are automated by eclipse and other IDEs.

```
protected void checkWinner()
{
    char player;
    for (char row='3'; row>='1'; row--) {
        player = this.get('a',row);
        if (player == this.get('b',row)
            && player == this.get('c',row)) {
            this.setWinner(player);
            return;
        }
    }
    for (char col='a'; col <='c'; col++) {
        player = this.get(col,'1');
        if (player == this.get(col,'2')
            && player == this.get(col,'3')) {
            this.setWinner(player);
            return;
        }
    }
    player = this.get('b','2');
    if (player == this.get('a','1')
        && player == this.get('c','3')) {
        this.setWinner(player);
        return;
    }
    if (player == this.get('a','3')
        && player == this.get('c','1')) {
        this.setWinner(player);
        return;
    }
}

/**
 * Look up which player is the winner, and set winner
 * accordingly. Hm. Maybe we should store Players
 * instead of chars in our array!
 */
protected void setWinner(char aPlayer) {
    if (aPlayer == ' ')
        return;
    if (aPlayer == player[X].mark())
        winner = player[X];
    else
        winner = player[0];
}
```



## Version 5 — refactoring

Now we must check which parts of `AbstractBoardGame` are *generic*, which must be *repaired*, and which must be *deferred* to its subclasses:

- > the number of rows and columns and the winning score may vary
  - introduce instance variables and an `init()` method
  - rewrite `toString()`, `invariant()`, and `inRange()`
- > `set()` and `get()` are inappropriate for a 19×19 board
  - index directly by integers
  - fix `move()` to take `String` argument (e.g., “f17”)
  - add methods to parse string into integer coordinates
- > `getWinner()` and `toString()` must be generalized

# AbstractBoardGame

*We introduce an abstract init() method for arbitrary sized boards:*

```
public abstract class AbstractBoardGame ... {  
    protected abstract void init();  
    ...  
}
```

*And call it from the constructors of our subclasses:*

```
public class TicTacToe extends AbstractBoardGame {  
    ...  
    protected void init() {  
        rows = 3;  
        cols = 3;  
        winningScore = 3;  
    }  
    ...  
}
```

*Or: introduce a constructor for AbstractBoardGame!*

# BoardGame

Most of the changes in `AbstractBoardGame` are to protected methods.

The only public (interface) method to change is `move ( )`:

```
public interface BoardGame {  
    ...  
    public void move(String coord, char mark);  
    ...  
}
```

# Player

*The Player's move() method can now be radically simplified:*

```
public void move(BoardGame game) throws IOException {
    String line;
    line = in.readLine();
    if (line == null) {
        throw new IOException("end of input");
    }
    game.move(line, this.mark());
}
```

 *How can we make the Player responsible for checking if the move is valid?*

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# Version 6 — Gomoku

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The final steps are:

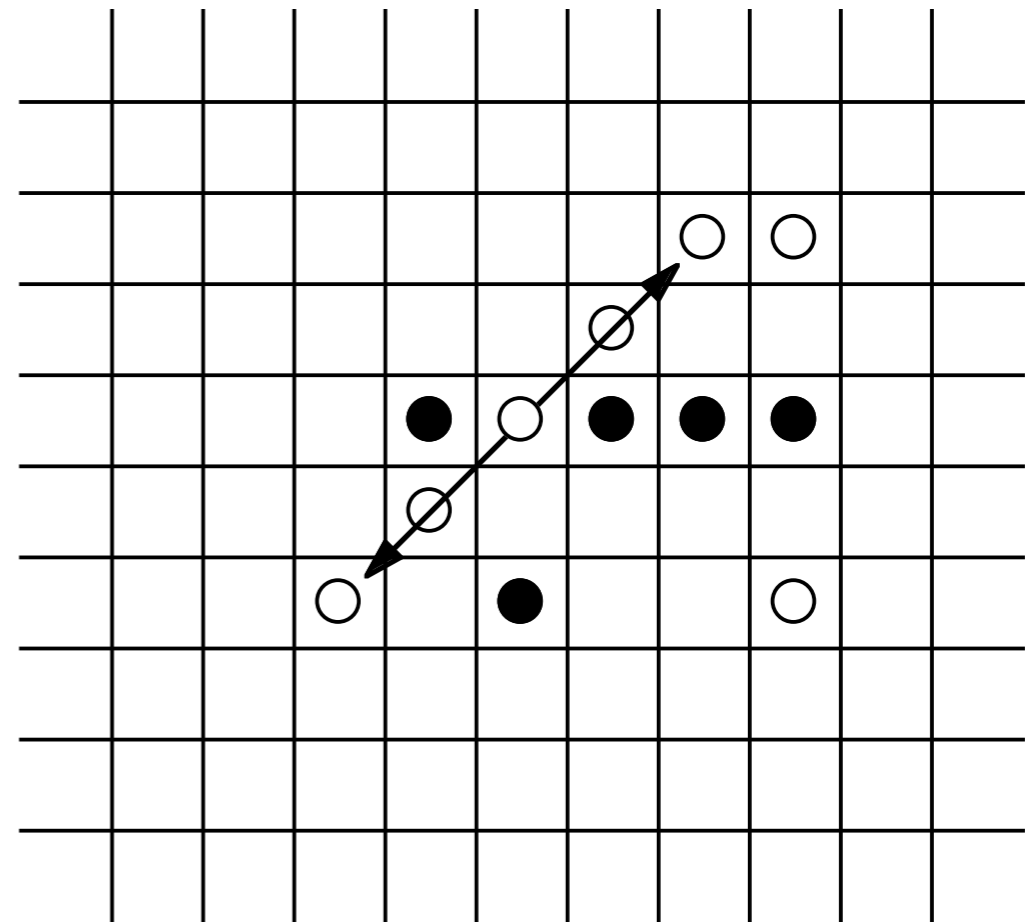
- > rewrite `checkWinner()`
- > introduce `Gomoku`
  - modify `TestDriver` to run tests for both `TicTacToe` and `Gomoku`
  - print game state whenever a test fails
- > modify `GameDriver` to query user for either `TicTacToe` or `Gomoku`



# Keeping Score

The Go board is *too large to search exhaustively* for a winning Go-moku score.

We know that *a winning sequence must include the last square marked*. So, it suffices to search in all four directions *starting from that square* to see if we find 5 in a row.



 *Whose responsibility is it to search?*

## A new responsibility ...

Maintaining the state of the board and searching for a winning run seem to be *unrelated responsibilities*. So let's introduce a new object (a Runner) to run and count a Player's pieces.

```
protected void checkWinner(int col, int row)... {
    char player = this.get(col,row);
    Runner runner = new Runner(this, col, row);
    // check vertically
    if (runner.run(0,1) >= this.winningScore)
        { this.setWinner(player); return; }
    // check horizontally
    if (runner.run(1,0) >= this.winningScore)
        { this.setWinner(player); return; }
    ...
}
```

# The Runner

The `Runner` must know its game, its home (start) position, and its current position:

```
public class Runner {
    BoardGame game;
    int homeCol, homeRow;           // Home col and row
    int col=0, row=0;              // Current col & row

    public Runner(BoardGame myGame, int myCol, int myRow) {
        game = myGame;
        homeCol = myCol;
        homeRow = myRow;
    }
    ...
}
```

# Top-down decomposition

*Implement algorithms abstractly, introducing helper methods for each abstract step, as you decompose:*

```
public int run(int dcol, int drow)
    throws AssertionError {
    int score = 1;
    this.goHome() ;
    score += this.forwardRun(dcol, drow);
    this.goHome();
    score += this.reverseRun(dcol, drow);
    return score;
}
```

*Well-chosen names eliminate the need for most comments!*

# Recursion

Many algorithms are more naturally expressed with recursion than iteration.

*Recursively move forward as long as we are in a run. Return the length of the run:*

```
private int forwardRun(int dcol, int drow) {
    this.move(dcol, drow);
    if (this.samePlayer())
        return 1 + this.forwardRun(dcol, drow);
    else
        return 0;
}
```

# More helper methods

Helper methods keep the main algorithm *clear and uncluttered*, and are mostly *trivial to implement*.

```
private int reverseRun(int dcol, int drow) ... {
    return this.forwardRun(-dcol, -drow);
}

private void goHome() {
    col= homeCol;
    row = homeRow;
}
```

 *How would you implement `move()` and `samePlayer()`?*

# BoardGame

The Runner now needs access to the `get()` and `inRange()` methods so we make them *public*:

```
public interface BoardGame {  
    ...  
    public char get(int col, int row);  
    public boolean inRange(int col, int row);  
    ...  
}
```

 Which methods should be public?

✓ *Only publicize methods that clients will really need, and will not break encapsulation.*

# Gomoku

Gomoku is similar to TicTacToe, except it is played on a 19x19 Go board, and the winner must get 5 in a row.

```
public class Gomoku extends AbstractBoardGame {
    public Gomoku(Player playerX, Player playerO) {
        super(playerX, playerO);
    }
    protected void init() {
        rows = 19;
        cols = 19;
        winningScore = 5;
    }
}
```

In the end, Gomoku and TicTacToe could inherit *everything* (except their constructor) from AbstractGameBoard!



# Abstract test framework

```
public abstract class AbstractBoardGameTest extends TestCase {
    protected BoardGame game;

    public AbstractBoardGameTest (String name) { super(name); }

    public void checkGame(String Xmoves, String Omoves,
                          String winner, int squaresLeft) {
        Player X = new Player('X', Xmoves);
        Player O = new Player('O', Omoves);
        game = makeGame(X,O);
        GameDriver.playGame(game, new PrintStream(new NullOutputStream()));
        assertEquals(game.winner().name(), winner);

        assertEquals(game.squaresLeft(), squaresLeft);
    }
    abstract protected BoardGame makeGame(Player X, Player O) ;
    ...
}
```

# Gomoku tests ...







Subclasses specialize the factory method for instantiating the game

```
public class GomokuTest extends AbstractBoardGameTest {
    ...

    public void testXWinsDiagonal() {
        checkGame( "\naa\n" // nonsense input
            + "f6\ng5\ne7\nd8\nc9\n",
            "b2\nh4\nc3\nd4\n",
            "X", (19*19-9));
    }

    protected BoardGame makeGame(Player X, Player O) {
        return new Gomoku(X, O);
    }
}
```

# *What you should know!*

-  *How does polymorphism help in writing generic code?*
-  *When should features be declared protected rather than public or private?*
-  *How do abstract classes help to achieve code reuse?*
-  *What is refactoring? Why should you do it in small steps?*
-  *How do interfaces support polymorphism?*
-  *Why should tests be silent?*

## *Can you answer these questions?*

- ✎ What would change if we didn't declare `AbstractBoardGame` to be abstract?*
- ✎ How does an interface (in Java) differ from a class whose methods are all abstract?*
- ✎ Can you write `generic toString()` and `invariant()` methods for `AbstractBoardGame`?*
- ✎ Is `TicTacToe` a special case of `Gomoku`, or the other way around?*
- ✎ How would you reorganize the class hierarchy so that you could run `Gomoku` with boards of different sizes?*

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