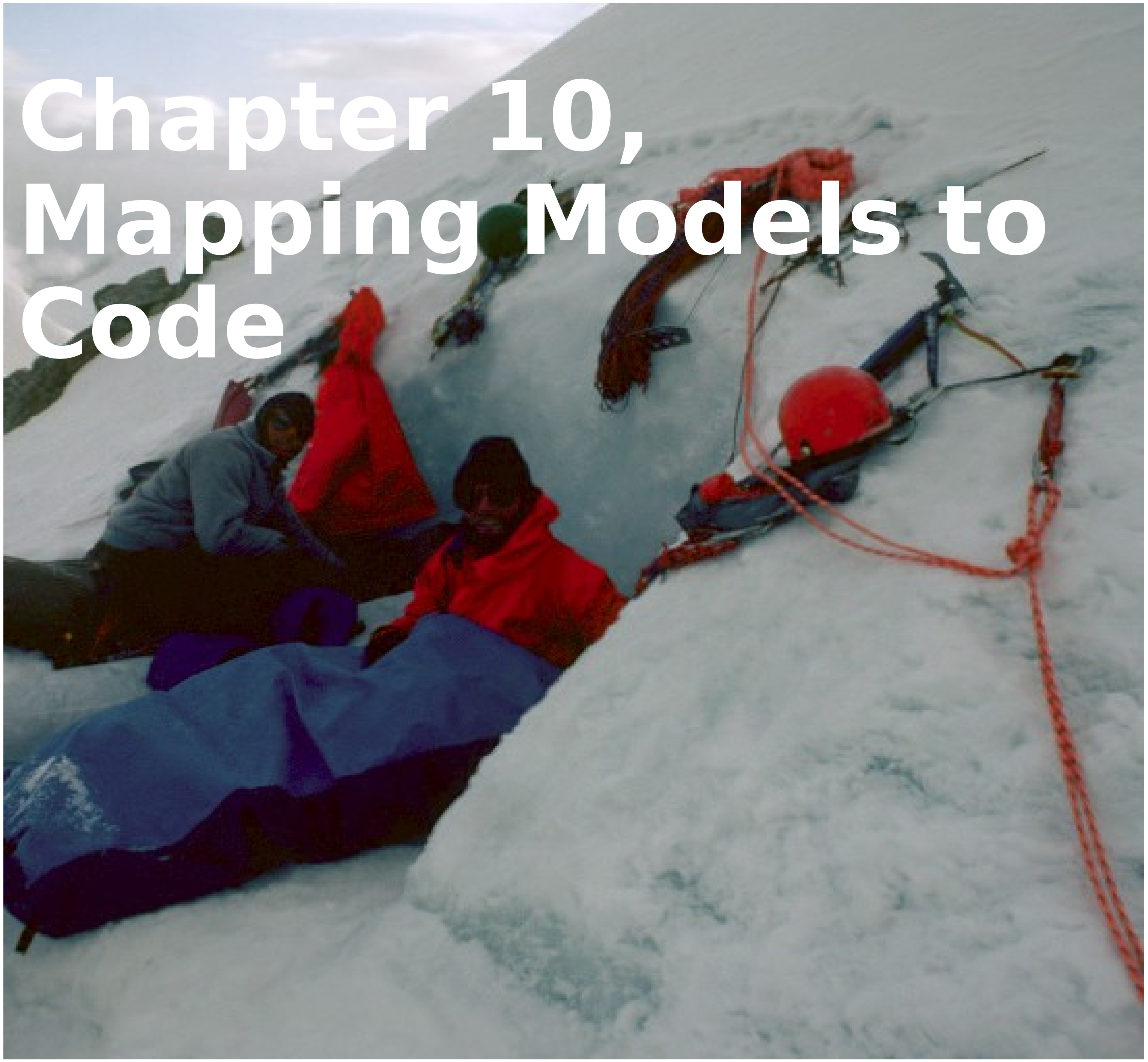
Chapter 10, Mapping Models to Code

Object-Oriented Software Engineering

Using UML, Patterns, and Java



Lecture Plan

- Part 1
  - Operations on the object model:
    - Optimizations to address performance requirements
  - Implementation of class model components:
    - Realization of associations
    - Realization of operation contracts
- Part 2
  - Realizing entity objects based on selected storage strategy
  - Mapping the object model to a storage schema
  - Mapping class diagrams to tables

Characteristics of Object Design Activities

- Developers try to improve modularity and performance
- Developers need to transform associations into references, because programming languages do not support associations
- If the programming language does not support contracts, the developer needs to write code for detecting and handling contract violations
- Developers need to revise the interface specification whenever the client comes up with new requirements.

State of the Art: Model-based Software Engineering

- The Vision
  - During object design we build an object design model that realizes the use case model and which is the basis for implementation (model-driven design)
- The Reality
  - Working on the object design model involves many activities that are error prone
  - Examples:
    - A new parameter must be added to an operation. Because of time pressure it is added to the source code, but not to the object model
    - Additional attributes are added to an entity object, but the data base table is not updated (as a result, the new attributes are not persistent).

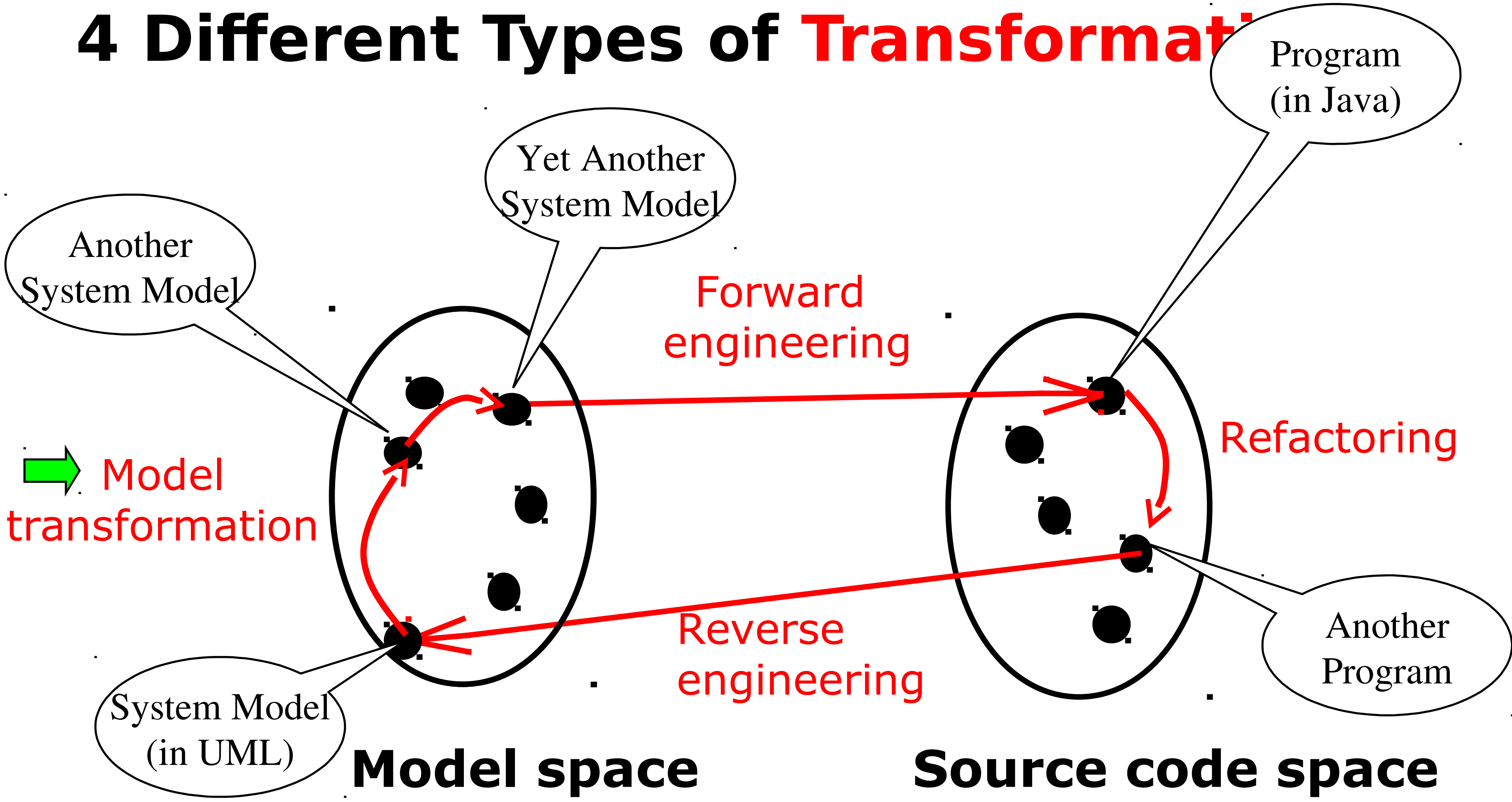
Other Object Design Activities

- Programming languages do not support the concept of a UML association
  - The associations of the object model must be transformed into collections of object references
- Many programming languages do not support contracts (invariants, pre and post conditions)
  - Developers must therefore manually transform contract specification into source code for detecting and handling contract violations
- The client changes the requirements during object design
  - The developer must change the interface specification of the involved classes
- All these object design activities cause problems, because they need to be done manually.

The Model Space and the Source Code Space

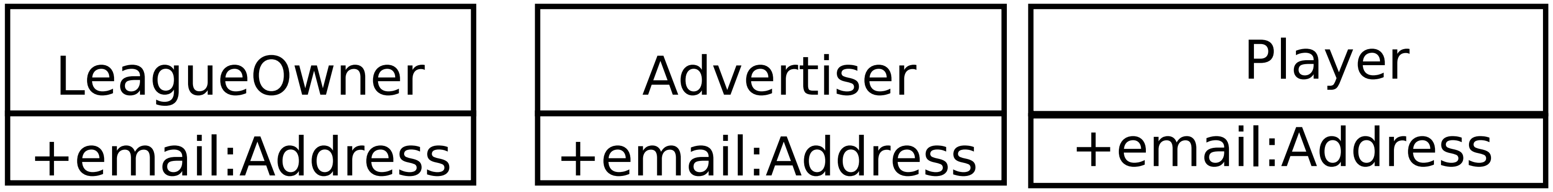
- Let us get a handle on these problems
- To do this we distinguish two kinds of spaces
  - the model space and the source code space
- and 4 different types of transformations
  - Model transformation
  - Forward engineering
  - Reverse engineering
  - Refactoring.

4 Different Types of Transformati

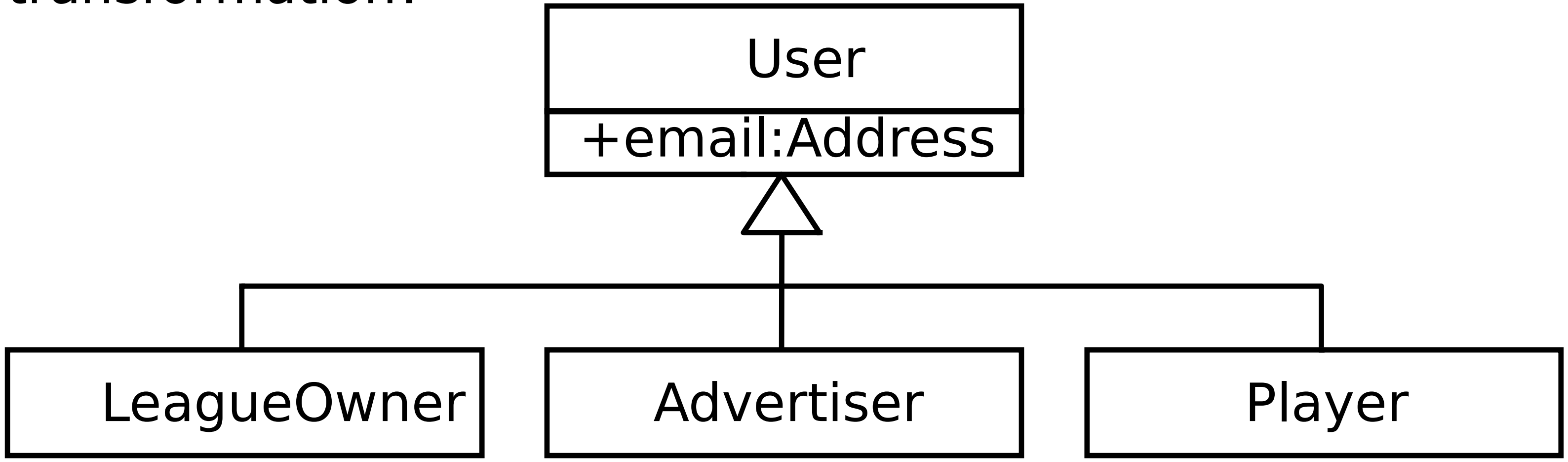


Model Transformation Example

Object design model before transformation:



Object design model
after transformation:



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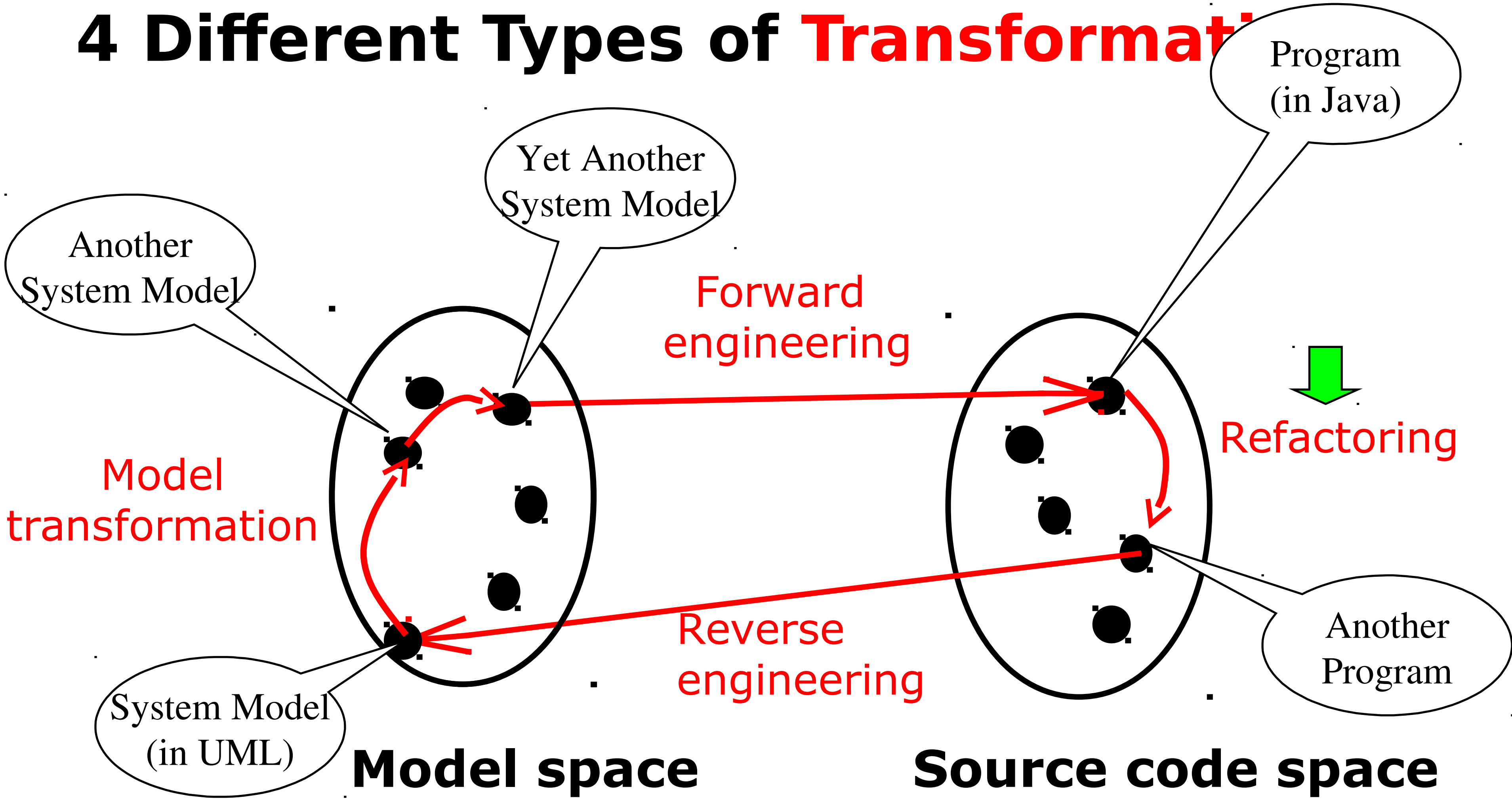

Refactoring Example: Pull Up Field

```
public class Player {
   private String email;
   //...
}
public class LeagueOwner {
   private String eMail;
   //...
}
public class Advertiser {
   private String email_address;
   //...
}
```

```
public class User {
   private String email;
}

public class Player extends User {
   //...
}

public class LeagueOwner extends User
   {
   //...
}

public class Advertiser extends User {
   //...
}
```

Refactoring Example: Pull Up Constructor Body

```
public class User {
    private String email;
}


public class Player extends User {
    public Player(String email) {
            this.email = email;
    }
}
public class LeagueOwner extends User{
    public LeagueOwner(String email) {
            this.email = email;
    }
}
public class Advertiser extendsUser{
    public Advertiser(String email) {
            this.email = email;
    }
}
```

```
public class User {
    public User(String email) {
            this.email = email;
    }
}

public class Player extends User {
            public Player(String email) {
                    super(email);
            }
}
public class LeagueOwner extends User
{
            public LeagueOwner(String
email) {
                    super(email);
            }
}
public class Advertiser extends User {
            public Advertiser(String email) {
                    super(email);
            }
}
```

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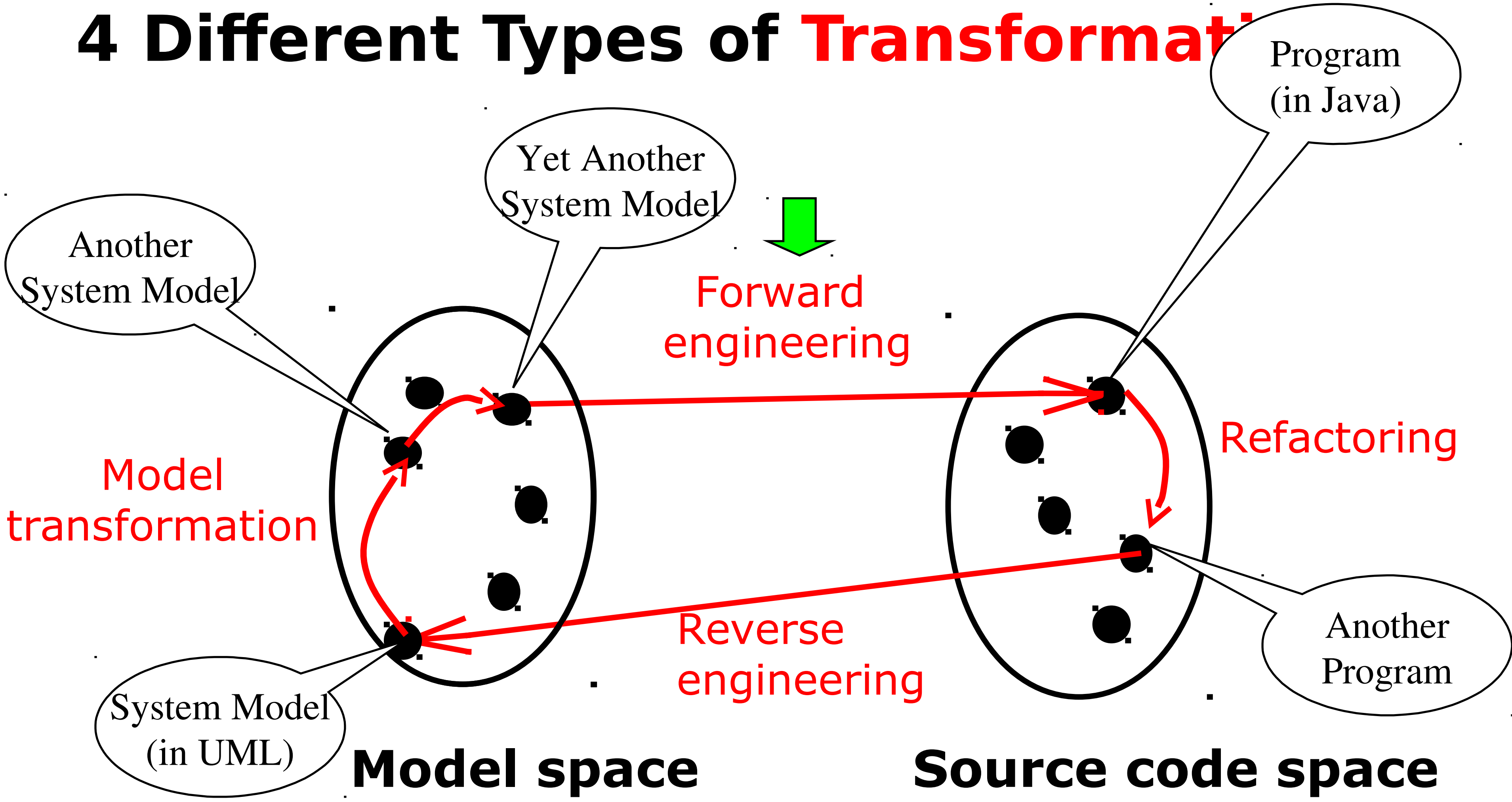
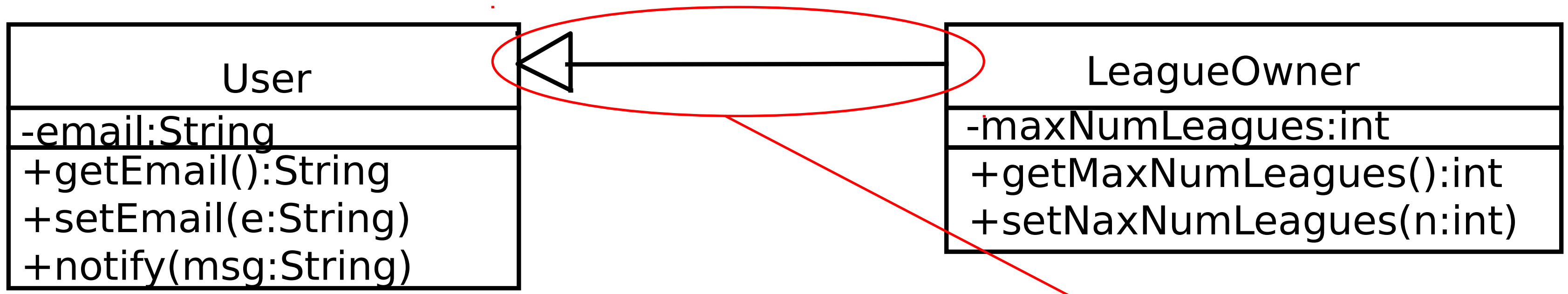


Forward Engineering Example

Object design model before transformation:



Source code after transformation:

```
public class User {
    private String email;
    public String getEmail() {
            return email;
    }
    public void setEmail(String value){
            email = value;
    }
    public void notify(String msg) {
            // ....
    }
}
```

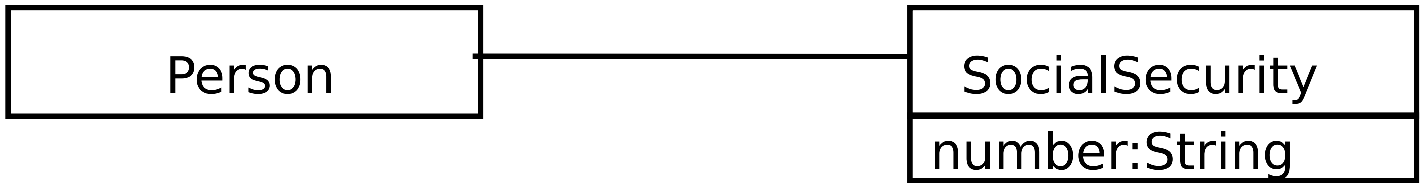
```
public class LeagueOwner extends User {
    private int maxNumLeagues;
    public int getMaxNumLeagues() {
            return maxNumLeagues;
    }
    public void setMaxNumLeagues
                    (int value) {
            maxNumLeagues = value;
    }
}
```

More Examples of Model Transformations and Forward Engineering

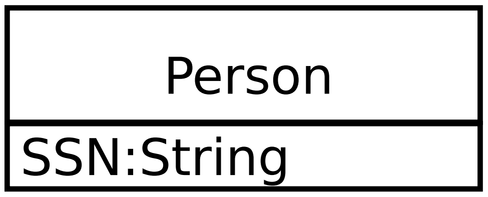
- Model Transformations
  - Goal: Optimizing the object design model
    - ➡ Collapsing objects
    - Delaying expensive computations
- Forward Engineering
  - Goal: Implementing the object design model in a programming language
  - Mapping inheritance
  - Mapping associations
  - Mapping contracts to exceptions
  - Mapping object models to tables

Collapsing Objects

Object design model before transformation:



Object design model after transformation:



Turning an object into an attribute of another object is usually done, if the object does not have any interesting dynamic behavior (only get and set operations).

Examples of Model Transformations and Forward Engineering

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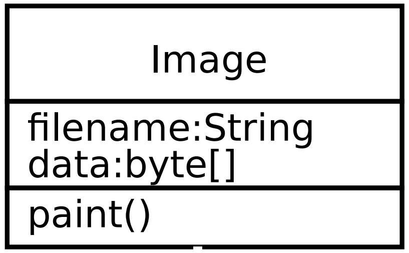
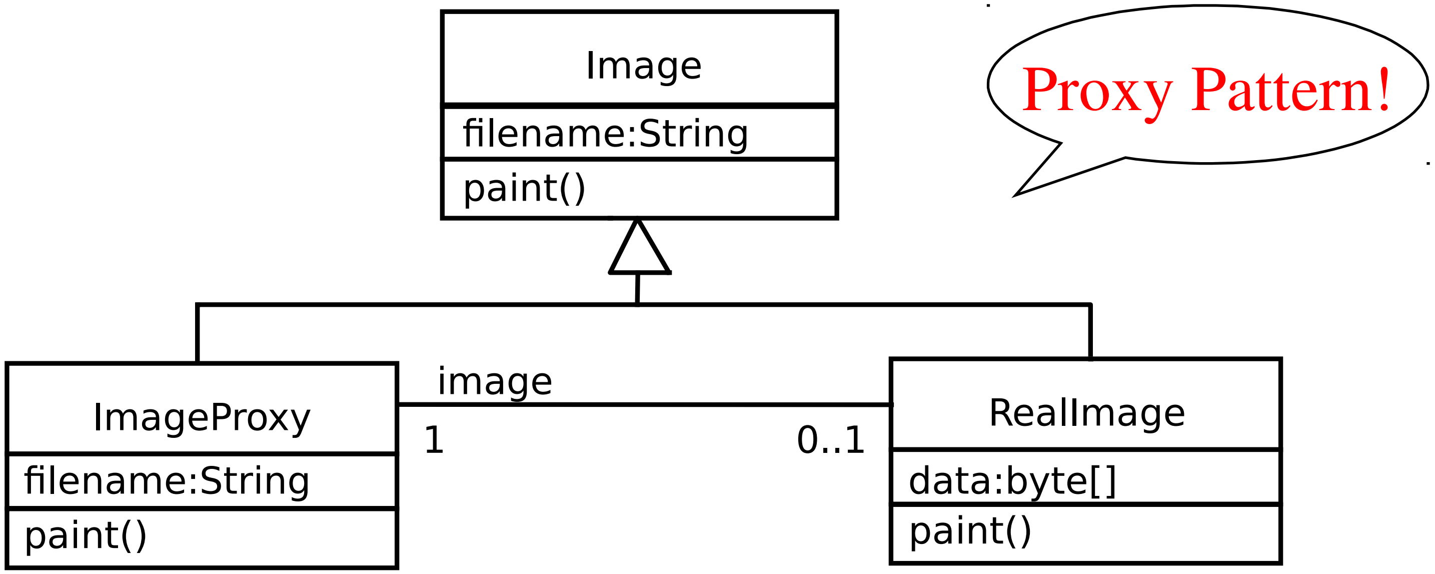
Delaying expensive computations

Object design model before transformation:



Object design model after transformation:



Examples of Model Transformations and Forward Engineering

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Forward Engineering: Mapping a UML Model into Source Code

- **Goal**: We have a UML-Model with inheritance. We want to translate it into source code
- **Question**: Which mechanisms in the programming language can be used?
  - Let’s focus on Java
- Java provides the following mechanisms:
  - Overwriting of methods (default in Java)
  - Final classes
  - Final methods
  - Abstract methods
  - Abstract classes
  - Interfaces.

Realizing Inheritance in Java

- Realisation of specialization and generalization
  - Definition of subclasses
  - Java keyword: **`extends`**
- Realisation of simple inheritance
  - Overwriting of methods is not allowed
  - Java keyword: **`final`**
- Realisation of implementation inheritance
  - Overwriting of methods
  - No keyword necessary:
    - Overwriting of methods is default in Java
- Realisation of specification inheritance
  - Specification of an interface
  - Java keywords: **`abstract`**, **`interface`**

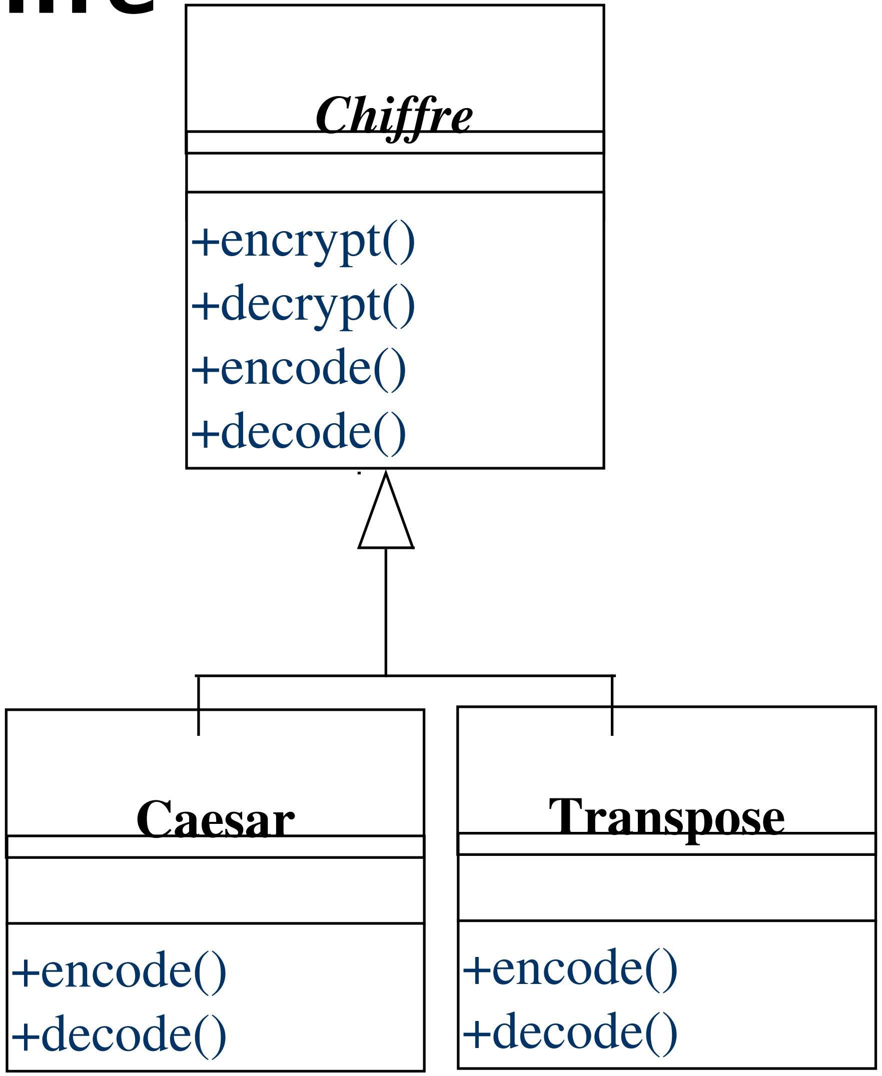
Example for the use of Abstract Methods: Cryptography

- Problem: Delivery a general encryption method
- Requirements:
  - The system provides algorithms for existing encryption methods (e.g. Caesar, Transposition)
  - New encryption algorithms, when they become available, can be linked into the program at runtime, without any need to recompile the program
  - The choice of the best encryption method can also be done at runtime.

Object Design of Chiffre

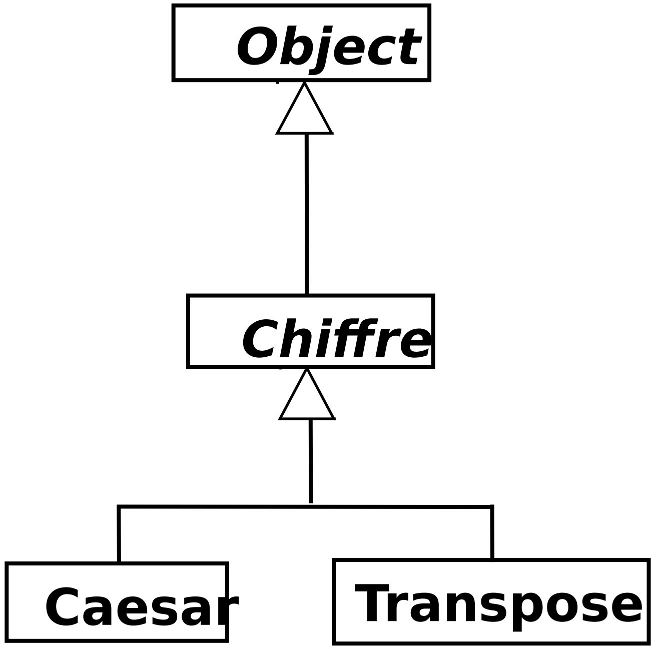
- We define a super class **`Chiffre`** and define subclasses for the existing existing encryption methods

- 4 public methods:
  - **`encrypt()`** encrypts a text of words
  - **`decrypt()`** deciphers a text of words
  - **`encode()`** uses a special algorithm for encryption of a single word
  - **`decode()`** uses a special algorithm for decryption of a single word.



Implementation of Chiffre in Java

- The methods `encrypt()` and `decrypt()` are the same for each subclass and can therefore be *implemented* in the superclass `Chiffre`
  - `Chiffre` is defined as subclass of `Object`, because we will use some methods of `Object`
- The methods `encode()` and `decode()` are specific for each subclass
  - We therefore define them as *abstract methods* in the super class and expect that they are *implemented* in the respective subclasses.



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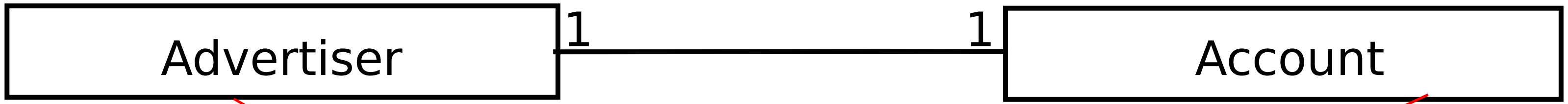
Mapping Associations

1. Unidirectional one-to-one association
2. Bidirectional one-to-one association
3. Bidirectional one-to-many association
4. Bidirectional many-to-many association
5. Bidirectional qualified association.

Unidirectional one-to-one association

Object design model before transformation:

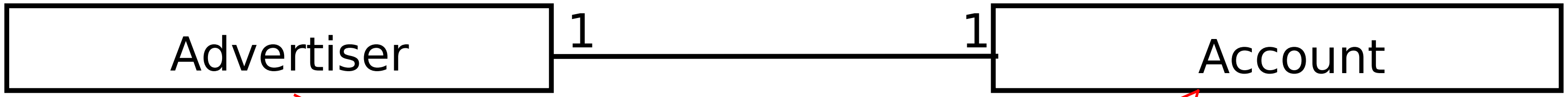


Source code after transformation:

```
public class Advertiser {
        private Account account;
        public Advertiser() {
                account = new Account();
        }
        public Account getAccount() {
                return account;
        }
}
```

Bidirectional one-to-one association

Object design model before transformation:



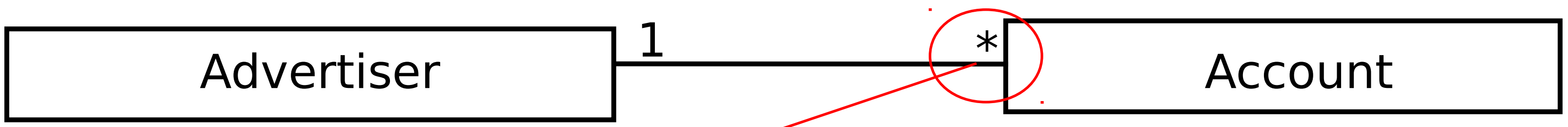
Source code after transformation:

```
public class Advertiser {
/* account is initialized
 * in the constructor and never
 * modified. */
    private Account account;
    public Advertiser() {
    account = new Account(this);
    }
    public Account getAccount() {
    return account;
    }
}
```

```
public class Account {
    /* owner is initialized
     * in the constructor and
     * never modified. */
    private Advertiser owner;
    publicAccount(owner:Advertiser) {
    this.owner = owner;
    }
    public Advertiser getOwner() {
    return owner;
    }
}
```

Bidirectional one-to-many association

Object design model before transformation:



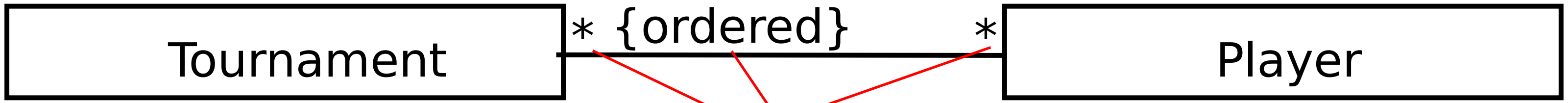
Source code after transformation:

```
public class Advertiser {
    private Set accounts;
    public Advertiser() {
    accounts = new HashSet();
    }
    public void addAccount(Account a) {
    accounts.add(a);
    a.setOwner(this);
    }
    public void removeAccount(Account a) {
    accounts.remove(a);
    a.setOwner(null);
    }
}
```

```
public class Account {
    private Advertiser owner;
    public void setOwner(Advertiser newOwner)
    {
    if (owner != newOwner) {
    Advertiser old = owner;
    owner = newOwner;
    if (newOwner != null)
    newOwner.addAccount(this);
    if (oldOwner != null)
    old.removeAccount(this);
    }
    }
}
```

Bidirectional many-to-many association

Object design model before transformation



Source code after transformation

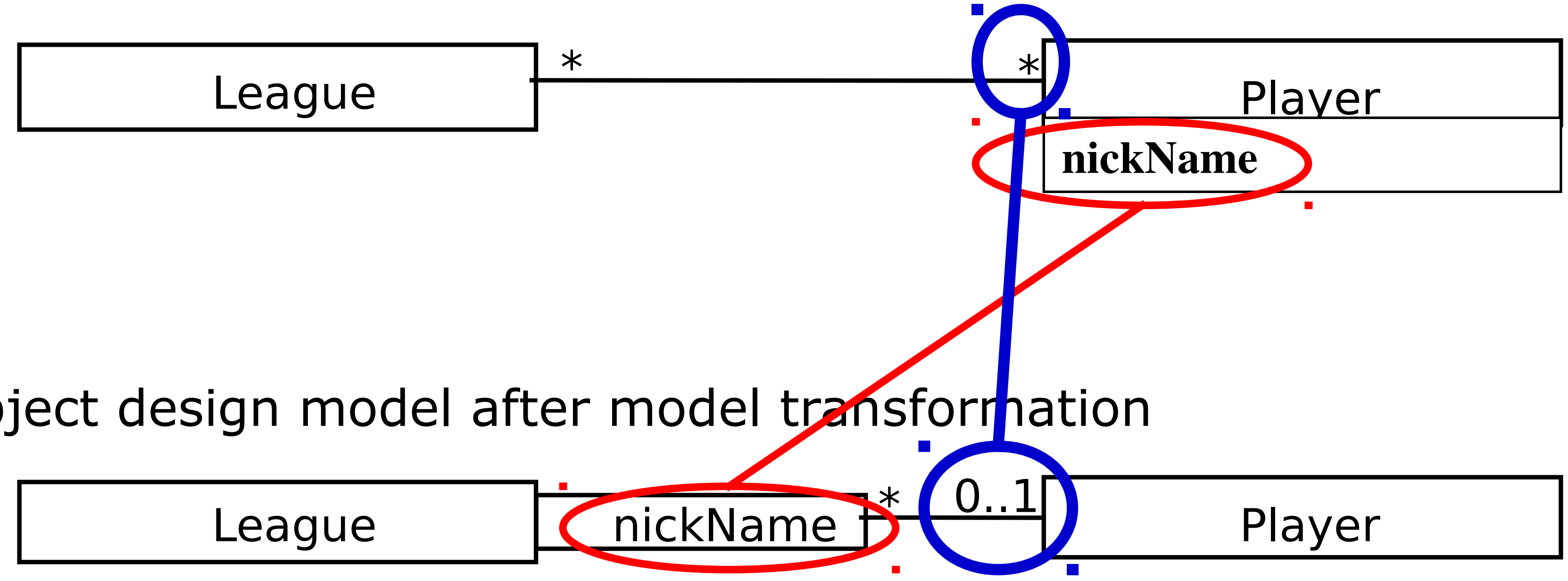
```
public class Tournament {
    private List players;
    public Tournament() {
        players = new ArrayList();
    }
    public void addPlayer(Player p) {
        if (!players.contains(p)) {
            players.add(p);
            p.addTournament(this);
        }
    }
}
```

```
public class Player {
    private List tournaments;
    public Player() {
    tournaments = new ArrayList();
    }
    public void
    addTournament(Tournament t) {
    if (!tournaments.contains(t)) {
    tournaments.add(t);
    t.addPlayer(this);
    }
    }
}
```

Bidirectional qualified association

Object design model before model transformation

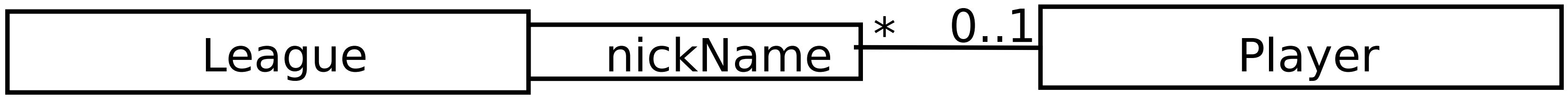
Object design model after model transformation



Source code after forward engineering (see next slide 31)

Bidirectional qualified association (2)

Object design model before forward engineering



Source code after forward engineering

```
public class League {
  private Map players;

  public void addPlayer
     (String nickName, Player p) {
    if (!players.containsKey(nickName)) {
        players.put(nickName, p);
        p.addLeague(nickName, this);
        }
    }
}
```

```
public class Player {
    private Map leagues;

    public void addLeague
          (String nickName, League l) {
          if (!leagues.containsKey(l)) {
           leagues.put(l, nickName);
           l.addPlayer(nickName, this);
          }
    }
}
```

Examples of Model Transformations and Forward Engineering

- Model Transformations
  - Goal: Optimizing the object design model
    - ✓ Collapsing objects
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  - Goal: Implementing the object design model in a programming language
  - ✓ Mapping inheritance
  - ✓ Mapping associations
  - Mapping contracts to exceptions
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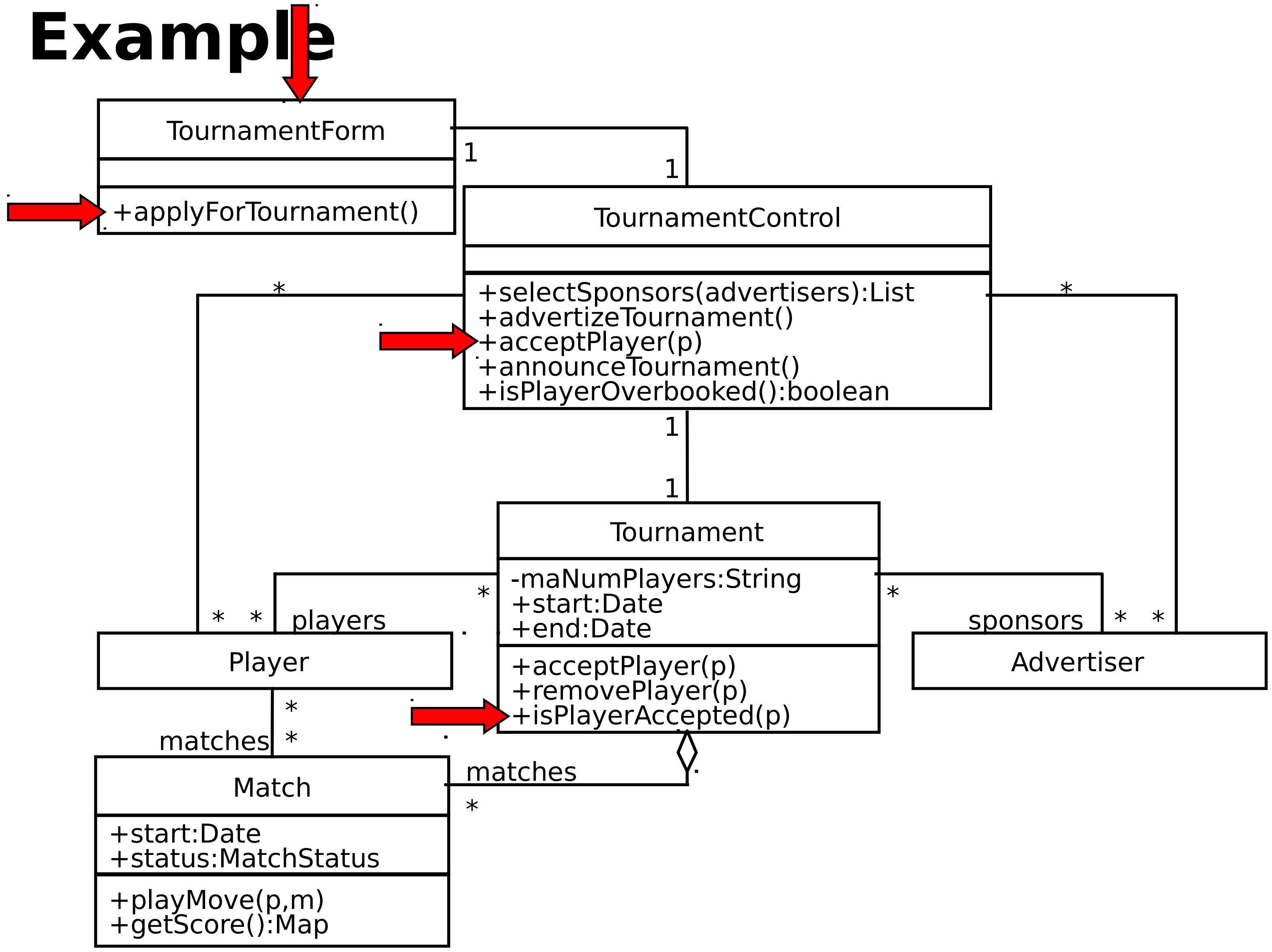
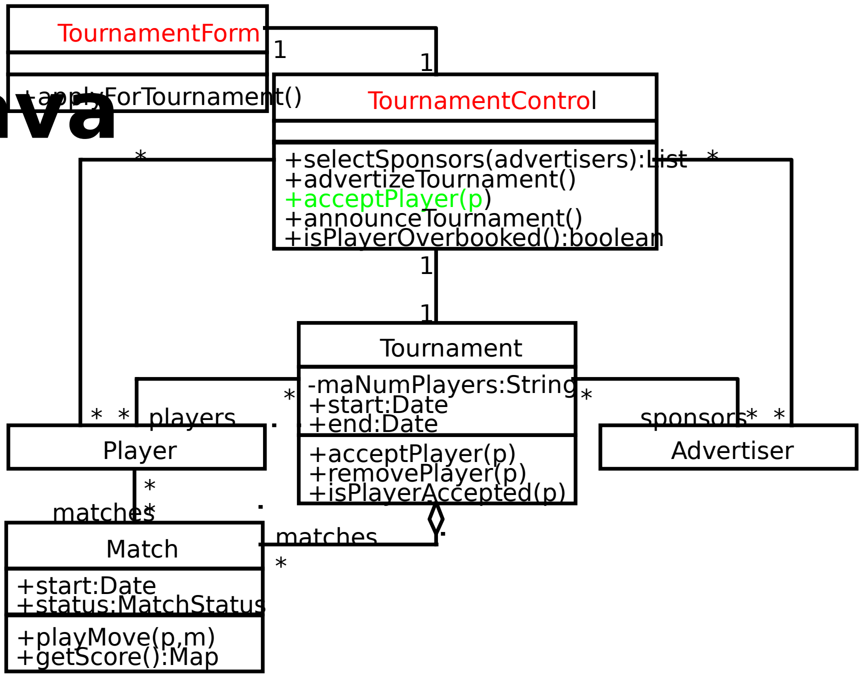
Implementing Contract Violations

- Many object-oriented languages do not have built-in support for contracts
- However, if they support exceptions, we can use their exception mechanisms for signaling and handling contract violations
- In Java we use the try-throw-catch mechanism
- Example:
  - Let us assume the acceptPlayer() operation of TournamentControl is invoked with a player who is already part of the Tournament
    - UML model (see slide 34)
  - In this case acceptPlayer() in TournamentControl should throw an exception of type KnownPlayer
    - Java Source code (see slide 35).

UML Model for Contract Violation Example



Implementation in Java



```
public class TournamentForm {
  private TournamentControl control;
  private ArrayList players;
  public void processPlayerApplications() {
   for (Iteration i = players.iterator(); i.hasNext();) {
      try {
         control.acceptPlayer((Player)i.next());
      }
      catch (KnownPlayerException e) {
        // If exception was caught, log it to console
        ErrorConsole.log(e.getMessage());
       }
      }
    }
}
```

The try-throw-catch Mechanism in Java

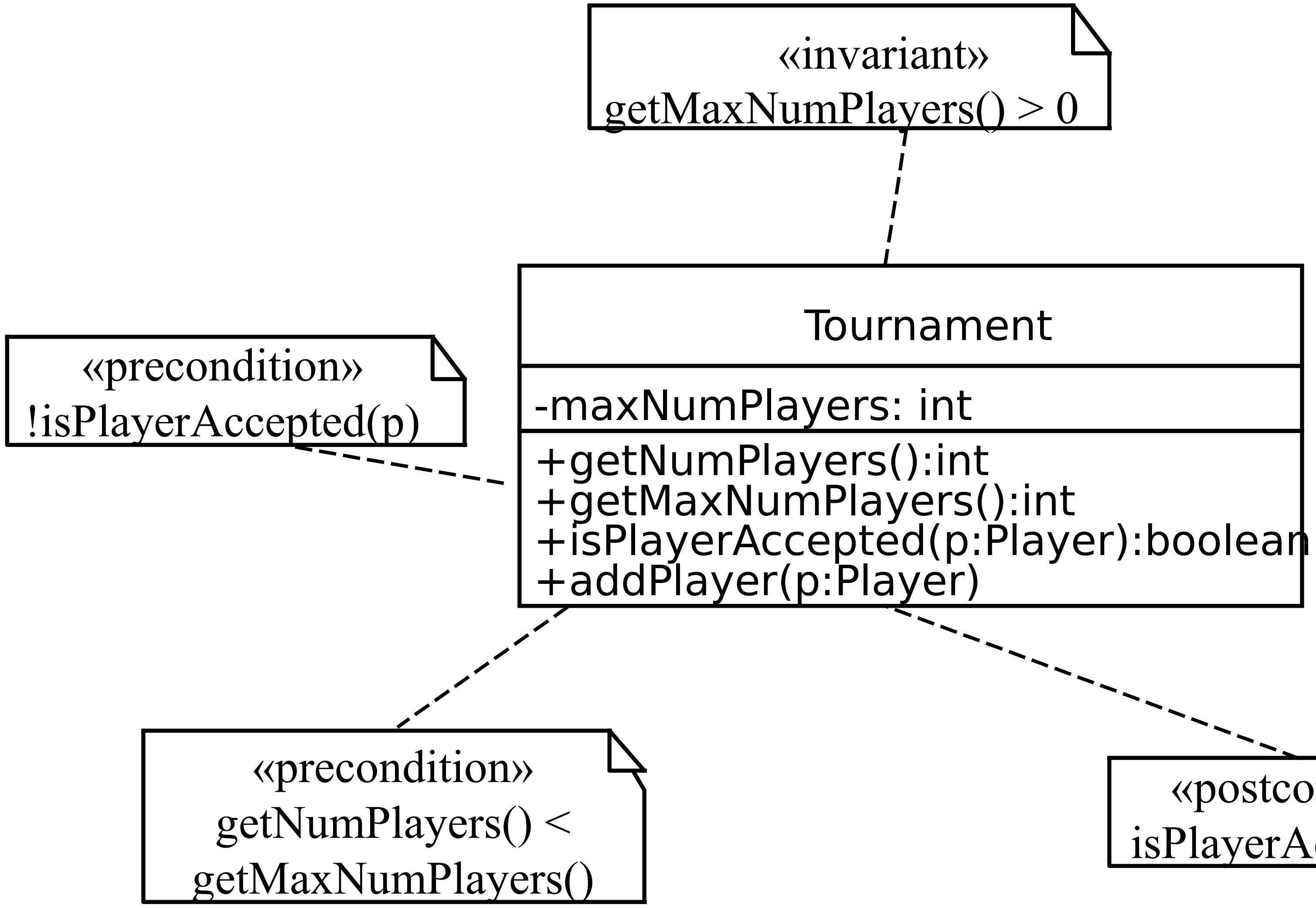
```
public class TournamentControl {
    private Tournament tournament;
    public void addPlayer(Player p) throws KnownPlayerException {
    if (tournament.isPlayerAccepted(p)) {
    throw new KnownPlayerException(p);
    }
    //... Normal addPlayer behavior
    }
}

public class TournamentForm {
  private TournamentControl control;
  private ArrayList players;
  public void processPlayerApplications() {
   for (Iteration i = players.iterator(); i.hasNext();) {
      try {
          control.acceptPlayer((Player)i.next());
       }
      catch (KnownPlayerException e) {
        // If exception was caught, log it to console
        ErrorConsole.log(e.getMessage());
       }
      }
     }
}
```

Implementing a Contract

- **Check each precondition**:
  - Before the beginning of the method with a test to check the precondition for that method
    - Raise an exception if the precondition evaluates to false
- **Check each postcondition:**
  - At the end of the method write a test to check the postcondition
    - Raise an exception if the postcondition evaluates to false. If more than one postcondition is not satisfied, raise an exception only for the first violation.
- **Check each invariant:**
  - Check invariants at the same time when checking preconditions and when checking postconditions
- **Deal with inheritance:**
  - Add the checking code for preconditions and postconditions also into methods that can be called from the class.

A complete implementation of the Tournament.addPlayer() contract



Heuristics: Mapping Contracts to Exceptions

- Executing checking code slows down your program
  - If it is too slow, omit the checking code for private and protected methods
  - If it is still too slow, focus on components with the longest life
    - Omit checking code for postconditions and invariants for all other components.

Heuristics for Transformations

- For any given transformation always use the same tool
- Keep the contracts in the source code, not in the object design model
- Use the same names for the same objects
- Have a style guide for transformations (Martin Fowler)

Object Design Areas

1. Service specification
   - Describes precisely each class interface
2. Component selection
   - Identify off-the-shelf components and additional solution objects
3. Object model restructuring
   - Transforms the object design model to improve its understandability and extensibility
4. Object model optimization
   - Transforms the object design model to address performance criteria such as response time or memory utilization.

Design Optimizations

- Design optimizations are an important part of the object design phase:
  - The requirements analysis model is semantically correct but often too inefficient if directly implemented.
- Optimization activities during object design:
  1. Add redundant associations to minimize access cost
  2. Rearrange computations for greater efficiency
  3. Store derived attributes to save computation time
- As an object designer you must strike a balance between efficiency and clarity.
  - Optimizations will make your models more obscure

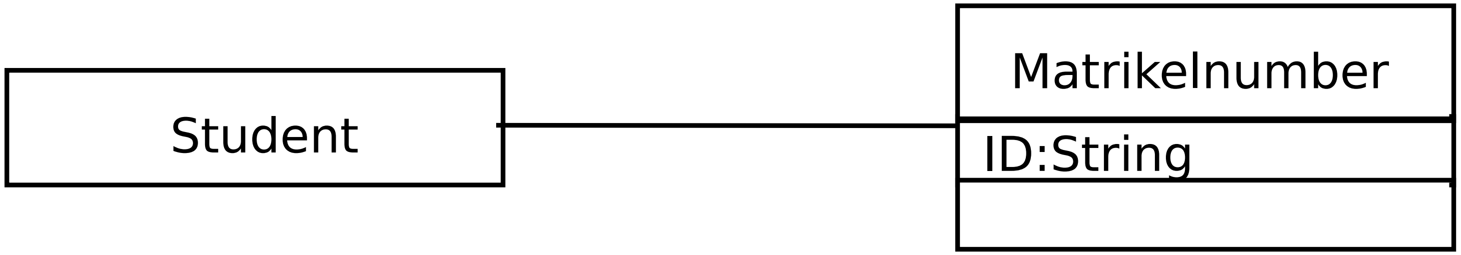
Design Optimization Activities

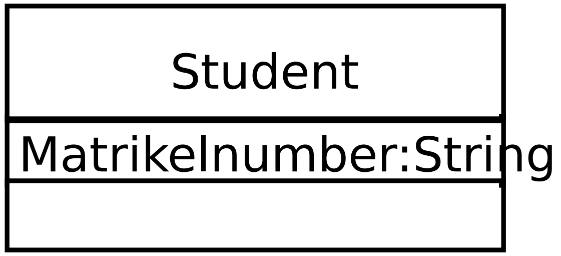
1. Add redundant associations:
   - What are the most frequent operations? (Sensor data lookup?)
   - How often is the operation called? (30 times a month, every 50 milliseconds)
2. Rearrange execution order
   - Eliminate dead paths as early as possible (Use knowledge of distributions, frequency of path traversals)
   - Narrow search as soon as possible
   - Check if execution order of loop should be reversed
3. Turn classes into attributes

Implement application domain classes

- To collapse or not collapse: Attribute or association?
- Object design choices:
  - Implement entity as embedded attribute
  - Implement entity as separate class with associations to other classes
- Associations are more flexible than attributes but often introduce unnecessary indirection
- Abbott's textual analysis rules.

Optimization Activities: Collapsing Objects





To Collapse or not to Collapse?

- Collapse a class into an attribute if the only operations defined on the attributes are Set() and Get().

Design Optimizations (continued)

Store derived attributes

- Example: Define new classes to store information locally (database cache)

- Problem with derived attributes:
  - Derived attributes must be updated when base values change.
  - There are 3 ways to deal with the update problem:
    - Explicit code: Implementor determines affected derived attributes (push)
    - Periodic computation: Recompute derived attribute occasionally (pull)
    - Active value: An attribute can designate set of dependent values which are automatically updated when active value is changed (notification, data trigger)

Increase Inheritance

- Rearrange and adjust classes and operations to prepare for inheritance
  - Generalization: Finding the base class first, then the sub classes
  - Specialization: Finding the the sub classes first, then the base class
- Generalization is a common modeling activity. It allows to abstract common behavior out of a group of classes
  - If a set of operations or attributes are repeated in 2 classes the classes might be special instances of a more general class
- Always check if it is possible to change a subsystem (collection of classes) into a superclass in an inheritance hierarchy.

Generalization: Finding the super class

- You need to prepare or modify your classes for generalization
- All operations must have the same signature but often the signatures do not match
- Superclasses are desirable. They
  - increase modularity, extensibility and reusability
  - improve configuration management
- Many design patterns use superclasses
  - Try to retrofit an existing model to allow the use of a design pattern.

Heuristics for Implementing Associations

- Two strategies for implementing associations:
  1. Be as uniform as possible
  2. Make an individual decision for each association
- Example of a uniform implementation (often used by CASE tools)
  - 1-to-1 association:
    - Role names are always treated like attributes in the classes and translate to references
  - 1-to-many association:
    - Always translated into a Vector
  - Qualified association:
    - Always translated into to a Hash table.

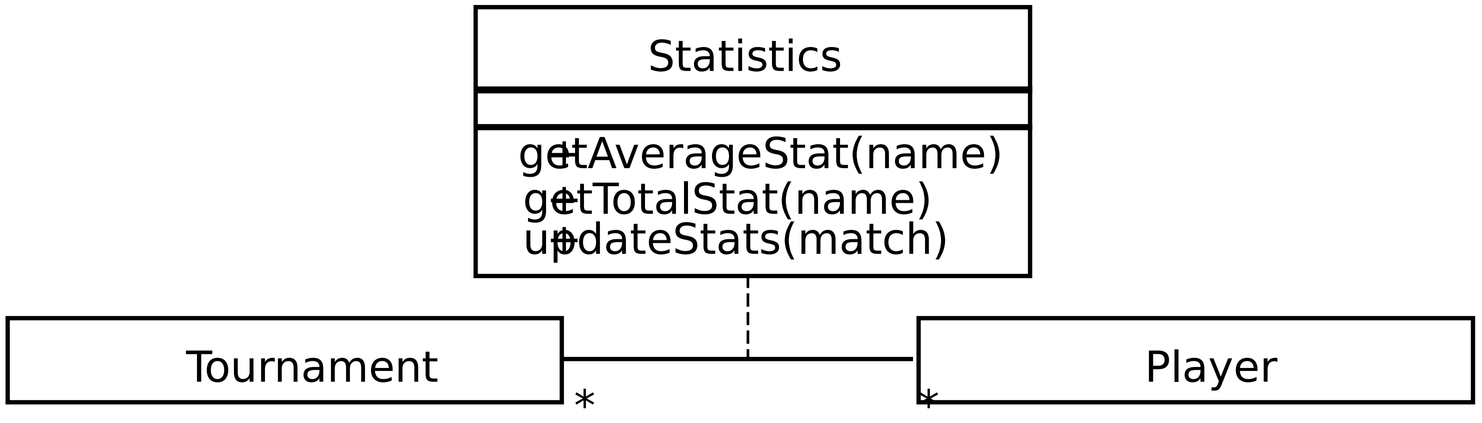
Summary

- Four mapping concepts:
  - Model transformation
  - Forward engineering
  - Refactoring
  - Reverse engineering
- Model transformation and forward engineering techniques:
  - Optiziming the class model
  - Mapping associations to collections
  - Mapping contracts to exceptions
  - Mapping class model to storage schemas

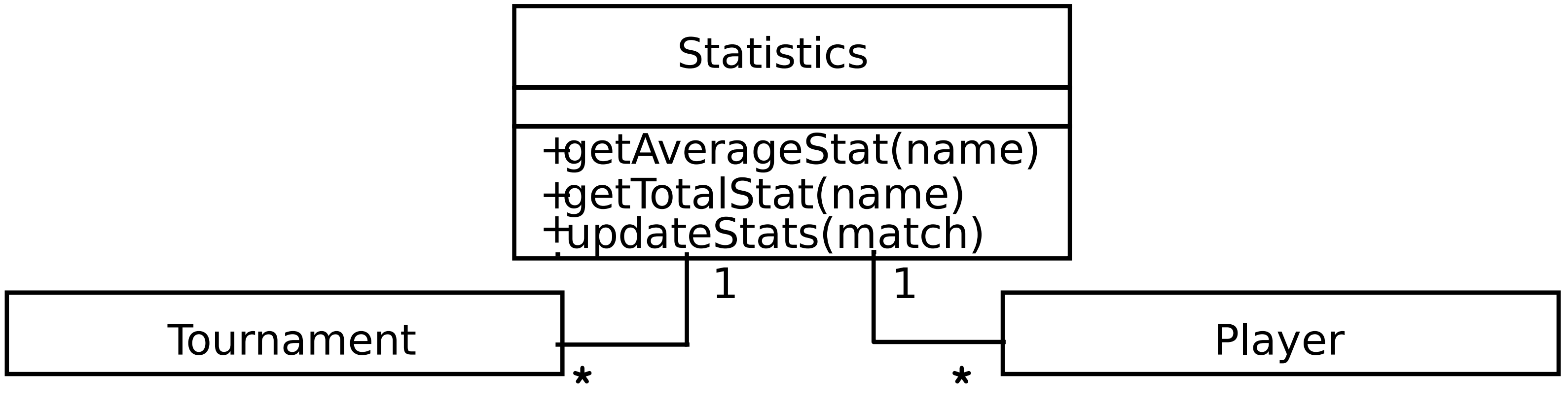
Backup and Additional Slides

Transformation of an Association Class

Object design model before transformation



Object design model after transformation:
1 class and 2 binary associations



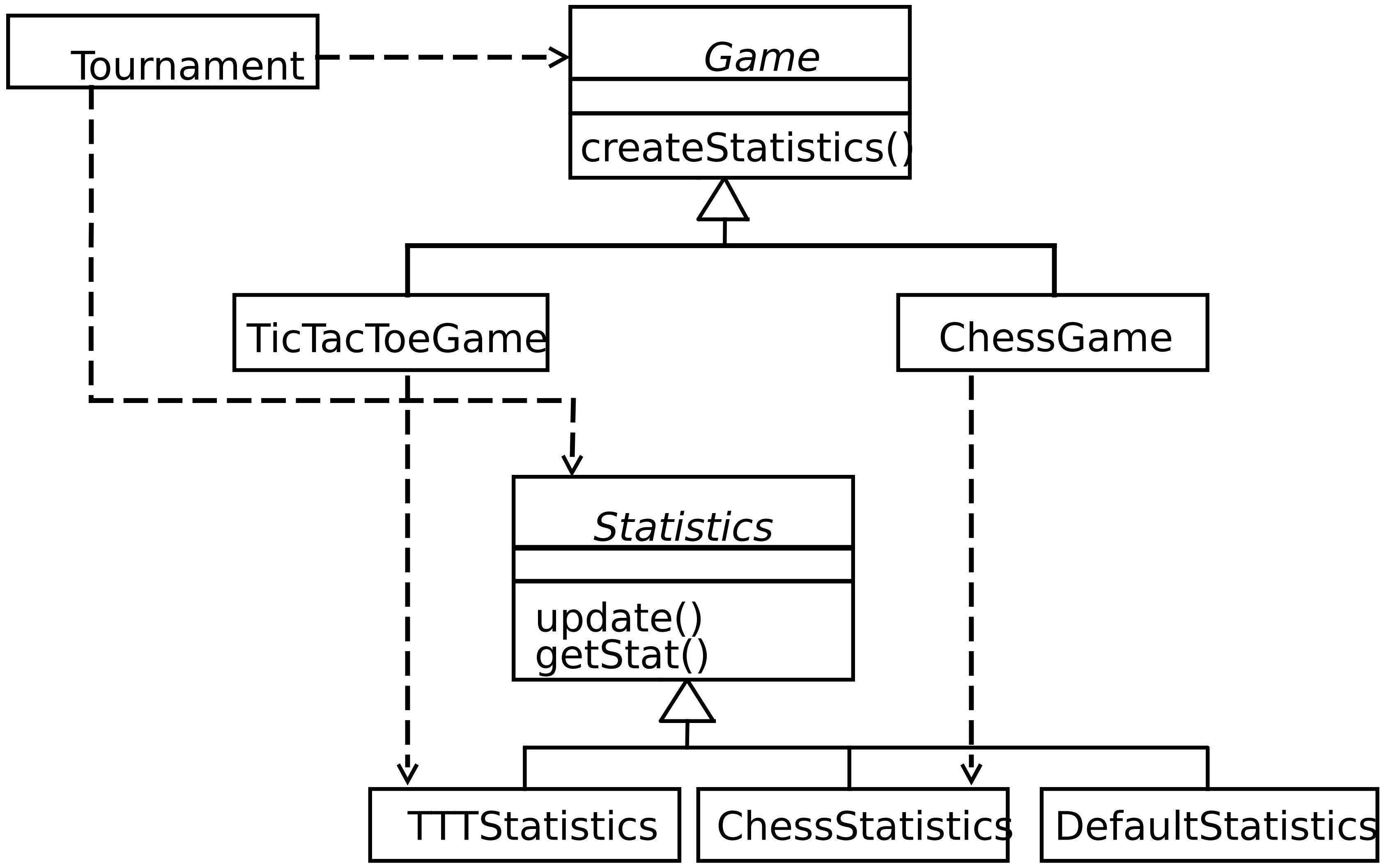
Review: Terminology

- Roundtrip Engineering
  - Forward Engineering + reverse engineering
  - Inventory analysis: Determine the Delta between Object Model and Code
  - Together-J and Rationale provide tools for reverse engineering
- Reengineering
  - Used in the context of project management:
  - Provding new functionality (customer dreams up new stuff) in the context of new technology (technology enablers)

Specifying Interfaces

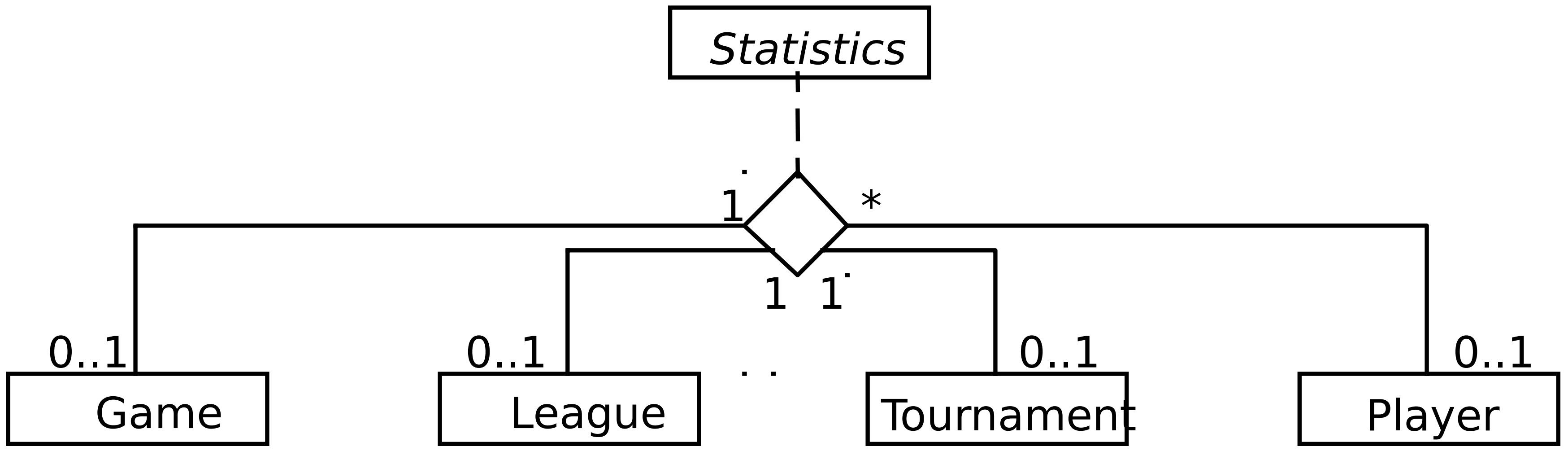
- The players in object design:
  - Class User
  - Class Implementor
  - Class Extender
- Object design: Activities
  - Adding visibility information
  - Adding type signature information
  - Adding contracts
- Detailed view on Design patterns
  - Combination of delegation and inheritance

Statistics as a product in the Game Abstract Factory

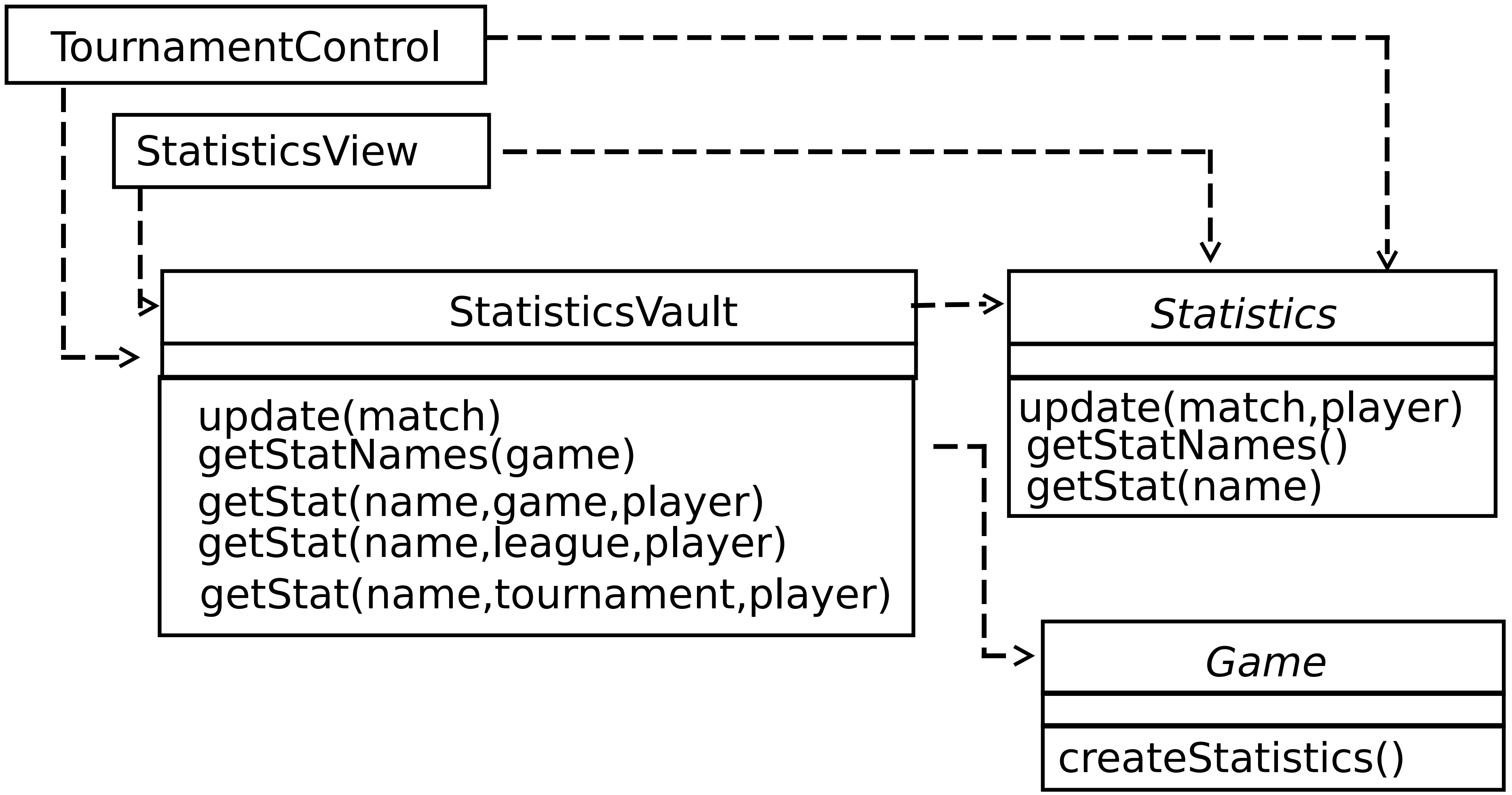


N-ary association class Statistics

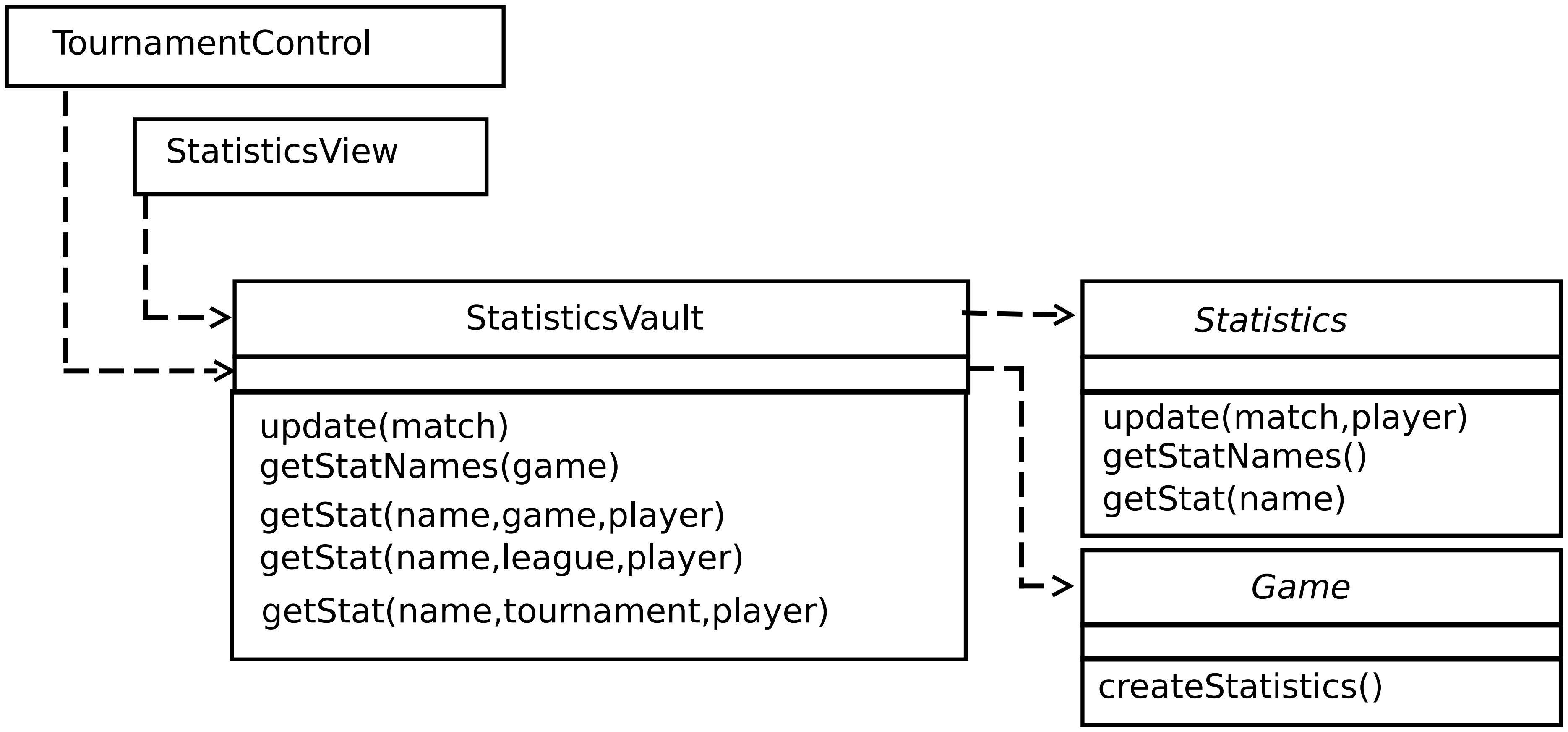
Statistics relates League, Tournament, and Player



Realization of the Statistics Association



StatisticsVault as a Facade



Public interface of the StatisticsVault class

```
public class StatisticsVault {
   public void update(Match m)
   throws InvalidMatch, MatchNotCompleted {...}

   public List getStatNames() {...}

   public double getStat(String name, Game g, Player p)
   throws UnknownStatistic, InvalidScope {...}

   public double getStat(String name, League l, Player p)
   throws UnknownStatistic, InvalidScope {...}

   public double getStat(String name, Tournament t, Player p)
   throws UnknownStatistic, InvalidScope {...}
}
```

Database schema for the Statistics Association

Statistics table

id:long	scope:long	scopetype:long	player:long

StatisticCounters table

id:long	name:text[25]	value:double

Game table

id:long	...

League table

id:long	...

Tournament table

id:long	...

Restructuring Activities

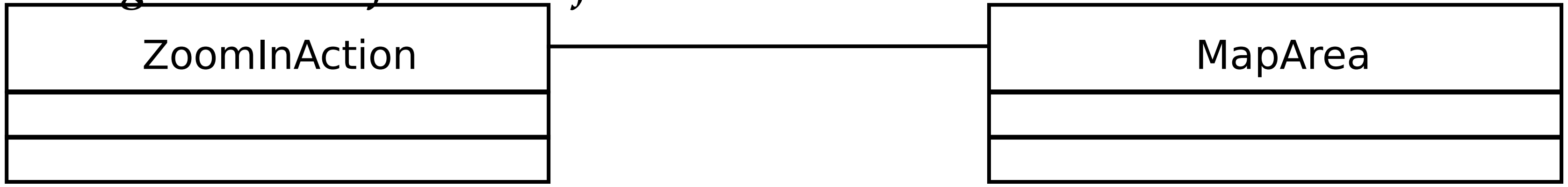
- Realizing associations
- Revisiting inheritance to increase reuse
- Revising inheritance to remove implementation dependencies

Realizing Associations

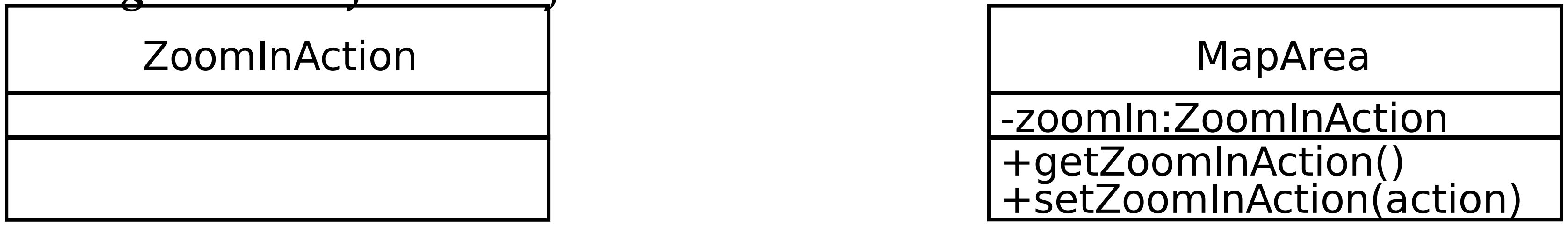
- Strategy for implementing associations:
  - Be as uniform as possible
  - Individual decision for each association
- Example of uniform implementation
  - 1-to-1 association:
    - Role names are treated like attributes in the classes and translate to references
  - 1-to-many association:
    - "Ordered many" : Translate to `Vector`
    - "Unordered many" : Translate to `Set`
  - Qualified association:
    - Translate to Hash table

Unidirectional 1-to-1 Association

Object design model before transformation

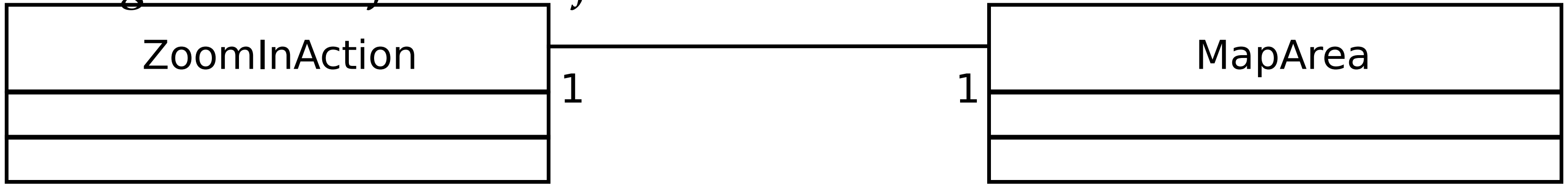


Object design model after transformation

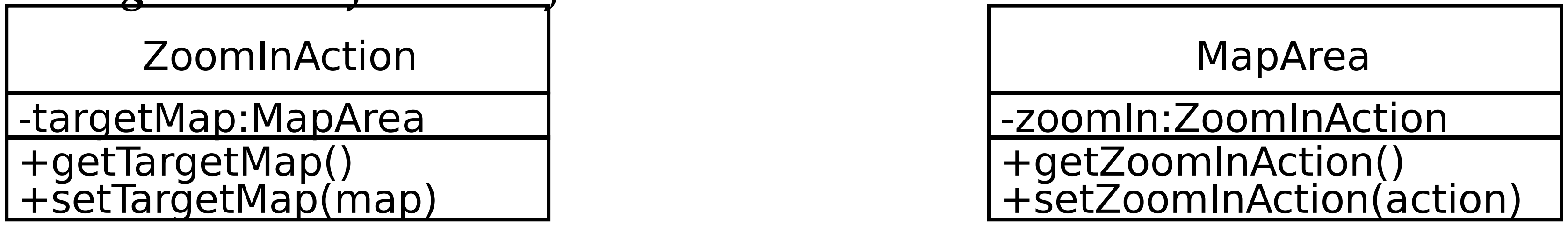


Bidirectional 1-to-1 Association

Object design model before transformation

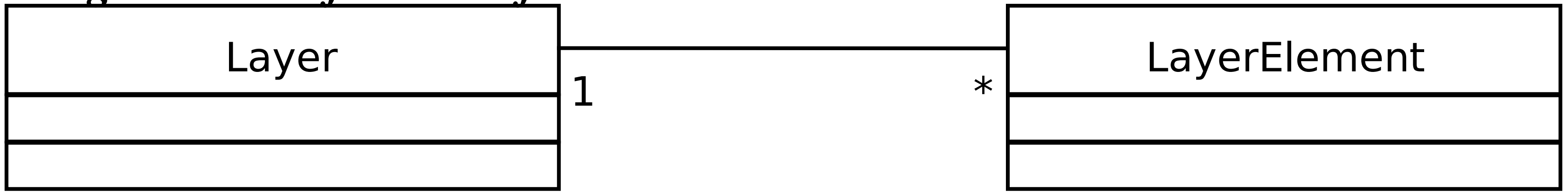


Object design model after transformation

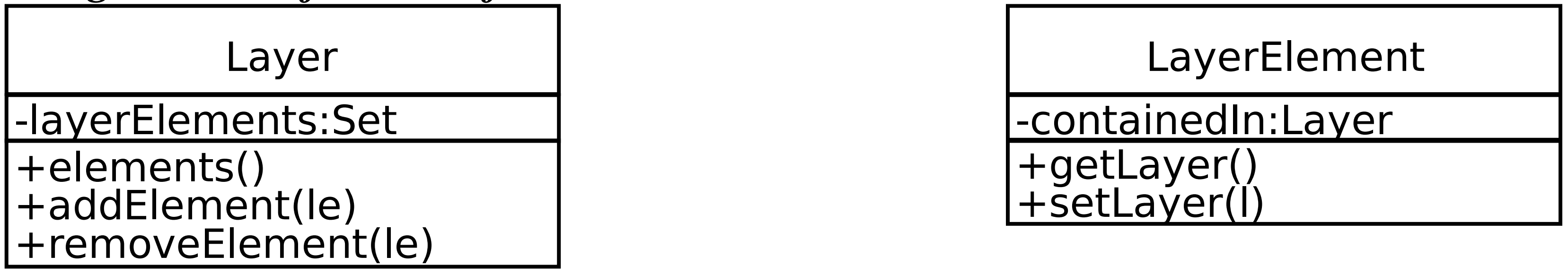


1-to-Many Association

Object design model before transformation

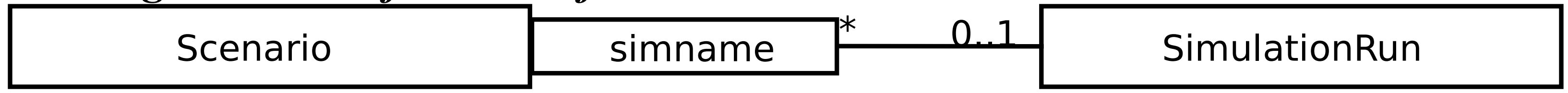


Object design model after transformation

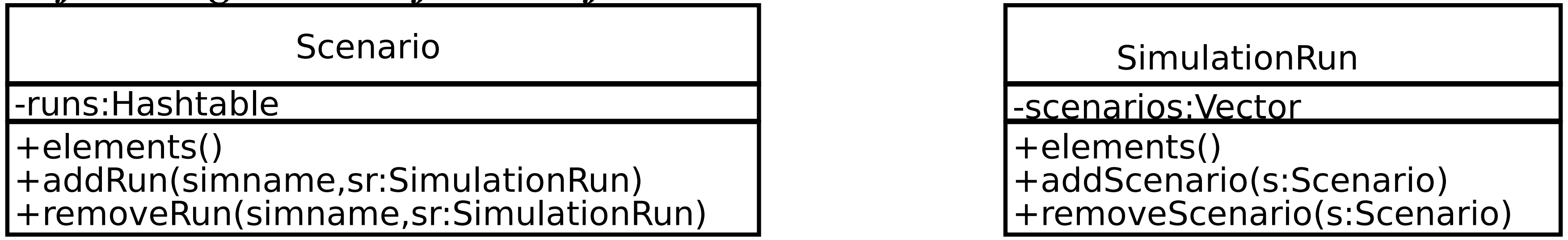


Qualification

Object design model before transformation



Object design model after transformation



Increase Inheritance

- Rearrange and adjust classes and operations to prepare for inheritance
- Abstract common behavior out of groups of classes
  - If a set of operations or attributes are repeated in 2 classes the classes might be special instances of a more general class.
- Be prepared to change a subsystem (collection of classes) into a superclass in an inheritance hierarchy.

Building a super class from several classes

- Prepare for inheritance. All operations must have the same signature but often the signatures do not match
- Abstract out the common behavior (set of operations with same signature) and create a superclass out of it.
- Superclasses are desirable. They
  - increase modularity, extensibility and reusability
  - improve configuration management
- Turn the superclass into an abstract interface if possible
  - Use Bridge pattern.