

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:

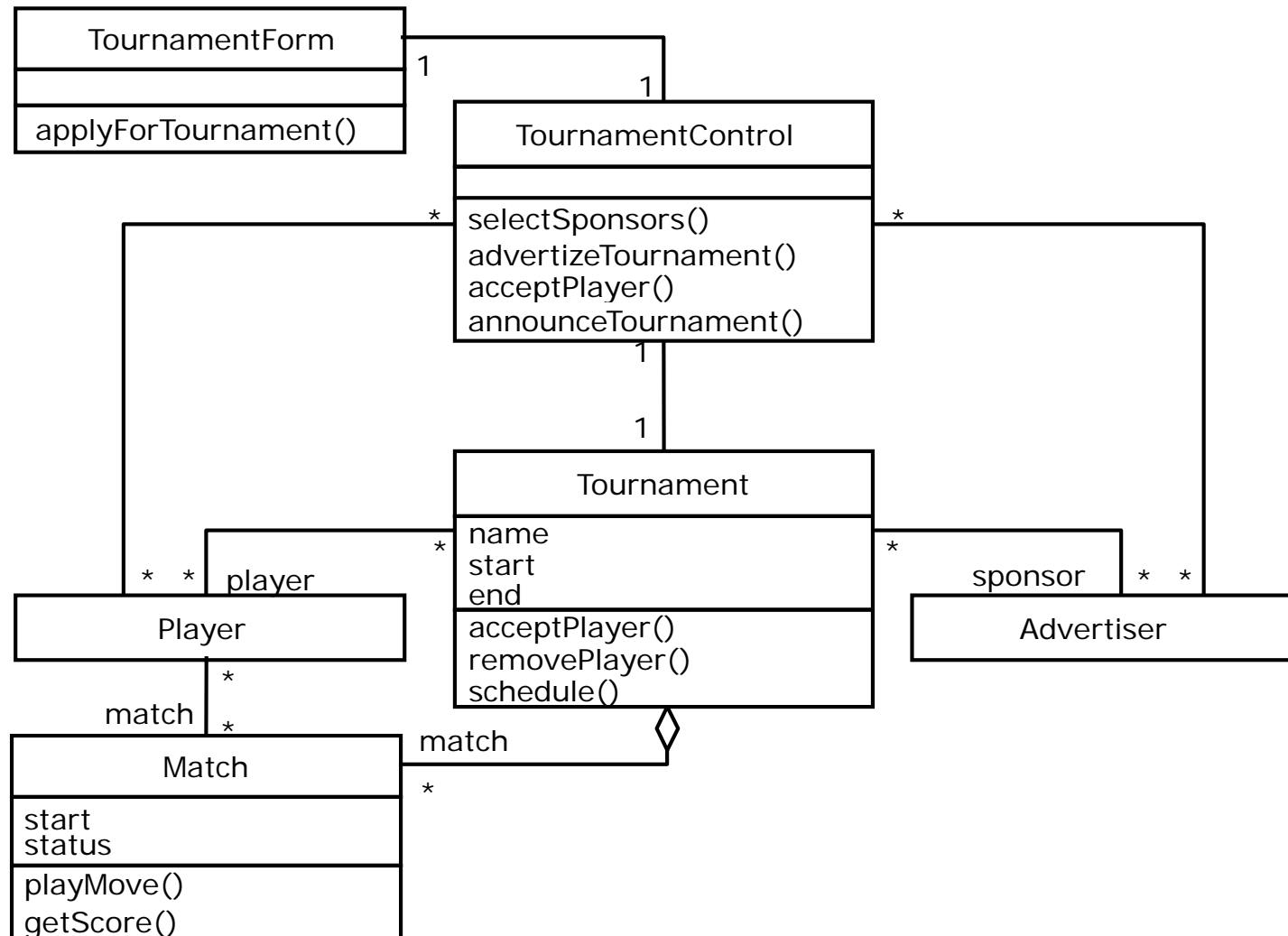
- Produkt (Komplexitätsprob.)
 - Anforderungen (Problemraum)
 - Entwurf (Lösungsraum)
- Prozess (psycho-soziale P.)
 - Kognitive Beschränkungen
 - Mängel der Urteilskraft
 - **Kommunikation, Koordination**
 - Gruppendynamik
 - Verborgene Ziele
 - Fehler

Welt der Lösungsansätze:

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

- 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

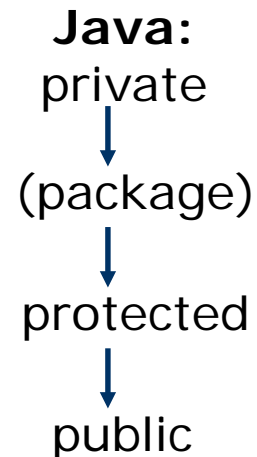
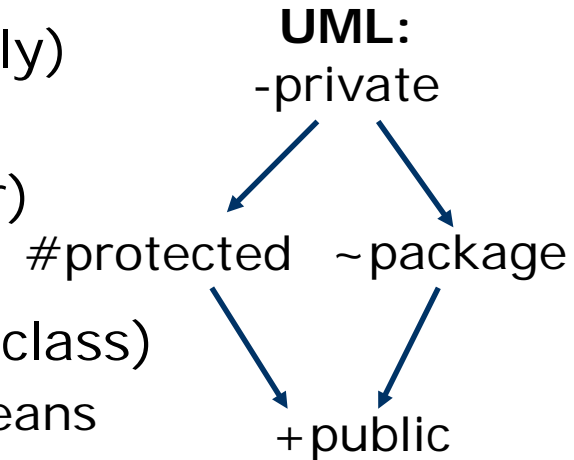


- Requirements analysis activities
 - Identifying attributes and operations without specifying their types or their parameters
 - Often not all attributes and operations are identified in this stage
- Object design: Four activities
 - 0. Identify remaining attributes and operations
 - 1. Add visibility information
 - 2. Add type signature information
 - 3. 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 throughout the package. This is not true (and cannot be expressed) in UML
 - The 'package' default promotes creation of Facades



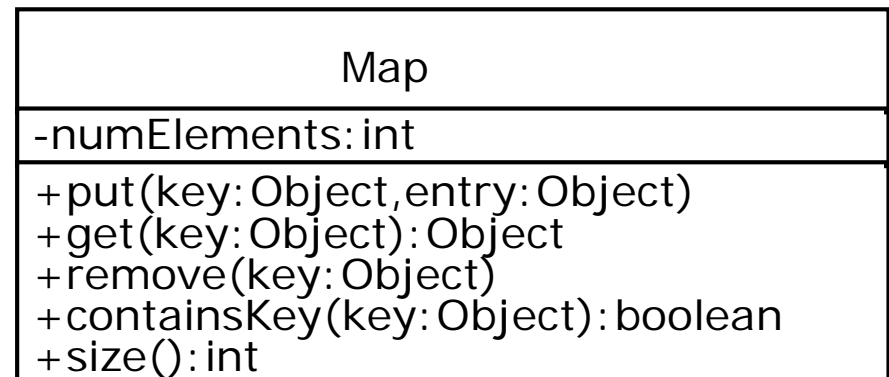
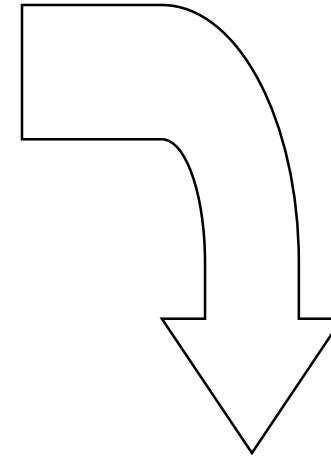
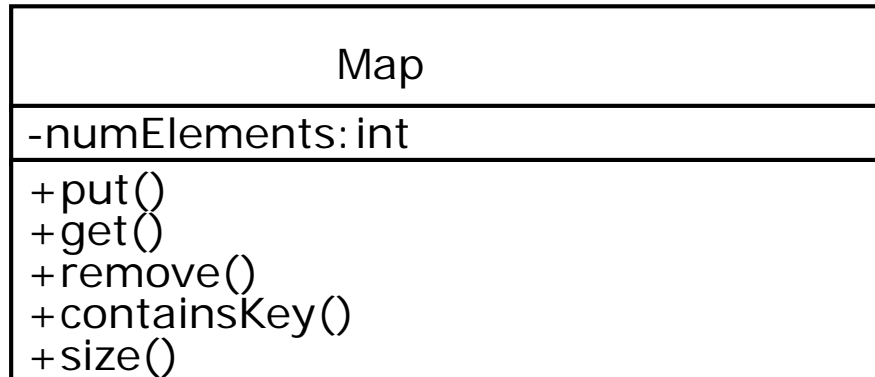
Information Hiding Heuristics

- 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 few cases, accessing a private attribute might be needed for speed reasons (for example in real-time systems or games)
 - BUT: *"Make it work first before you make it work fast"*

Java: Packages as modules

- 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



Attributes and operations without type information are acceptable during analysis

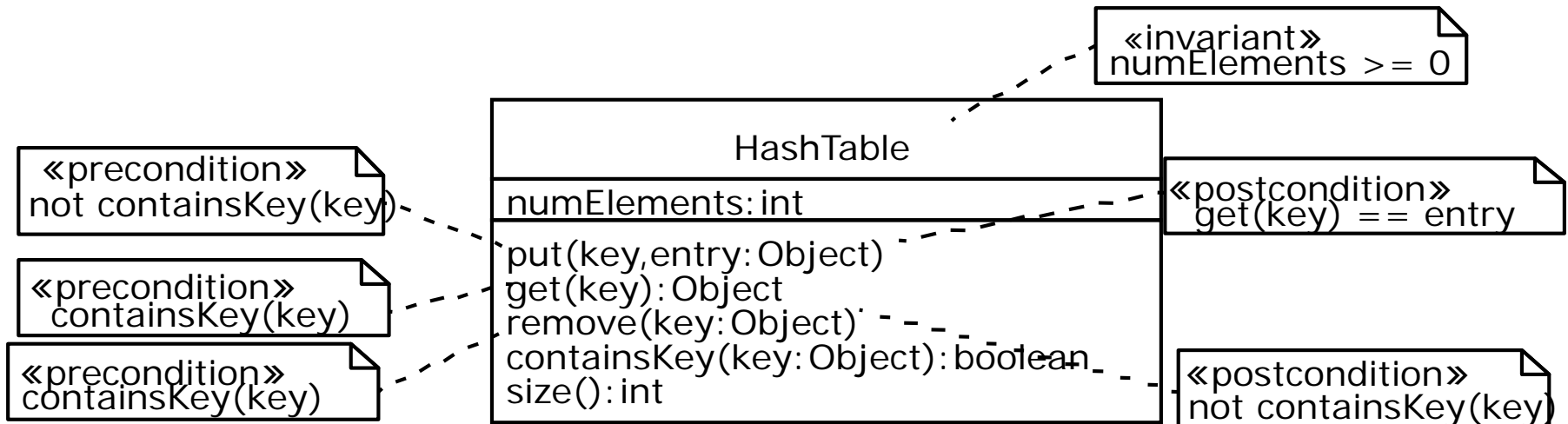
3. Add Contracts

- 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 true for an instance after any external 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

- An OCL 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:**
 $\text{getNumPlayers}() = \text{getNumPlayers}@pre() - 1$

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. See http://en.wikipedia.org/wiki/Design_by_contract for a list of tools.

Constraints can involve more than one class

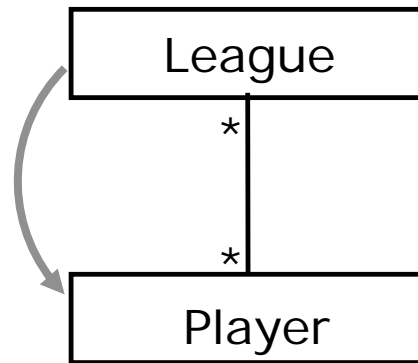
**How do we specify constraints on
more than one class?**

3 Types of Navigation through a Class Diagram

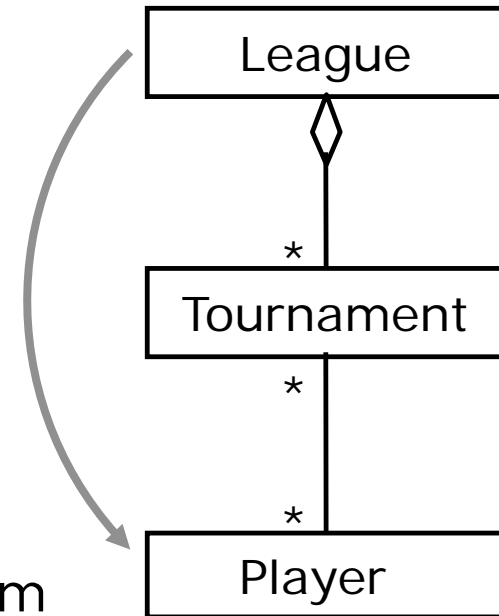
1. Local attribute



2. Directly related class

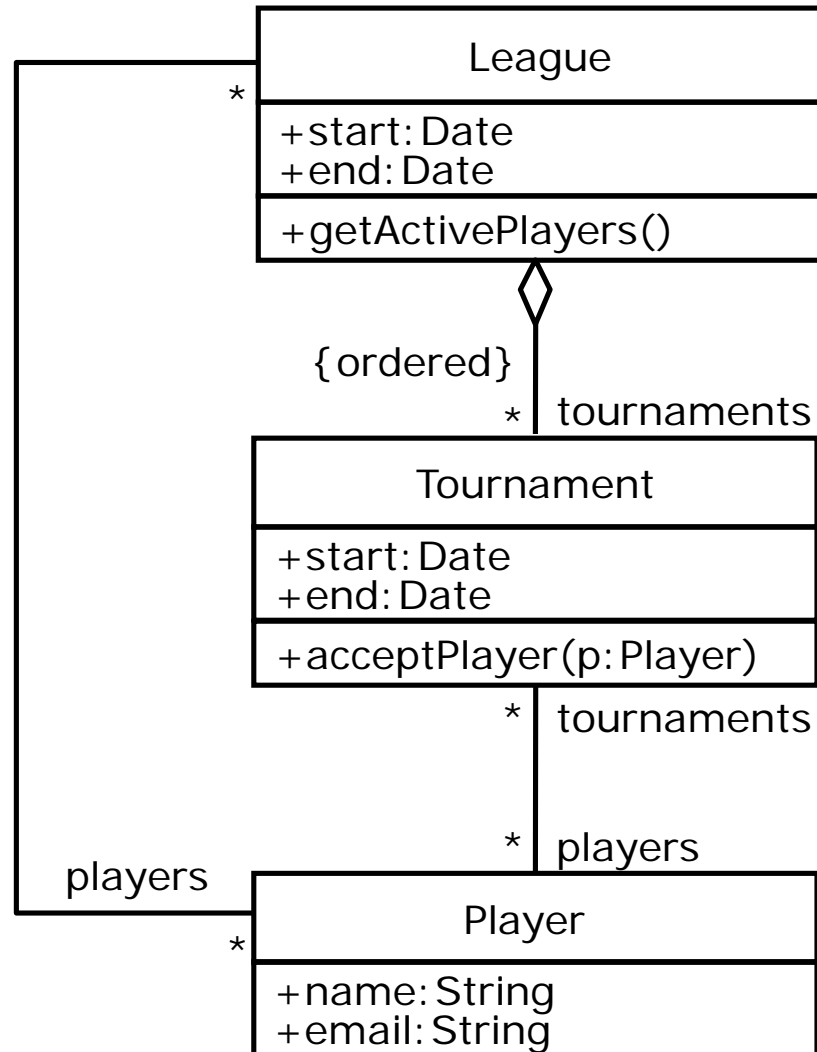


3. Indirectly related class



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

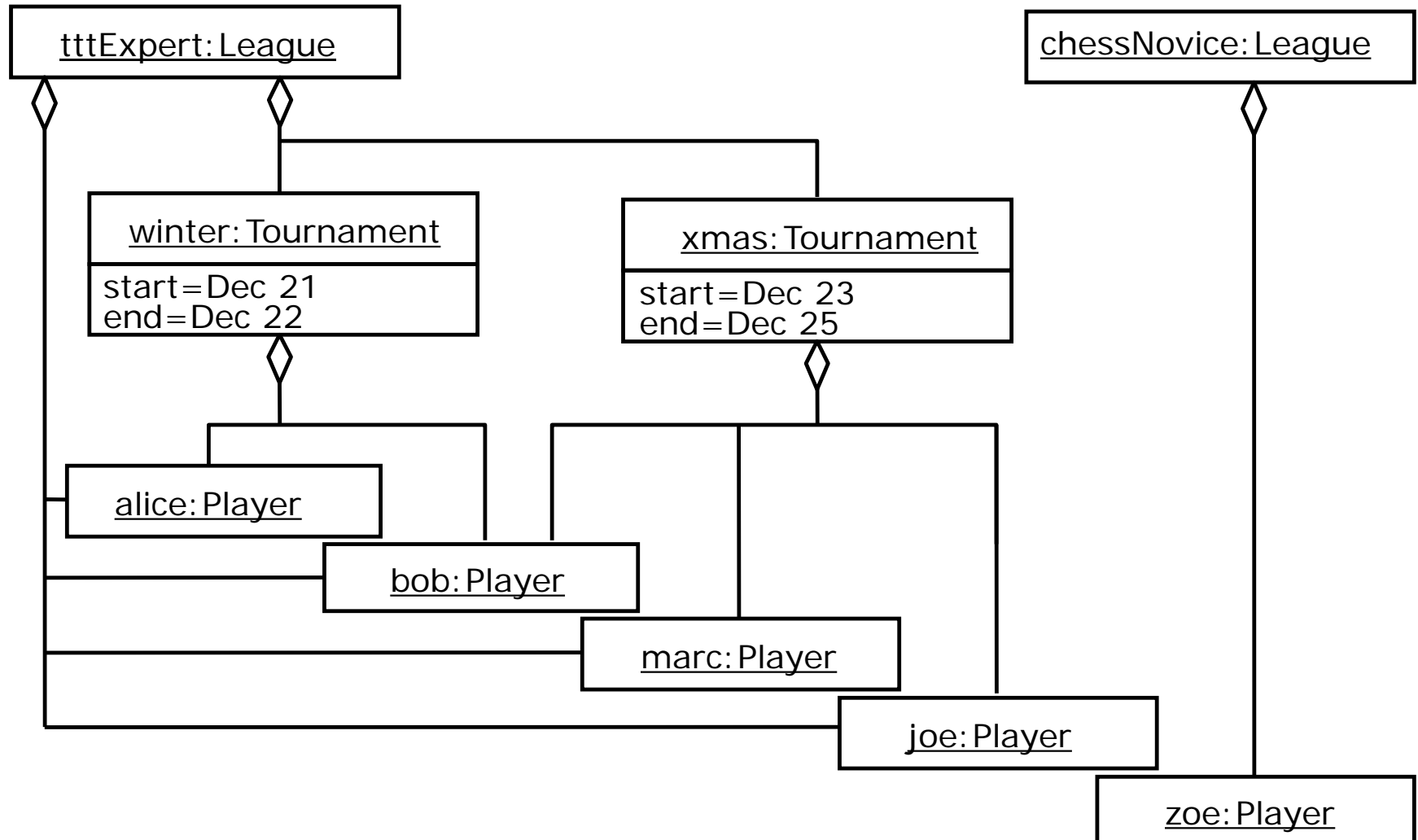
ARENA Example: League, Tournament and Player



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 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



Specifying the Model Constraints

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?

Specifying the Model Constraints

Local attribute navigation

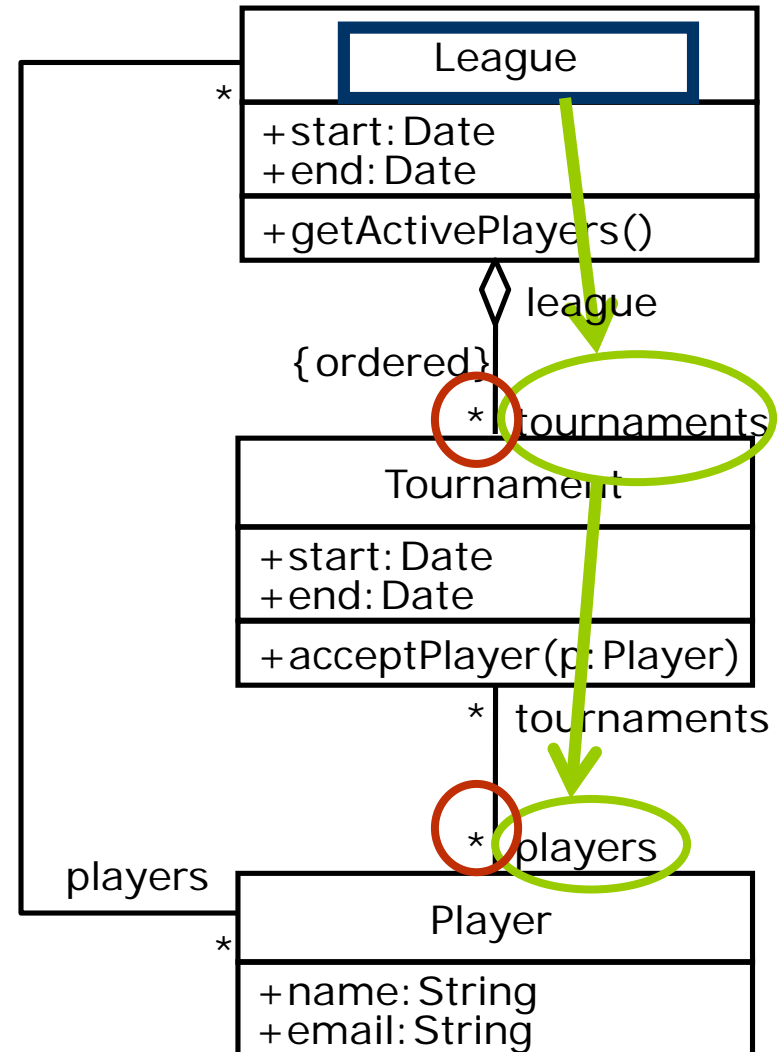
context **Tournament** inv:
end - start <= Calendar.WEEK

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?

TournamentControl
+selectSponsors(advertisers): List +advertizeTournament() +acceptPlayer(p) +announceTournament() +isPlayerOverbooked(): boolean

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

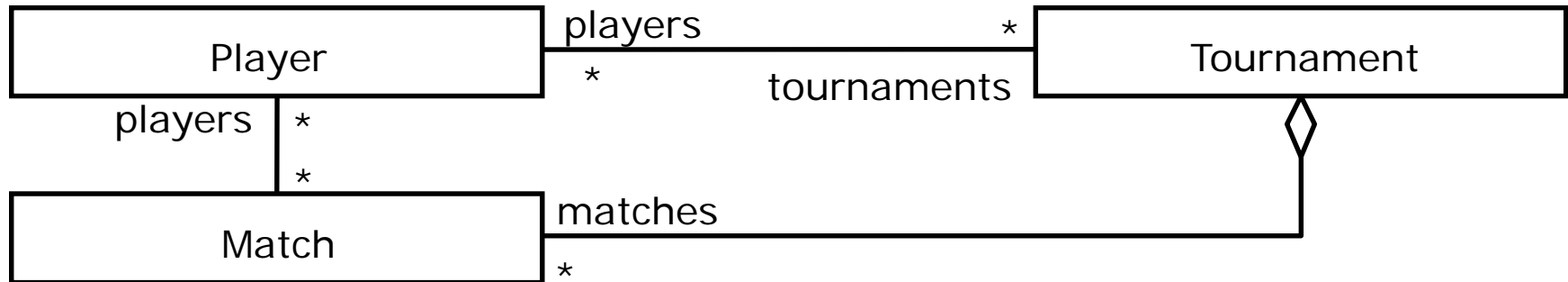
- OCL **forall** quantifier
/ "All Matches in a Tournament occur within the Tournament's time frame": */*
 - context Tournament inv:
 matches->forall(m |
 m.start.after(self.start) and m.end.before(self.end))
- OCL **exists** quantifier
/ "Each Tournament conducts at least one Match on the first day of the Tournament": */*
 - context Tournament inv:
 matches->exists(m | m.start.equals(self.start))

There is at least one dubious condition here. Which?

- */* "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 Match m7 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) /* insufficient! */
```

```
/* this condition is too weak, as it requires only one player to be registered */
```

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
- Some languages have such (or perhaps simpler) mechanisms built-in
 - e.g. Eiffel: keywords *require*, *ensure*, *invariant*
 - Plain Java: **assert** expressions

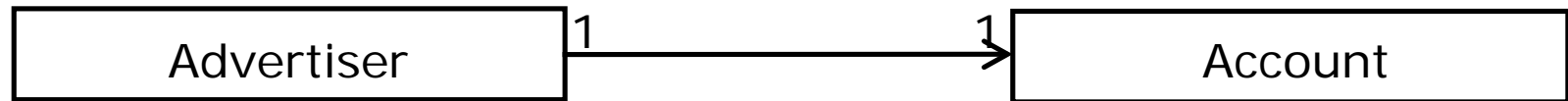
OCL in practice: future

- 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 compile-time verification
 - Will not be able to check all kinds of OCL specification, but many
- Consequence:
Start specifying contracts as soon as possible in your daily work

- 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

Realization of a unidirectional, one-to-one association

Object design model before transformation



Source code after transformation

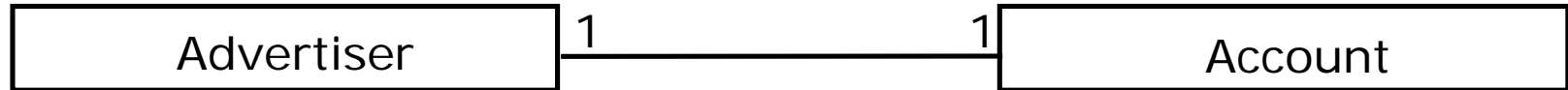
```
public class Advertiser {
    protected Account account;
    public Advertiser() {
        account = new Account();
    }
    public Account getAccount() {
        return account;
    }
}
```

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



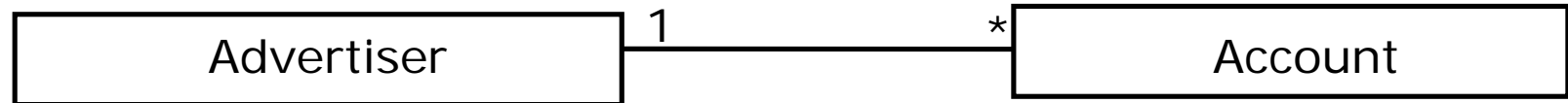
Source code after transformation

```
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?

Object design model before transformation



Source code after transformation

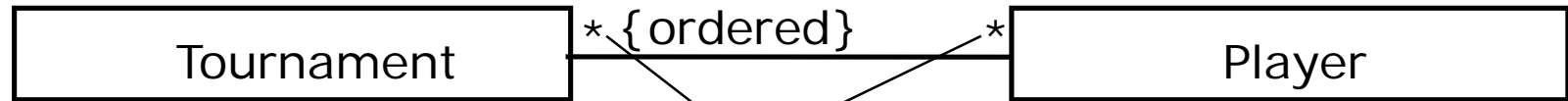
```
public class Advertiser {
    protected Set accounts = new HashSet();
    public void addAccount(Account a) {
        accounts.add(a);
        if (a.getOwner() != this)
            a.setOwner(this);
    }
    public void removeAccount(Account a) {
        accounts.remove(a);
        if (a.getOwner()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

Bidirectional, many-to-many association

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:

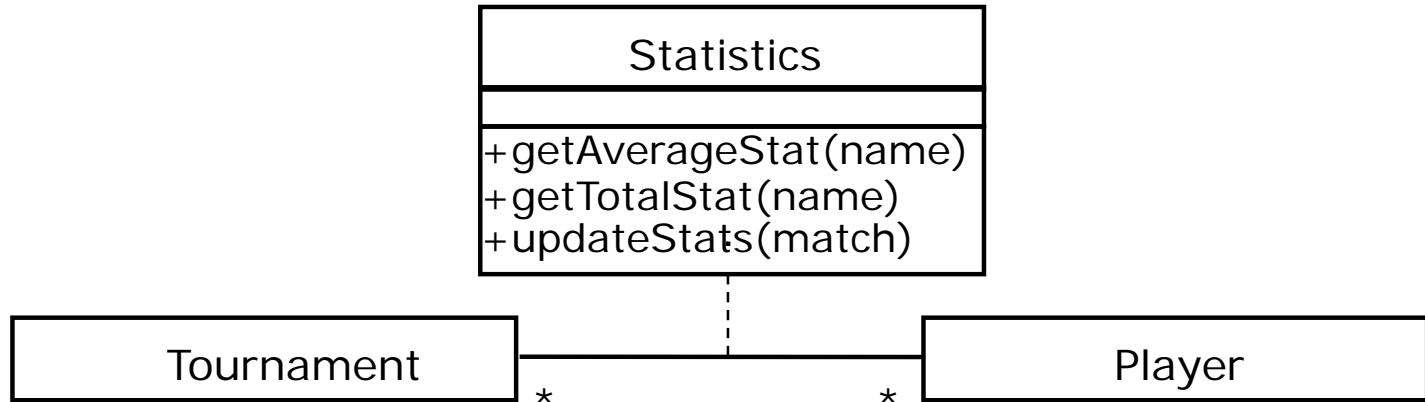
```
public class League {
    protected Map players;

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

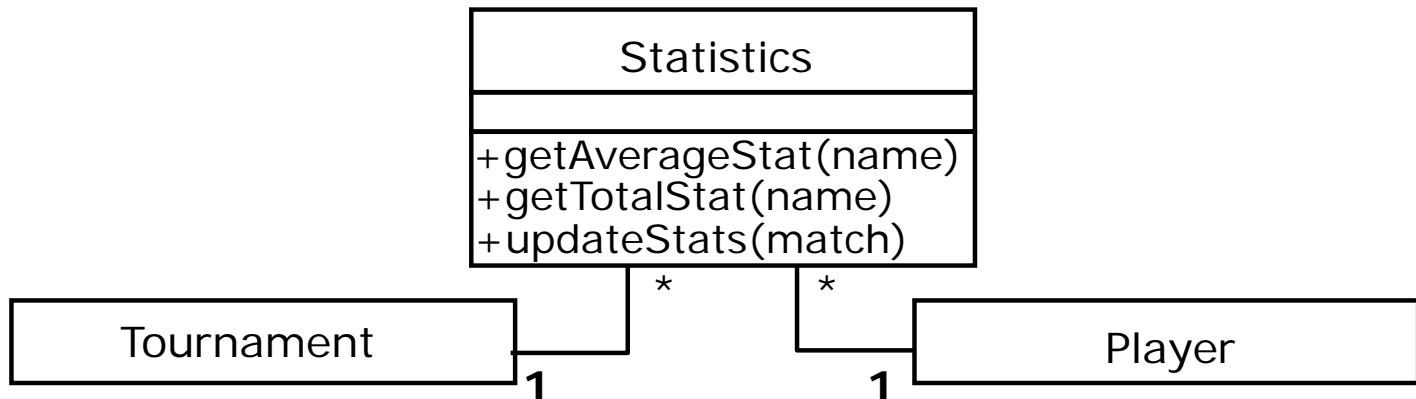
```
public class Player {
    protected Map leagues;

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

Object design model before transformation



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



- 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!