Software Design and Construction 2
SOFT3202 / COMP9202

Software Verification
Theory and Examples

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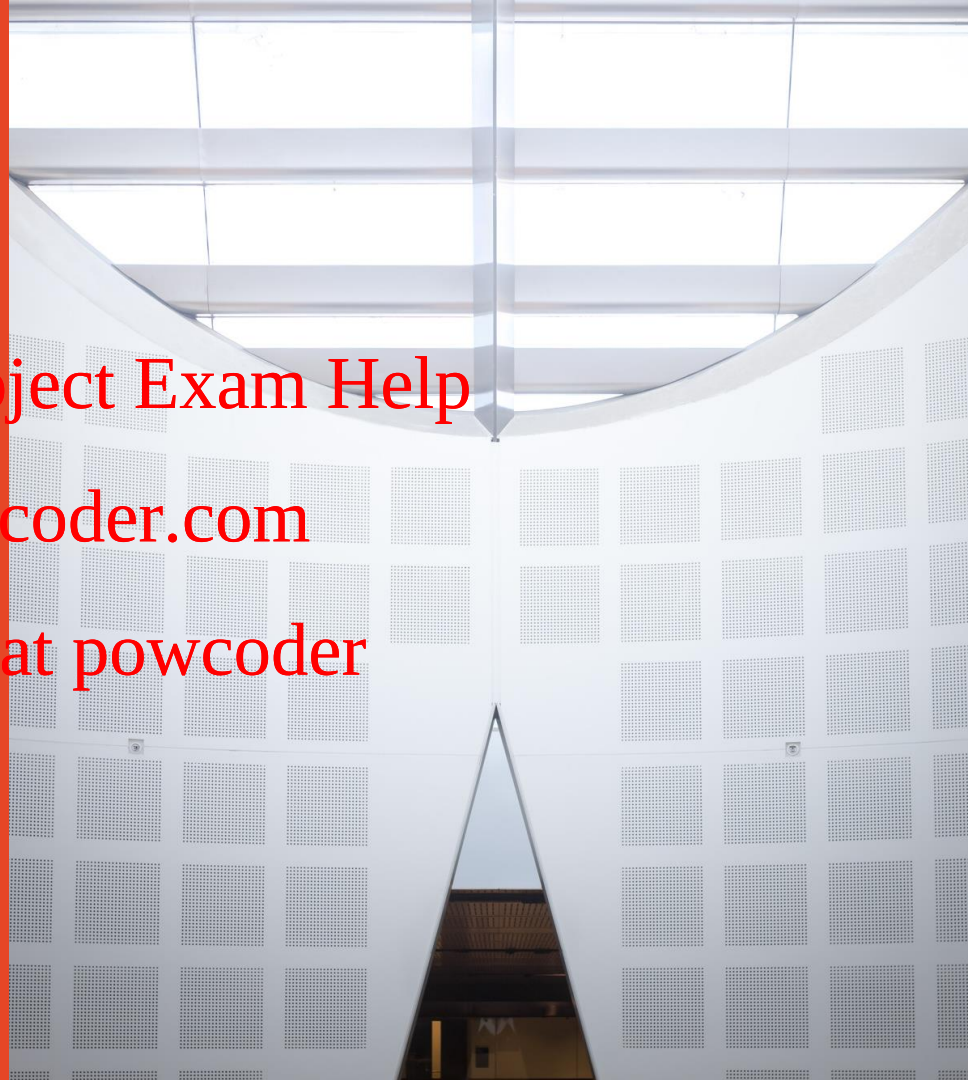

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Agenda

- Software Verification Theory
- Design by Contract
  - Pre-conditions and post-conditions
  - Class invariants

Software Validation and Verification

Theory

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Software Testing – Revisit

- Software process to
  - Demonstrate that software meets its requirements (*validation testing*)
  - Find incorrect or undesired behavior caused by defects/bugs (defect testing)
    - E.g., System crashes, incorrect computations, unnecessary interactions and data corruptions
- Part of software verification and validation (V&V) process

Software Verification and Validation

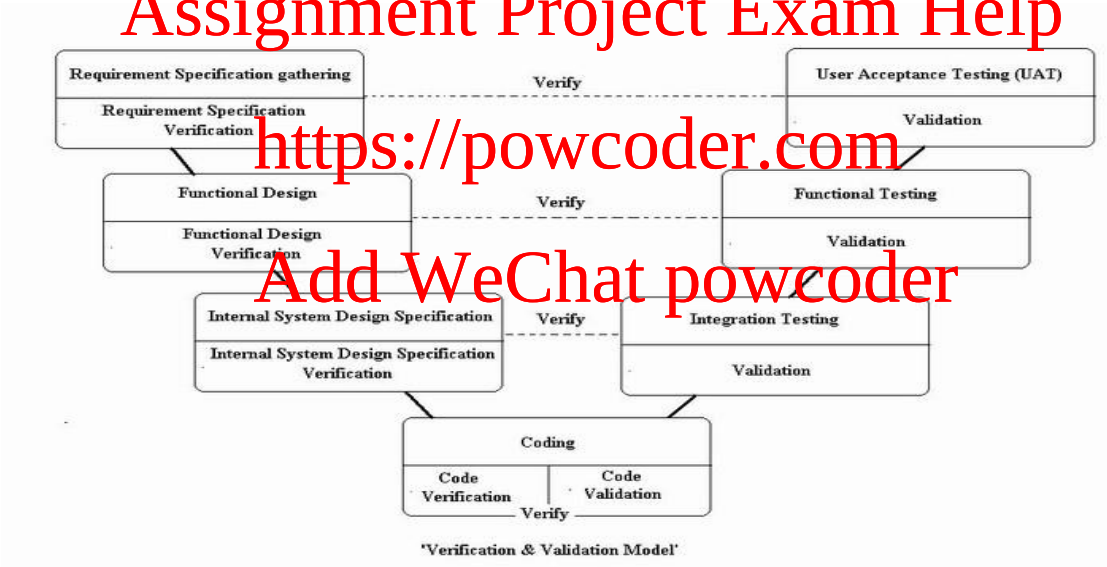
- Software testing is part of software Verification and Validation (V&V)
- The goal of V&V is to establish confidence that the software is "*fit for purpose*"
- Software Validation
  - Are we building the right product?
  - Ensures that the software meets customer expectations/needs
- Software Verification
  - Are we building the product right?
  - Ensures that the software meets its stated functional and non-functional requirements

Software V&V

- Software Verification
  - Concerned with the software requirements/specifications
  - Can be ambiguous
- Software Validation
  - Customer/end user's expectation
  - Disambiguate the requirements

V-Model

- Link each phase of the SDLC with its associated testing phase
- Each verification stage relates to a validation stage



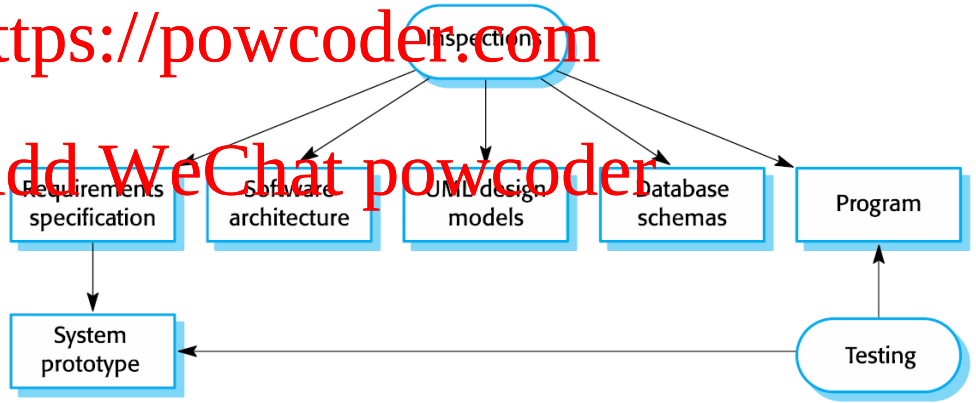
https://www.buzzle.com/editorials/4-5-2005-68117.asp

Software Verification

- Artifact/specification verification
  - Review the resulted software artifacts to verify that specifications are met
- Check the output of each software development phase against the input specification (specs.)
  - Design specifications against requirement specifications
    - Detailed design correctly implement the requirements (F & NF)
  - Construction (code) against the design specs.
    - Source code/user interfaces correctly implements the design specs.
- Include inspections, reviews, walkthrough

Static Verification

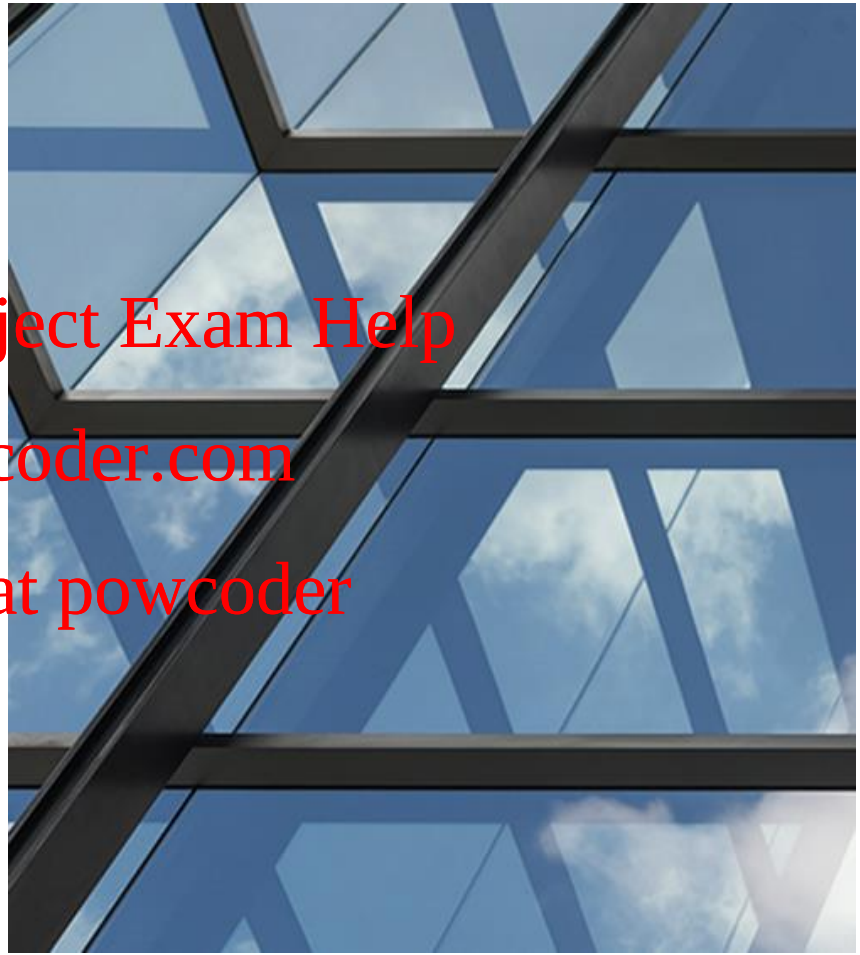
- Static Verification
  - Static system analysis to discover problems
  - May be applied to requirements, design/models, configuration and test data
- Reviews
  - Walk through
  - Code inspection



Software Validation

- Artifact/specification validation
  - Validate the requirements from the end user perspective
- Check that the needs of all stakeholders (users, managers, investors) are met
  - Validate the output of main development stages from the stakeholder's point of view
    - Validate if the requirements represent the will and goals of the stakeholders
- Include Unit testing, integration/functional testing, and user acceptance testing

Design by Contract



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Contract

- A lawful agreement between two parties in which both parties accept obligations and on which both parties can found their rights
- The remedy for breach of a contract is usually an award of money to the injured party

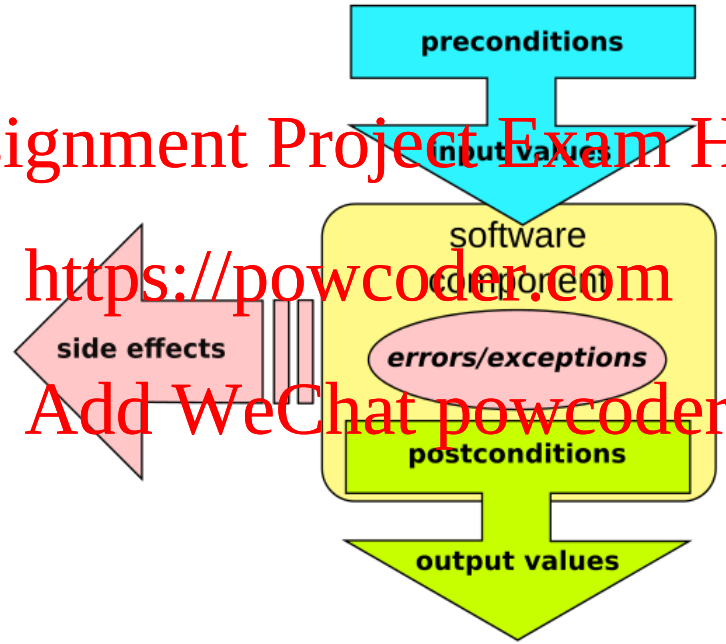
Object-Oriented Contract

- Specifies the expected services that can be provided if certain conditions are satisfied
- Services = "*Obligations*" and conditions = "*Rights*"
- Breach of a contract results in generating an exception

Design by Contract (DbC)

- A software design approach for program correctness
- Known as contract programing, programming by contract, design-by-contract programming
- Definition of formal, precise and verifiable interface specification for software components
  - Pre-conditions, postconditions and invariants (contract)

Design by Contract (DbC)



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Contracts in OO Design

Object-oriented contract

- Describes the services that are provided by an object if certain conditions are fulfilled
  - services = "obligations", conditions = "rights"
- An OO-contract for each service specifically describes:
  - The *conditions* under which the service will be provided
  - A *specification* of the result of the service that is provided
- The remedy for breach of an OO-contract is the generation of an exception

Object-Oriented Contract –

- Examples:
  - A letter posted before 18:00 will be delivered on the next working day to any address within Australia
  - For the price of $7 a letter with a maximum weight of 80 grams will be delivered anywhere in Australia within 4 hours of pickup

- Exercise: identify the conditions/rights and obligations/services of the above delivery services.

Modeling Constraints with Contracts

Modeling Constraints with Contracts

- Example of constraints in Arena:
  - An already registered player cannot be registered again
  - The number of players in a tournament should not be more than maxNumPlayers
  - One can only remove players that have been registered

- We model them with contracts
- Contracts can be written in OCL

Modeling OO-Contracts – Formal Specifcation

- Natural Language
- Mathematical Notation
- Models and contracts:
  - A language for the formulation of constraints with the formal strength of the mathematical notation and the easiness of natural language:

    ⇒ UML + OCL (Object Constraint Language)
  - Uses the abstractions of the UML model
  - OCL is based on predicate calculus

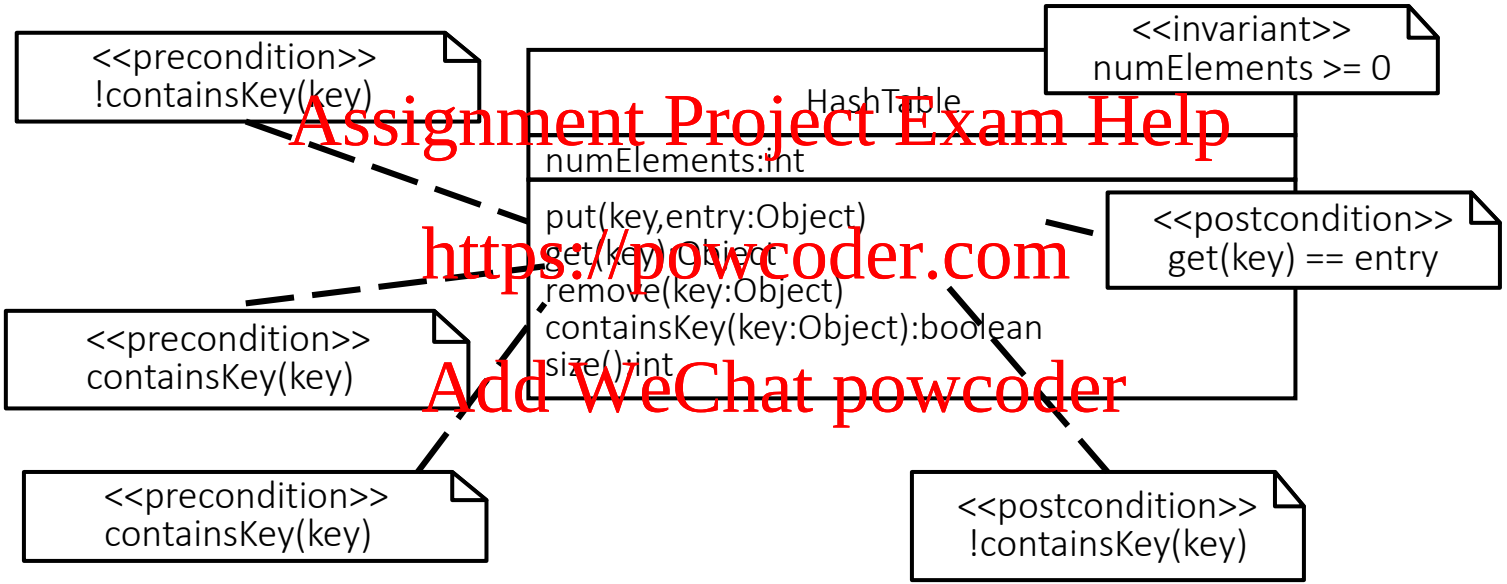
Contracts and Formal Specification

- A Contract share same assumptions about the class
- Three constraints:
  - Invariant:
    - A predicate that is always true for all instances of a class
  - Precondition ("rights"):
    - Must be true before an operation is invoked
  - Postcondition ("obligation"):
    - Must be true after an operation is invoked.

Formal Specification

- A contract is called a formal specification, if the invariants, rights and obligations in the contract are unambiguous

Expressing Constraints in UML Models



Use Contracts in Requirements Analysis

- Many constraints represent domain-level information
- Why not use them in requirements analysis?
  - Increase requirements precision
  - Yield more questions for the end user
  - Clarify the relationships among several objects
- Constraints are sometimes used during requirements analysis, however there are trade-offs

Object Constraint Language (OCL)

Object Constraint Language (OCL)

- Formal language for expressing constraints over a set of objects and their attributes

- Part of the UML standard

- Used to write constraints that cannot otherwise be expressed in a diagram

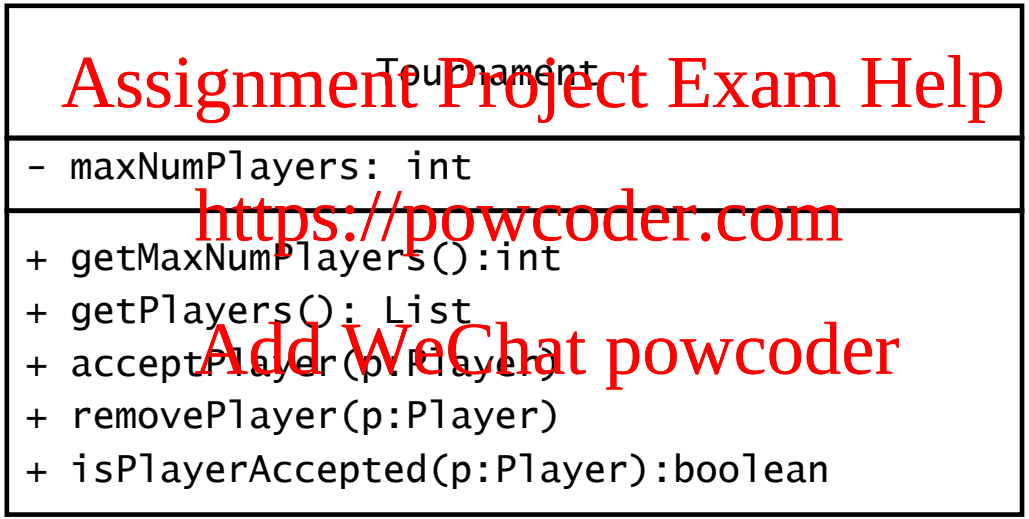
- Declarative
  - No side effects
  - No control flow

- Based on Sets and Multi Sets

OCL Basic Concepts

- OCL expressions
  - Return **True** or **False**
  - Are evaluated in a specified *context*
  - All *constraints* apply to *all instances*

Example – Tournament Class



OCL Simple Predicates

"The maximum number of players in any tournament should be a positive number."


```
context Tournament inv: self.getMaxNumPlayers() > 0
```


Notes:

- OCL uses the same dot notation as Java

OCL Preconditions – Examples

"The *acceptPlayer(p)* operation can only be invoked if player *p* has not yet been accepted in the tournament."


```
context Tournament::acceptPlayer(p) pre:
   not self.isPlayerAccepted(p)
```


Questions:

- What is the context the pre-condtion?
- What is "isPlayerAccepted(p)"?

OCL Postconditions – Example

"The number of accepted player in a tournament increases by one after the completion of acceptPlayer()"


```
context Tournament::acceptPlayer(p) post:
   self.getNumPlayers() =
    self@pre.getNumPlayers() + 1
```


Notes:

- self@pre: the state of the tournament before the invocation of the operation
- self: denotes the state of the tournament after the completion of the operation

OCL 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() = @pre.getNumPlayers() + 1
```

OCL 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() = @pre.getNumPlayers() - 1
```

Java Implementation of Tournament class (Contract as a set of JavaDoc comments)

```
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() {…}
```

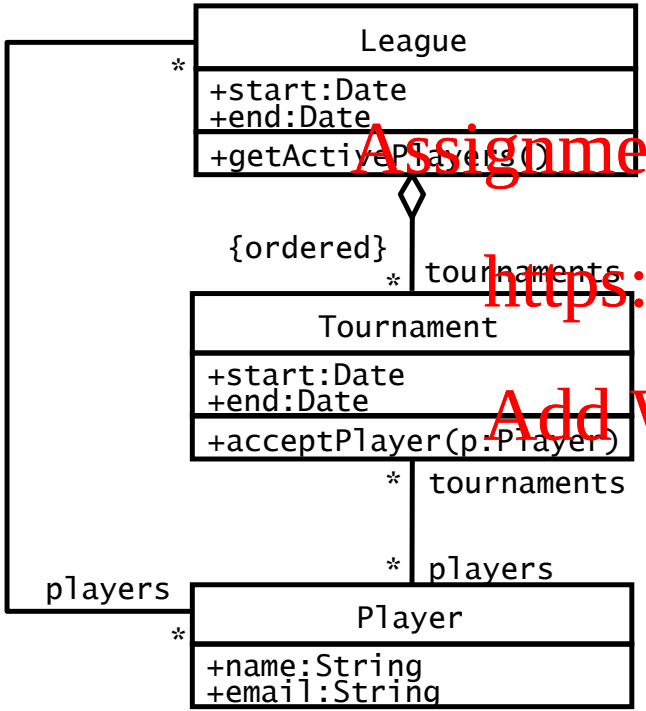
```
/** The acceptPlayer() operation
 * assumes that the specified
 * player has not been accepted
 * in the Tournament yet.
 * @pre !isPlayerAccepted(p)
 * @pre getNumPlayers()<maxNumPlayers
 * @post isPlayerAccepted(p)
 * @post getNumPlayers() =
 *      @pre.getNumPlayers() + 1
 */
public void acceptPlayer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

}
```

Constraints can involve more than one class

How do we specify constraints on on a group of classes?

Starting from a specific class in the UML class diagram, navigate the associations in the class diagram to refer to the other classes and their properties (attributes and operations).

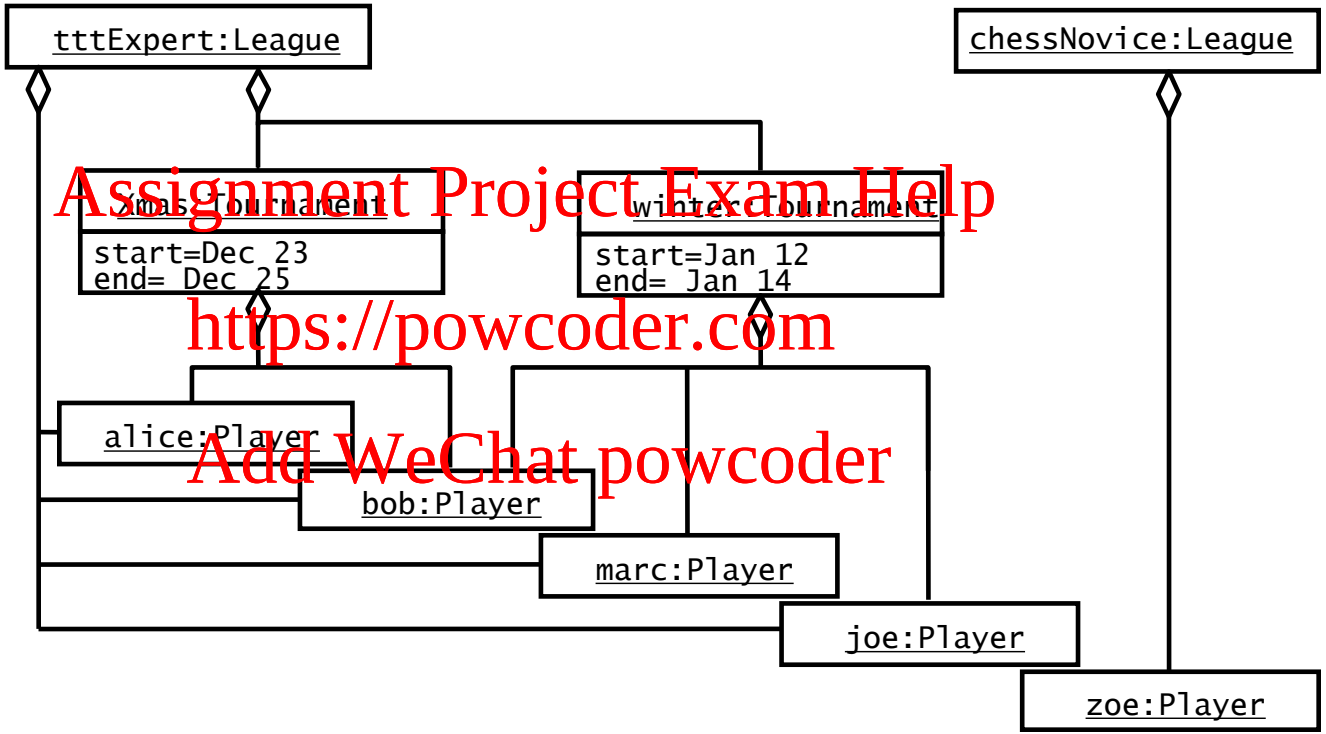
Example from ARENA: League, Tournament and Player



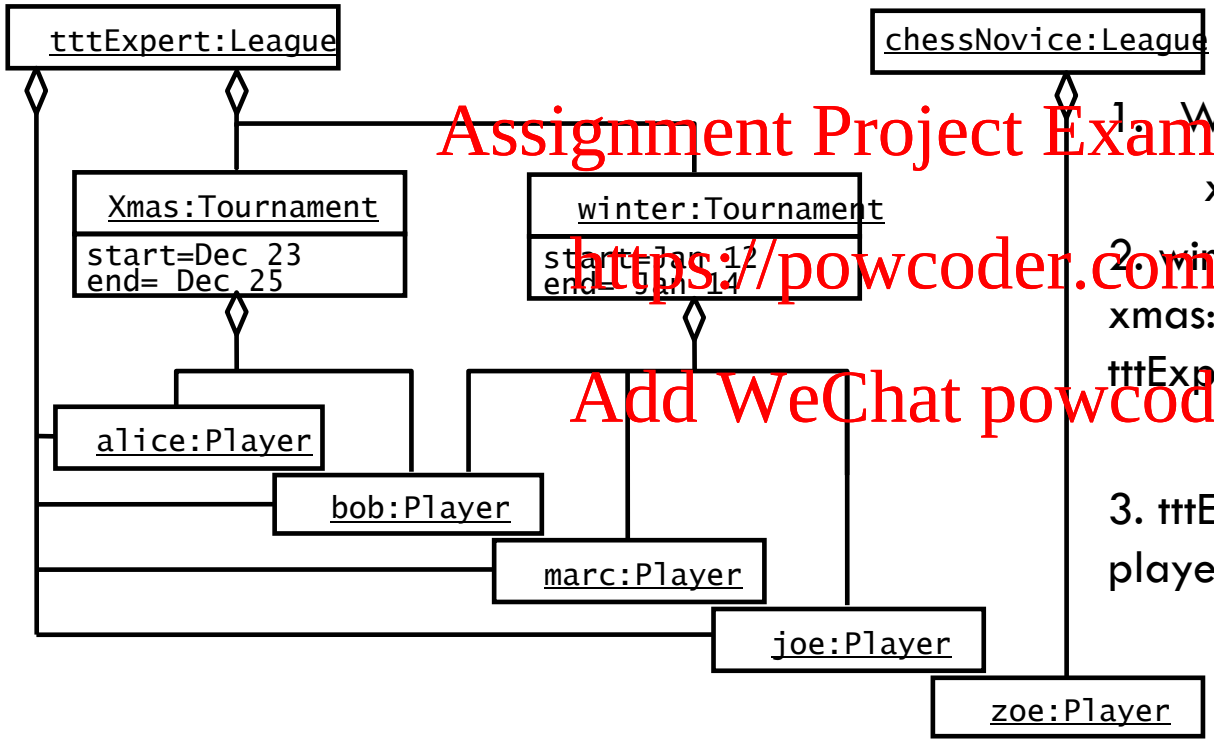
Constraints:

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.

Instance Diagram: 2 Leagues 5 players

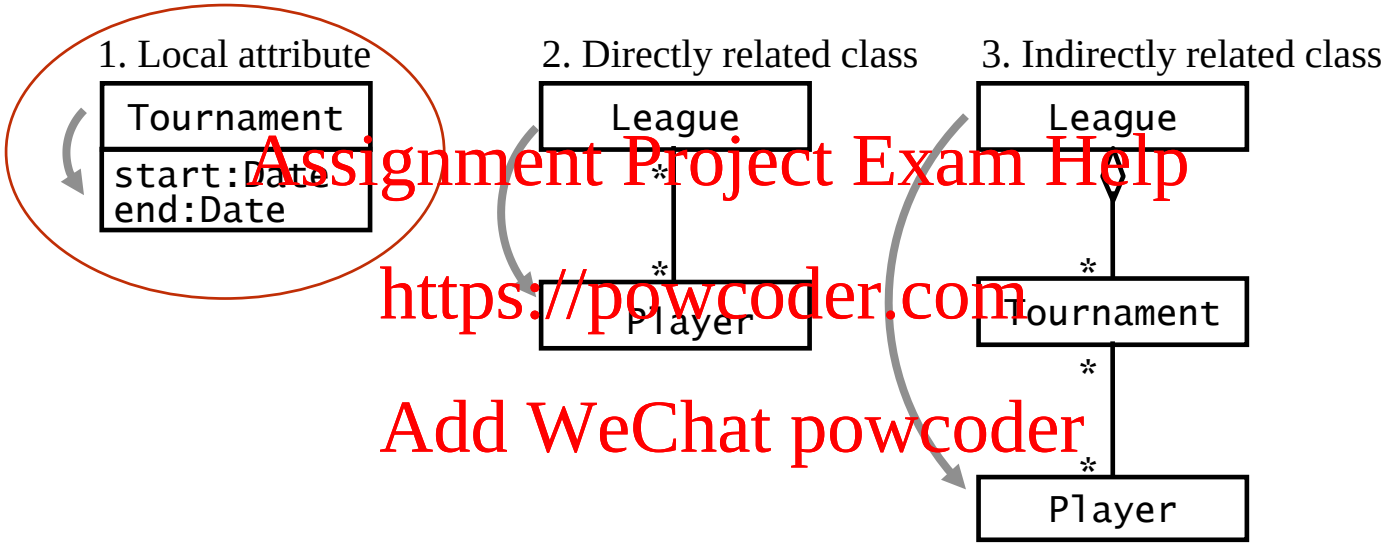


Instance Diagram: Review Constraints



1. Winter:Tournament lasts 2 days
   xmas:Tournament lasts 3 days
2. winter:tournament and xmas:tournament associated with tttExpert:League
3. tttExpertPlayer has 4 active players, ChessNovice:Legue has none

3 Types of Navigation through a Class Diagram



Any constraint for an arbitrary UML class diagram can be specified using only a combination of these 3 navigation types!

Local Attribute

context Tournament inv: self.end - self.start < 7

Specifying the Model Constraints in OCL

Local attribute navigation

```
context Tournament inv:
    end - start < 7
```

Directly related class navigation

```
context
 Tournament::acceptPlayer(p)
   pre:
    league.players->includes(p)
```

OCL Sets, Bags and Sequences

- Sets, Bags and Sequences are predefined in OCL
  - Subtypes of Collection

- OCL offers a large number of predefined operations on collections. All of the form:


```
collection->operation(arguments)
```

OCL-Collection

- The **OCL-Type** Collection is the generic superclass of a collection of objects of Type T
- Subclasses of Collection are
  - Set: Set in the mathematical sense. Every element can appear only once
  - Bag: A collection, in which elements can appear more than once (also called multiset)
  - Sequence: A multiset, in which the elements are ordered
- Example for Collections:
  - Set(Integer): a set of integer numbers
  - Bag(Person): a multiset of persons
  - Sequence(Customer): a sequence of customers

OCL-Operations for OCL-Collections (1)

`size: Integer`
Number of elements in the collection

`includes(o:OclAny): Boolean`
True, if the element o is in the collection

`count(o:OclAny): Integer`
Counts how many times an element is contained in the collection

`isEmpty: Boolean`
True, if the collection is empty

`notEmpty: Boolean`
True, if the collection is not empty

The OCL-Type **OclAny** is the most general OCL-Type

OCL-Operations for OCL-Collections(2)

`union(c1:Collection)`

Union with collection **`c1`**

`intersection(c2:Collection)`

Intersection with Collection **`c2`** (contains only elements, which appear in the collection as well as in collection **`c2`** auftreten)

`including(o:OclAny)`

Collection containing all elements of the Collection and element **`o`**

`select(expr:OclExpression)`

Subset of all elements of the collection, for which the OCL-expression **`expr`** is true

Evaluating OCL Expressions

The value of an OCL expression is an object or a collection of objects.

- Multiplicity of the association-end is 1
  - The value of the OCL expression is a single object
- Multiplicity is 0..1
  - The result is an empty set if there is no object, otherwise a single object
- Multiplicity of the association-end is *
  - The result is a collection of objects
    - By default, the navigation result is a Set
    - When the association is {ordered}, the navigation results in a Sequence
    - Multiple "1-Many" associations result in a Bag

OCL Quantifiers

forAll

- *forAll (variable|expression)* is True if expression is True for all elements in the collection

exist

- *exists (variable|expression)* is True if there exists at least one element in the collection for which expression is True

OCL Quantifiers – forAll Example

Given the following OCL quantifier


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


Exercise: explain what this OCL attempts to verify.

OCL Quantifiers – Exists Example

Given the following OCL quantifier

```
context Tournament inv:
    matches->exists(m:Match | m.start.equals(start))
```

References

- Ian Sommerville. 2016. Software Engineering (10th ed.) Global Edition. Pearson.
- Wikipedia, Software Verification and Validation, https://en.wikipedia.org/wiki/Software_verification_and_validation
- Object-Oriented Software Engineering: Using UML, Patterns, and Java, 3rd Edition, *Bernd Bruegge & Allen H. Dutoit, Pearson.*

W12 Tutorial: Practical Exercises

Design Pattern Assignment Demo

W12 Lecture: Specification Languages

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Specifying the Model Constraints: Using asSet

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.players->asSet
```