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Course "Softwaretechnik"
Book Chapters 9, 10

Object Design: Specifying Interfaces, Model-to-implementation mapping

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- Visibility
- Type information
- Contracts: OCL
  - preconditions, postconditions, invariants
  - includes, asSet, forAll, exists
- Mapping associations to code

Wo sind wir?: Taxonomie "Die Welt der Softwaretechnik"

Welt der Problemstellungen:

- Produkt (Komplexitätsprob.)
  - Anforderungen (Problemraum)
  - **Entwurf (Lösungsraum)**
- Prozess (psycho-soziale P.)
  - Kognitive Beschränkungen
  - Mängel der Urteilskraft
  - **Kommunikation, Koordination**
  - Gruppendynamik
  - Verborgene Ziele
  - Fehler

Welt der Lösungsansätze:

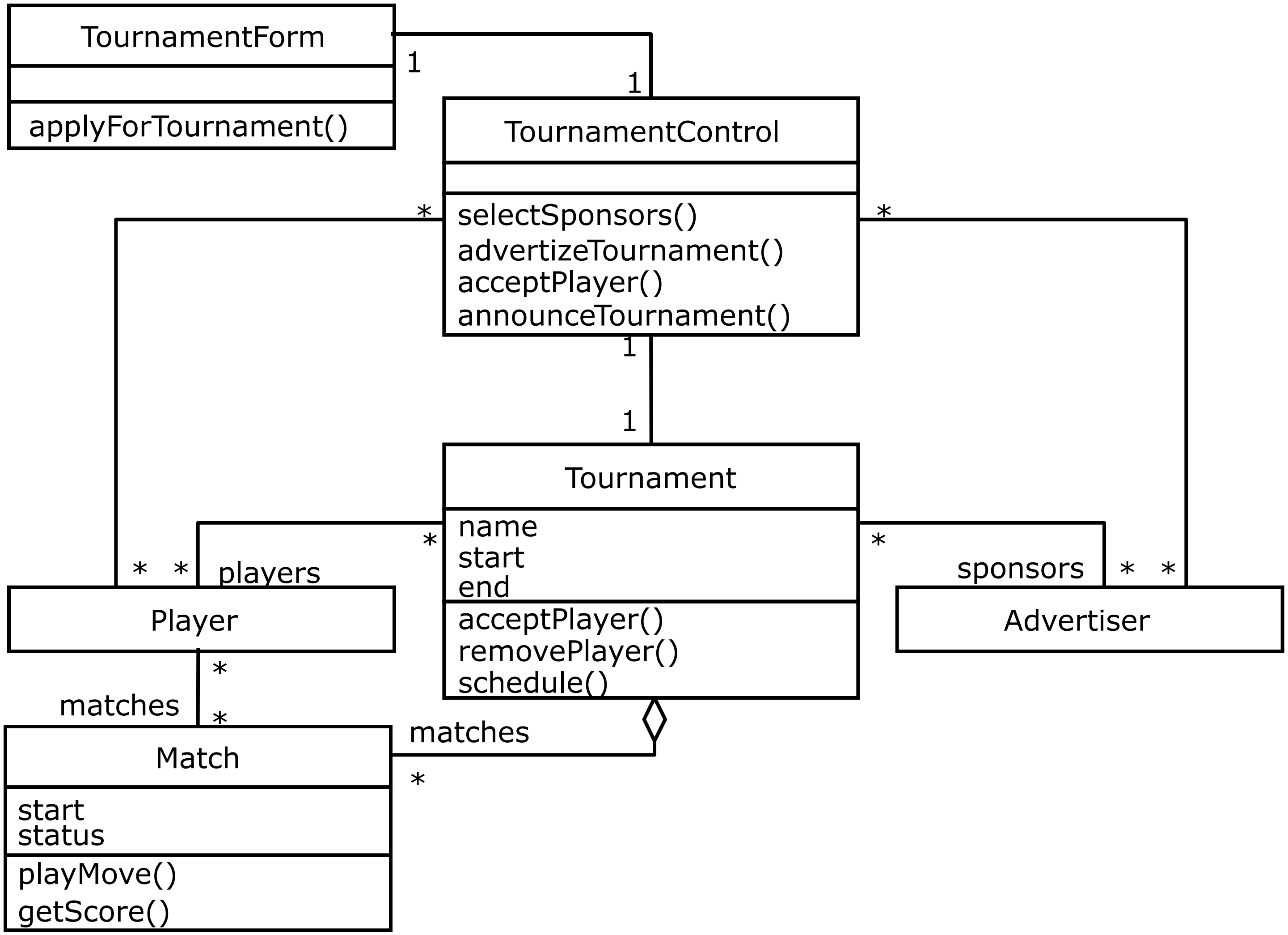
- Technische Ansätze ("hart")
  - **Abstraktion**
  - **Wiederverwendung**
  - **Automatisierung**
- Methodische Ansätze ("weich")
  - Anforderungsermittlung
  - **Entwurf**
  - Qualitätssicherung
  - Projektmanagement

Wo sind wir?: Entwurf

- Einsicht: Man sollte *vor* dem Kodieren über eine günstige Struktur der Software nachdenken
  - und diese als Koordinationsgrundlage schriftlich festhalten

- Prinzipien:
  - **Trennung von Belangen**
  - **Architektur**: Globale Struktur festlegen (Grobentwurf), insbes. für das Erreichen der nichtfunktionalen Anforderungen
  - **Modularisierung**: Trennung von Belangen durch Modularisierung, Kombination der Teile durch Schnittstellen (information hiding, Lokalität)
  - **Wiederverwendung**: Erfinde Architekturen und Entwurfsmuster nicht immer wieder neu
  - **Dokumentation**: Halte sowohl Schnittstellen als auch zu Grunde liegende Entwurfsentscheidungen und deren Begründungen fest

Part of ARENA's object model identified during the analysis



Specifying Interfaces

- Requirements analysis activities
  - Identifying attributes and operations without specifying their types or their parameters
    - Often not all attributes and operations are identified in this stage

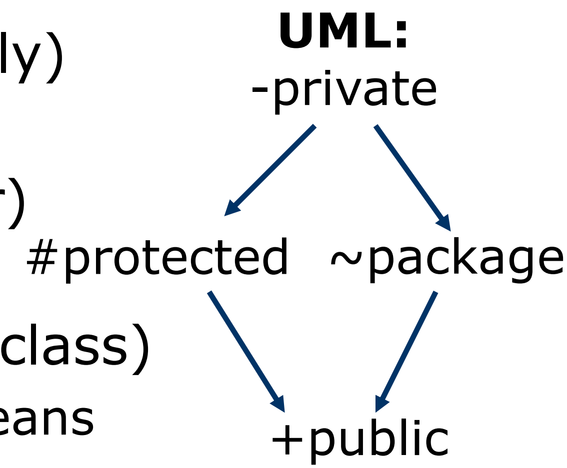
- Object design: Four activities
  - Identify remaining attributes and operations
  - Add visibility information
  - Add type signature information
  - Add contracts

- Object design is a detail-level subtask of modularization

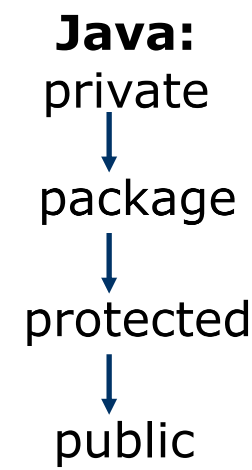
1. Add Visibility Information

UML defines four kinds of visibility:

- 1: Private (visible for class implementer only)
  - marked by '-' in diagrams
- 2a: Protected (visible also for class extender)
  - marked by '#' in diagrams
- 2b: Package (private to a package, not to a class)
  - when a package represents a module, this means 'publicly visible inside the module'
  - marked by '~' in diagrams
- 3: Public (fully visible)
  - marked by '+' in diagrams



- Difference to Java visibilities:
  - Java: 'protected' is also visible for classes in the package. This is not true (and cannot be expressed) in UML
    - The 'package' default promotes creation of Facades



Information Hiding Heuristics

- Carefully define the public interface for classes as well as subsystems (façade)
- Always apply the "Need to know" principle
  - Only if somebody needs to access the information make it publicly possible,
  - but then only through well-defined channels, so the module can control the access (in particular changes to individual attributes).
- The less an operation knows
  - the less likely it will be affected by any changes
  - the easier the module can be changed
- Trade-off: Information hiding vs. efficiency
  - In a <u>few</u> cases, accessing a private attribute might be too slow (for example in real-time systems or games)
    - BUT: "Make it work first before you make it work fast"

Java: Packages as modules

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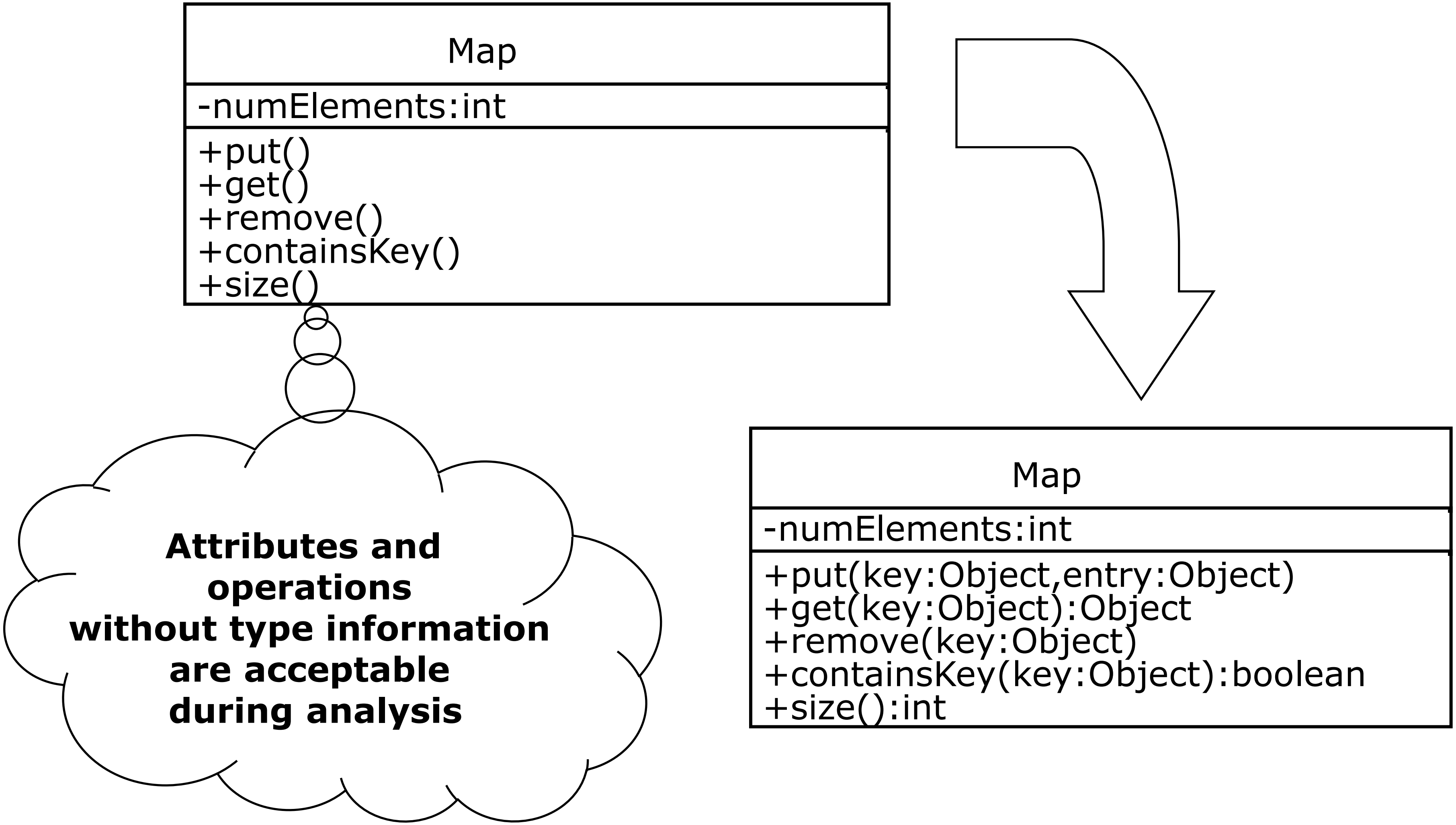
- The module interface contains one *Facade* class (for methods) plus perhaps several data type classes (for data and methods)
  - perhaps interfaces only, not actual classes
- These classes or interfaces are *public*, all others have *package* visibility
  - and all members of these 'other' classes have *package* or *private* visibility (*public* and *protected* would not help)
  - *Package* (or *default*) visibility in Java has no visibility declarator
- Most members of *public* classes have *public* or *protected* visibility
  - Note that protected members add an inheritance aspect to the interface of the class that results in less information hiding.
  - *private* should be used when the class is so complicated that *protected* would likely lead to integrity violations
  - *package* (for module-internal class-external access) is rarely needed

2. Add Type Signature Information



3. Add Contracts

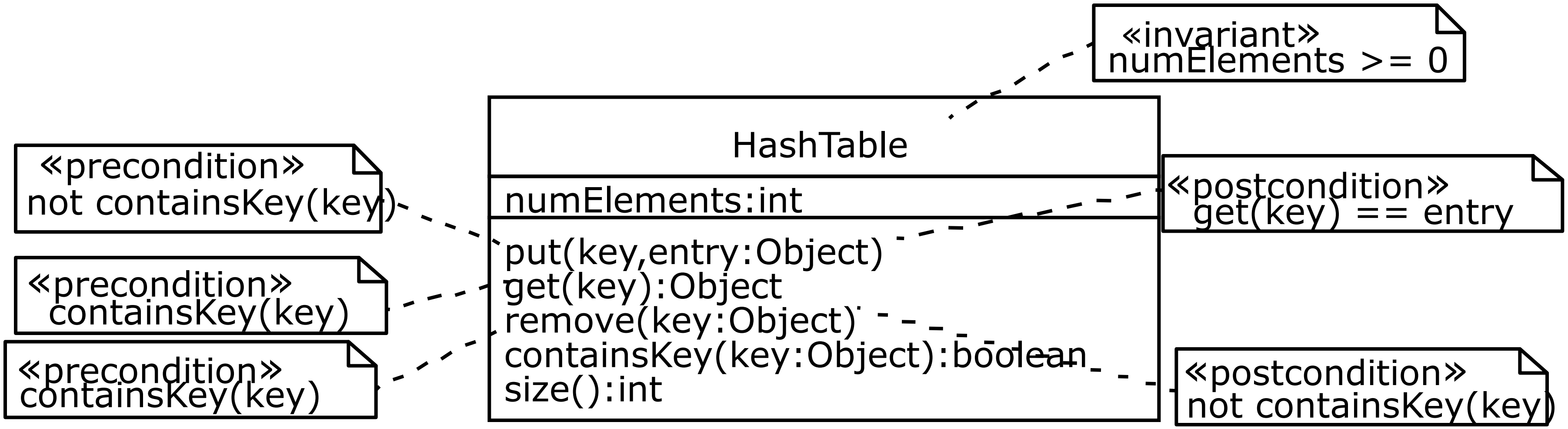
- Contracts on a class enable caller and callee to share the same assumptions about the class

Contracts include three types of constraints:

- Invariant:
  - A predicate that is always true for an instance after any call. Invariants are constraints associated with classes or interfaces
  - The invariant is thus an implicit part of each postcondition
- Precondition:
  - Preconditions are predicates associated with a specific operation and must be true before the operation is invoked
  - They specify constraints that a caller must ensure before the call
- Postcondition:
  - Postconditions are predicates associated with a specific operation and must be true after the operation is invoked
  - They specify constraints that the class must ensure when the call returns

Expressing Constraints in UML Models

- A constraint can be depicted as a note attached to the constrained UML element by a dependency relationship



- Or it can be specified textually outside the UML diagram:

Contract for acceptPlayer in Tournament

context Tournament::acceptPlayer(p) **pre**:
  not isPlayerAccepted(p)

context Tournament::acceptPlayer(p) **pre**:
  getNumPlayers() < getMaxNumPlayers()

context Tournament::acceptPlayer(p) **post**:
  isPlayerAccepted(p)

context Tournament::acceptPlayer(p) **post**:
  getNumPlayers() = getNumPlayers@pre() + 1

The value of the expression before the call

Contract for removePlayer in Tournament

context Tournament::removePlayer(p) **pre**:
isPlayerAccepted(p)

context Tournament::removePlayer(p) **post**:
not isPlayerAccepted(p)

context Tournament::removePlayer(p) **post**:
getNumPlayers() = getNumPlayers@pre() - 1

Is this contract complete?

No. OCL specifications tend to make the tacit assumption that "everything else stays the same" -- they are very often incomplete.

Annotation of Tournament class

```
public class Tournament {
    /** The maximum number of players
     * is positive at all times.
     * @invariant maxNumPlayers > 0
     */
    private int maxNumPlayers;

    /** The players List contains
     * references to Players who are
     * are registered with the
     * Tournament. */
    private List players;

    /** Returns the current number of
     * players in the tournament. */
    public int getNumPlayers() {…}

    /** Returns the maximum number of
     * players in the tournament. */
    public int getMaxNumPlayers() {…}

    /** Assumes that the specified
     * player has not been accepted
     * in the Tournament yet.
     * @pre !isPlayerAccepted(p)
     * @pre getNumPlayers()<maxNumPlayers
     * @post isPlayerAccepted(p)
     * @post getNumPlayers() =
     *    @pre.getNumPlayers() + 1
     */
    public void acceptPlayer (Player p) {…}

    /** The removePlayer() operation
     * assumes that the specified player
     * is currently in the Tournament.
     * @pre isPlayerAccepted(p)
     * @post !isPlayerAccepted(p)
     * @post getNumPlayers() =
     *    @pre.getNumPlayers() - 1
     */
    public void removePlayer(Player p) {…}
}
```

Note: `@pre` etc. is not Javadoc syntax, but JContract (or similar) syntax

Constraints can involve more than one class

How do we specify constraints on more than one class?

3 Types of Navigation through a Class Diagram

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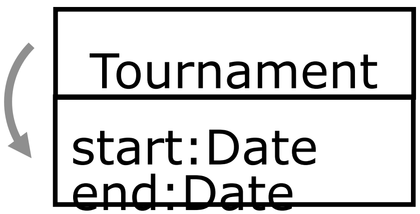
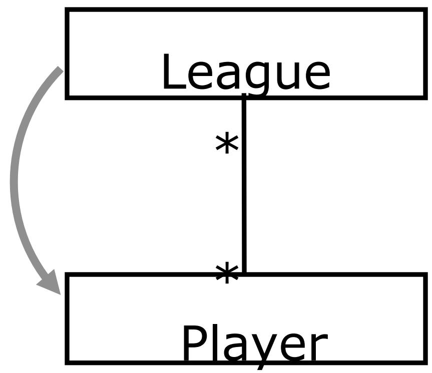
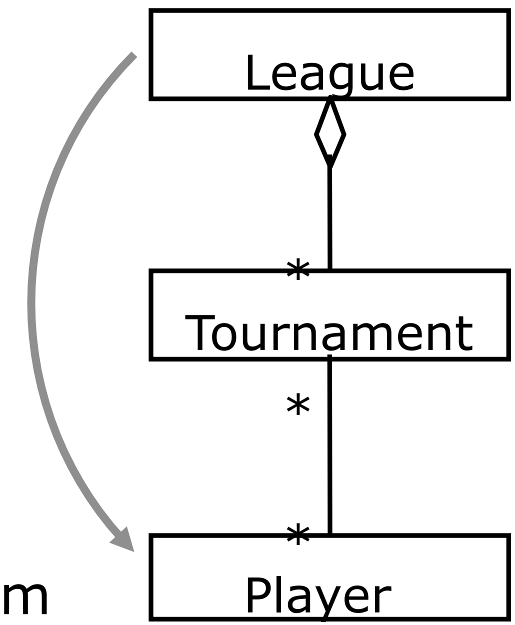
1. Local attribute



2. Directly related class

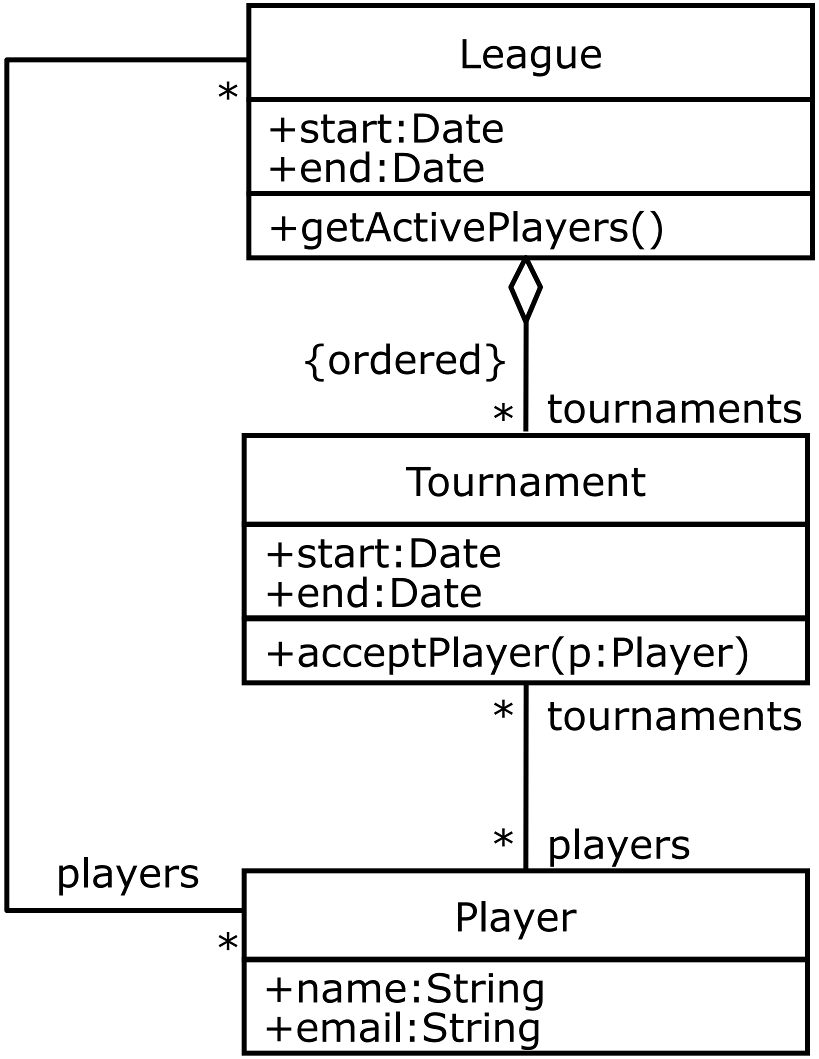


3. Indirectly related class



Any OCL constraint for any class diagram can be built using only a combination of these three navigation types

ARENA Example: League, Tournament and Player



Model refinement with 3 additional constraints

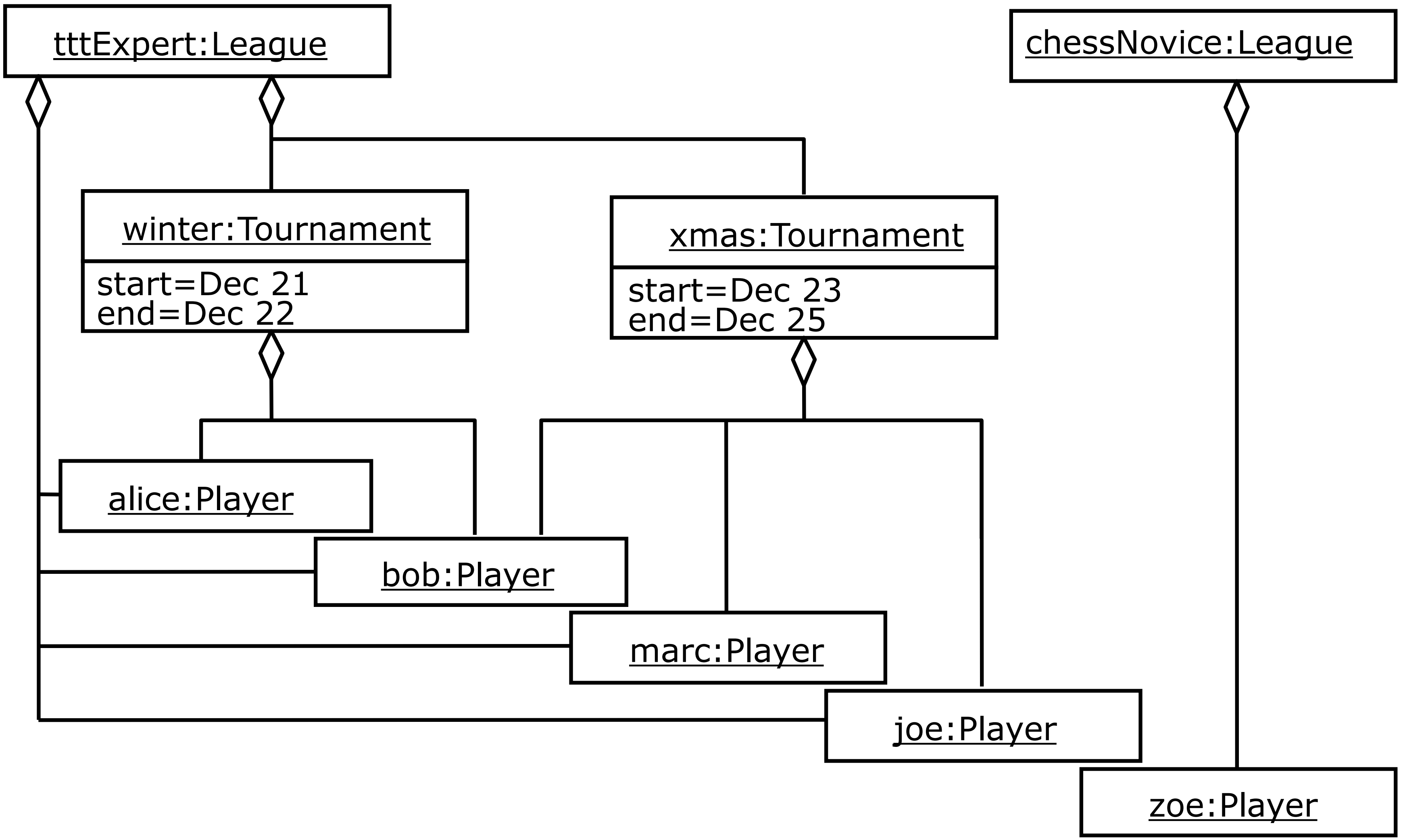
1. A Tournament's planned duration must be under one week

2. Players can be accepted in a Tournament only if they are already registered with the corresponding League

3. The number of active Players in a League are those that have taken part in at least one Tournament of the League

- To better understand these constraints we instantiate the class diagram for a specific group of instances
  - 2 Leagues, 2 Tournaments and 5 Players

Instance Diagram: 2 Leagues, 2 Tournaments, and 5 Players



Local attribute navigation

context **Tournament** inv:

end - start <= Calendar.WEEK

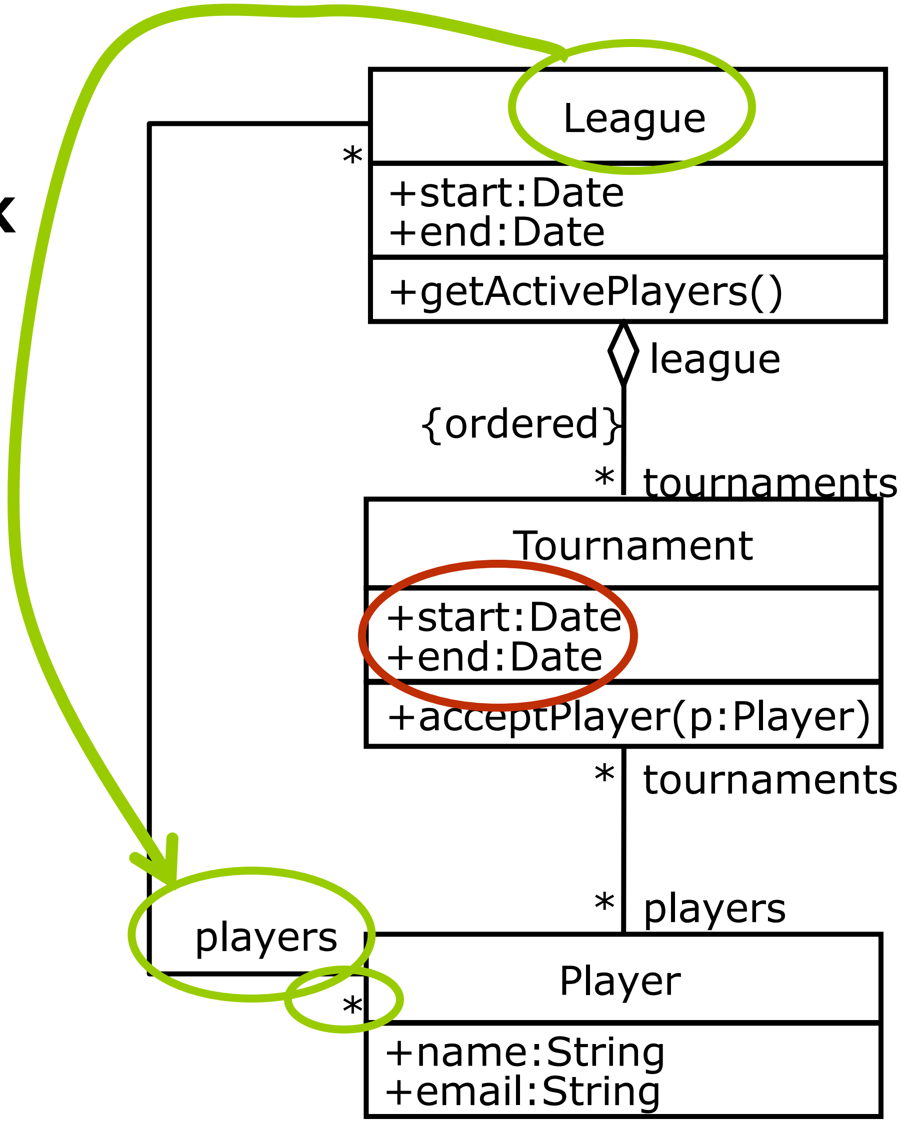
Directly related class navigation

context

Tournament::acceptPlayer(p)

pre:

league.players->includes(p)



Is the *League* arrow correct?

Local attribute navigation

context **Tournament** inv:

end - start <= Calendar.WEEK

Directly related class navigation

context **Tournament::acceptPlayer(p)** pre:

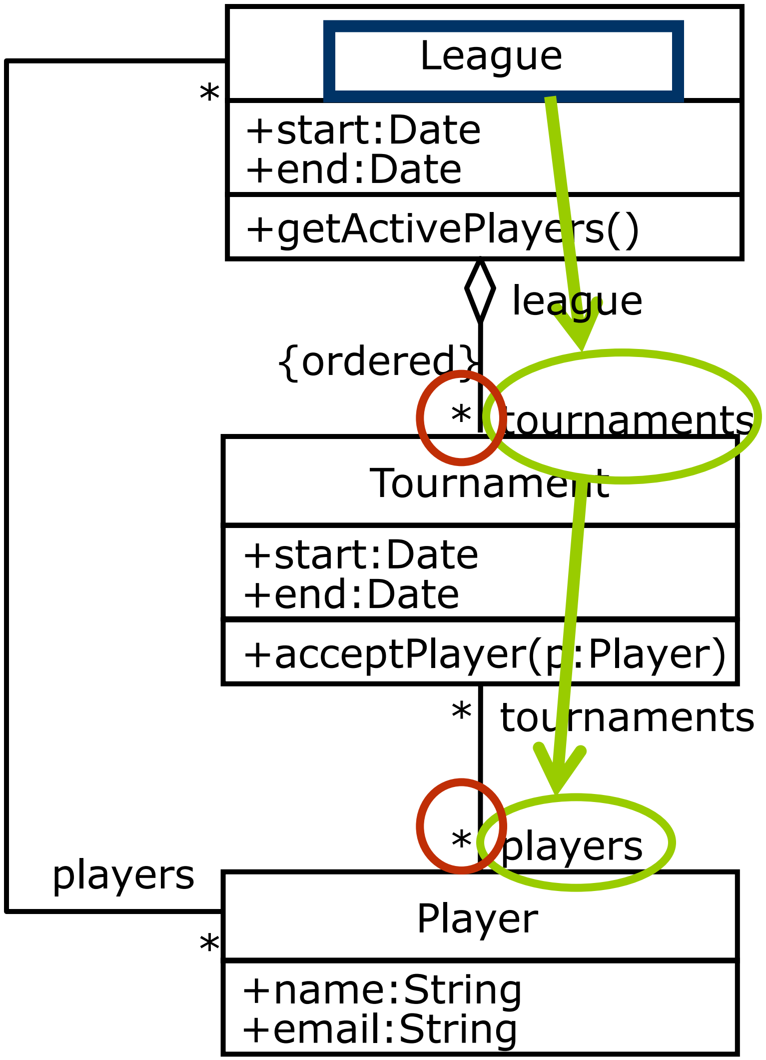
league.players->includes(p)

Indirectly related class navigation

context **League::getActivePlayers** post:

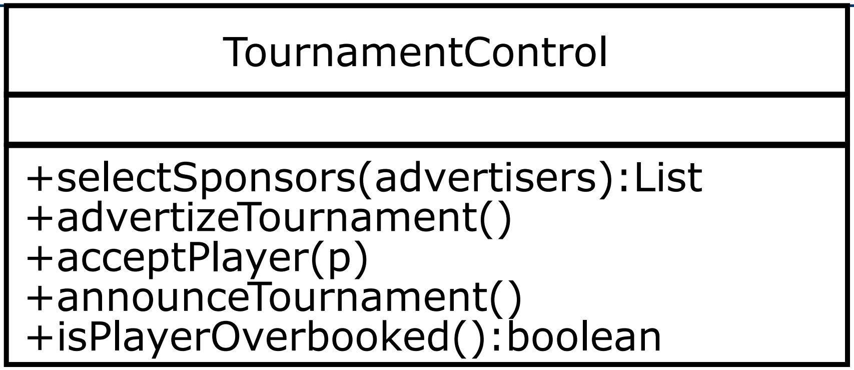
result = tournaments->iterate(

t, p = {} | p.union(t.players))



Pre- and post-conditions for ordering operations on TournamentControl

1. Which order of calls will be enforced?
2. There are at least two dubious conditions here. Which?



context TournamentControl::selectSponsors(advertisers) **pre**:
  interestedSponsors->notEmpty and tournament.sponsors->isEmpty
context TournamentControl::selectSponsors(advertisers) **post**:
  tournament.sponsors.equals(advertisers)

context TournamentControl::advertiseTournament() **pre**:
  tournament.sponsors->isEmpty and not tournament.advertised
context TournamentControl::advertiseTournament() **post**:
  tournament.advertised

context TournamentControl::acceptPlayer(p) **pre**:
  tournament.advertised and interestedPlayers->includes(p) and
    not isPlayerOverbooked(p)
context TournamentControl::acceptPlayer(p) **post**:
  tournament.players->includes(p)

OCL supports Quantification

- OCL **forall** quantifier
  / "All Matches in a Tournament occur within the Tournament's time frame": */*
  - context Tournament inv:
    matches->forAll(m |
    m.start.after(self.start) and m.end.before(self.end))

- OCL **exists** quantifier
  / "Each Tournament conducts at least one Match on the first day of the Tournament": */*
  - context Tournament inv:
    matches->exists(m | m.start.equals(self.start))

There is at least one dubious condition here. Which?

Specifying invariants on Tournament and Tournament Control

- */* "All Matches in a Tournament occur within the Tournament's time frame": */*

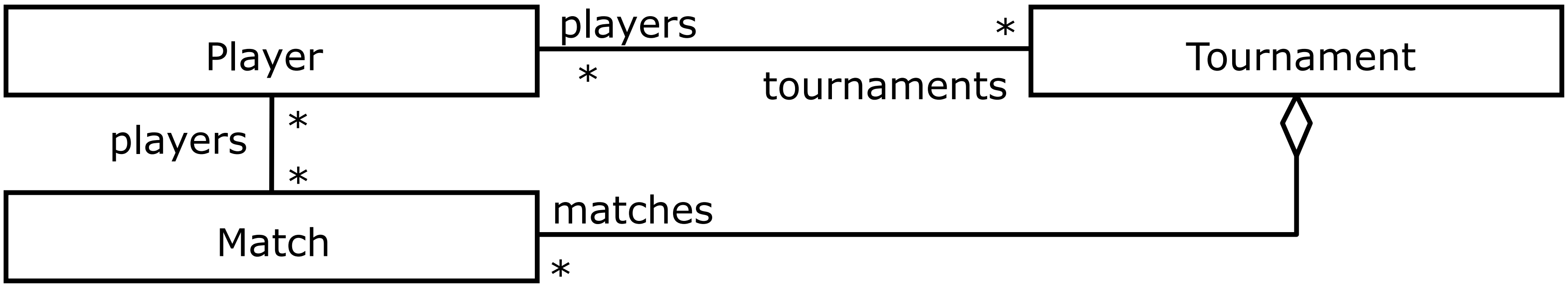
  ```
  context Tournament inv:
        matches->forAll(m | m.start.after(self.start) and
                            m.end.before(self.end))
  ```

- */* "No Player can take part in two or more Tournaments that overlap": */*

  ```
  context TournamentControl inv:
        tournament.players->forAll(p|
              p.tournaments->forAll(t|
                    t <> tournament implies
                          not t.overlap(tournament)))
  ```

Specifying invariants on Match

In this diagram, can M be among a Tournament's Matches without being among that Tournament's Players' Matches?



Yes. So we specify:

/* "A match can only involve players who are accepted in the tournament" */

context Match **inv**:
    players->forAll(p|
        p.tournaments->exists(t|
            t.matches->includes(self)))

context Match **inv**:
    players.tournaments.matches.includes(self)

/* this condition is weaker, as it does not talk about each player separately */

OCL in practice: general comments

Rules of thumb:

- Preconditions can often be expressed quite easily
- Invariants as well
- Postconditions are usually difficult to express in OCL
  - but even incomplete specifications can be useful
  - In that case, add a comment describing the rest
- It is often useful to introduce predicate methods in a class for simplifying the OCL expressions
  - see examples above

OCL in practice: today

- OCL can be used to generate code which checks the behavior of classes at run time
  - Such implementations today often do not handle quantifiers
    - because their operationalization is often not practical
  - Similar mechanisms are available for Java by means of preprocessors
    - e.g. JContract
    - The constraints are expressed using Javadoc tags
    - The preprocessor inserts appropriate code

- A simpler mechanism is built into the Eiffel language
  - keywords *require, ensure, invariant*
- Plain Java uses **`assert`** expressions in the code instead

OCL in practice: future

- In the future, more and more compilers will be able to check the consistency of code and OCL specifications
  - so no runtime checks are required
  - May often even be capable of checking quantified expressions
    - by applying formal verification
  - Will not be able to check all kinds of OCL specification, but many

- Consequence:
  Start using OCL as soon as possible in your daily work

Model-to-implementation mapping

- Some aspects of detailed UML design models can be mapped into implementations schematically
  - More and more often, this is done automatically by tools (Model-driven architecture, MDA)
- Examples:
  - Mapping associations to code
  - Mapping contract violations to exceptions
  - Mapping classes and associations to rDBMS database tables (Object-relational mapping, ORM)
- Let us look at association mapping as an example

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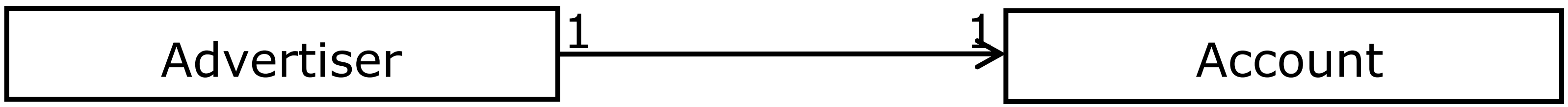
Object design model before transformation



Source code after transformation

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

create a *setAccount()* if the *Account* object is pre-existing

for bidirectional associations do likewise in *Account:*

Bidirectional one-to-one association

Object design model before transformation

Source code after transformation

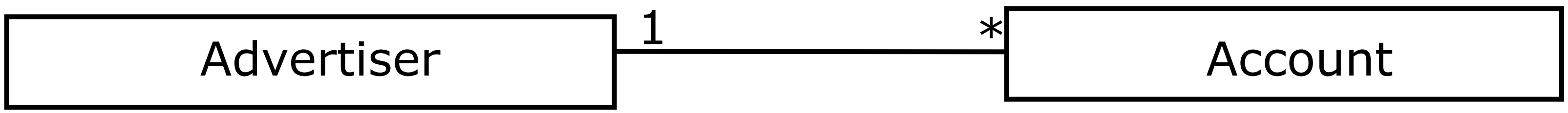
```
public class Advertiser {
    /* account is initialized in
     * constructor, never modified.
     */
    protected Account account;
    public Advertiser() {
     account = new Account(this);
    }
    public Account getAccount() {
            return account;
    }
}
```

```
public class Account {
    /* owner is initialized in
     * constructor, never modified.
     */
    protected Advertiser owner;

    public Account(
                Advertiser owner) {
            this.owner = owner;
    }
    public Advertiser getOwner() {
            return owner;
    }
}
```

Does this work as intended? What can go wrong?

Bidirectional, one-to-many association

Object design model before transformation



Source code after transformation

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

```
public class Account {
    protected Advertiser owner = null;
    public void setOwner(Advertiser
                              newOwner) {
       Advertiser oldOwner = owner;
       owner = null;  // cancel previous owner
       if (oldOwner != null)
           oldOwner.removeAccount(this);
       owner = newOwner;
       if (newOwner != null)
           newOwner.addAccount(this);
    }
    public Advertiser getOwner() {
       return owner;
    }
}
```

(beware of infinite recursion!)

Object design model before transformation

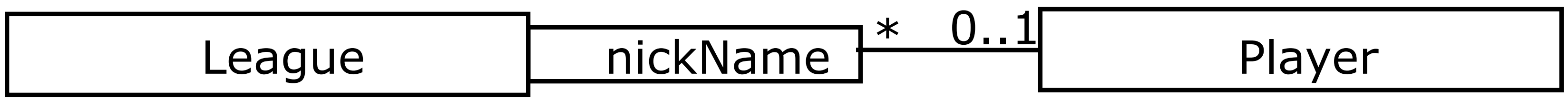
Source code after transformation

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

(beware of infinite recursion!)

Bidirectional qualified association (2)



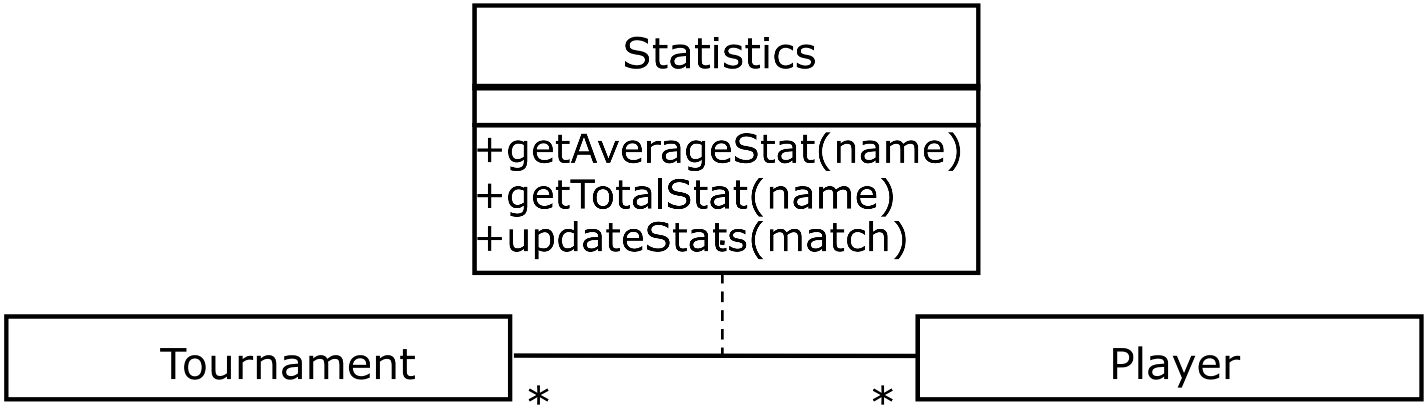
Source code after forward engineering:

```
public class League {
  protected Map players;

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

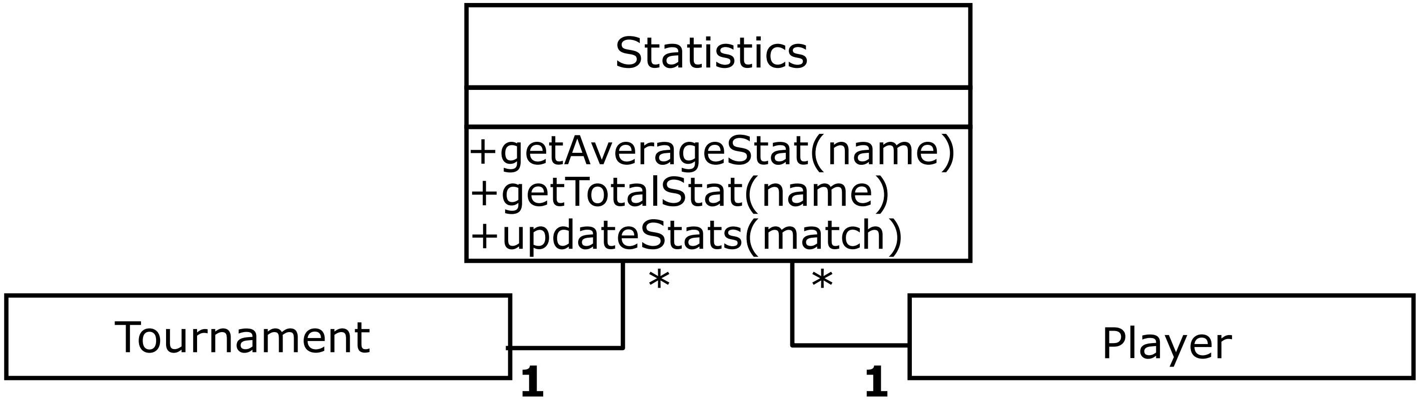
```
public class Player {
  protected Map leagues;

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

Transformation of an association class

Object design model before transformation



Object design model after transformation: A class and two binary associations



Summary

- During object design (and only then) we specify **visibility**
- **Contracts** are constraints on a class that enable class users, implementers, and extenders to share the same assumptions about the class ("Design by contract")
  - **Constraints** are boolean expressions on model elements
- **OCL** is a language that allows us to express constraints
  - OCL (object constraint language) is part of the UML world
- Complicated constraints involving more than one class, attribute or operation can be expressed with 3 basic navigation types
- Various types of models can be mapped to code systematically

Thank you!