CSC 308 Lecture Notes Weeks 6 and 7
Introduction to Fully Formal Specification

I. Some practical benefits of formal specification.

- A. Better understanding of software.
- B. Precise communication among developers.
- C. Basis for thorough testing.
- D. Basis for formal verification (when appropriate).
- E. Basis for automatic programming (dream on).
- F. Here's a motivational bottom line:
  1. Suppose your boss says:

     I want you to do whatever it takes to build me software of the best possible quality, that has the smallest possible likelihood of failing.

  2. For some academics and software professionals, formal specification is a key part of addressing a mandate like this.

II. Formal specification with preconditions and postconditions.

- A. As model object and operation definitions take shape, we are ready to formalize the definitions fully.
- B. The formal technique we will use in 308 is based on operation *preconditions* and *postconditions*.
  1. A precondition is a predicate (i.e., boolean-valued expression) that is true before an operation executes.
  2. A postcondition is a predicate that is true upon completion of an operation.
  3. Since pre- and postconditions are predicates, this style of formal specification called *predicative*.
- C. The pre- and postconditions are used to specify fully what the system does, including all user-level requirements for the system.
- D. This formal specification is part of the overall requirements specification process we're following, with these steps:
  1. gather user-level requirements via usage scenarios
  2. identify objects and operations
  3. formalize operations with pre- and postconditions
  4. refine user-level requirements based on formal specs
  5. refine formal specs based on user-level refinements
  6. iterate steps 1-5 until done
- E. The "until done" step involves two levels of validation.
  1. First, we must validate that the specified system is complete and consistent from the end user's perspective.
     - a. That is, the system meets all end-user needs and does so in a way that is wholly satisfactory to the end user.
     - b. This is accomplished by continued consultation with the end user.
  2. The second level of validation involves completeness and consistency from a formal perspective.
     - a. This can be accomplished in a number of ways.
     - b. In the case of mechanized specification languages, such as Spest, some completeness and consistency checking is done using a computer-based analyzer.
     - c. Another valuable validation technique is peer review via formal walk-throughs.
     - d. Also, there are techniques for formal specification testing, including the postulation and proof of

putative theorems.

i. Such theorems define properties of the system that we expect to be true, and which can be proved true formally with respect to the pre- and postconditions.

ii. We will discuss putative theorems briefly in 308, but not use them.

III. Formal specification maxims.

A. In developing any formal software specification, it is useful to observe the following two maxims:

1. *Nothing is obvious.*
2. *Never trust the programmer.*

B. The first maxim relates primarily to user-level requirements.

1. It is often easy to think that a requirement is sufficiently obvious that it need not be stated formally.
2. The problem with this thinking is that one person's obvious is not always the same as another's.
3. To ensure that a specification is sufficiently precise, stating the "obvious" is necessary.

C. The second maxim is necessary to avoid nasty surprises in an implementation.

1. In many cases, we might consider an application to be sufficiently simple that we can trust the programmer to get a user-level requirement right if we forget to specify it.
2. In general, such trust is a bad idea.
3. It is better for the specifier to maintain a respectfully and cordially adversarial relationship with the implementor.

IV. Overview of Spest predicate notation.

A. Predicates in Spest use standard Java notation for Boolean expressions, augmented with additional predicate logic operators.

B. In addition to Java Boolean expressions, we'll use standard Java arithmetic, and methods available on Java `Collections` and `Strings`.

C. These operations are summarized in Table 1.

1. The predicate logic operators are used in boolean-valued expressions.

a. Logical and, or, and not have the same meaning as their equivalents in a programming language, e.g., "&&", "||", and "!" in C and C++.

b. Logical implication and equivalence have their standard logical meanings, per the following truth tables

p	*q*	*p => q*
0	0	1
0	1	1
1	0	0
1	1	1

p	*q*	*p <=> q*
0	0	1
0	1	0
1	0	0
1	1	1

c. The conditional choice operator has the truth table:

p	*x*	*y*	*p ? x : y*
0	x	y	y
1	x	y	x

where expressions *x* and *y* must have the same type.

Predicate Logic:

Operator	Description
`&&`	logical and
`||`	logical or
`!`	logical not
`if (...)`	logical implication
`iff`	logical equivalence
`if (...) else`	conditional choice
`forall`	universal quantification
`exists`	existential quantification

Relational:

Operator	Description
`==`	primitive equality
`!-`	primitive inequality
`<`	primitive less than
`>`	primitive greater than
`<=`	primitive less than or equal to
`>=`	primitive grtr than or equal to
`.equals`	object equality
`.compareTo`	object comparison

Logical Extensions:

Operator	Description
`x'`	value after execution
`return`	return value of method

Arithmetic:

Operator	Description
`+`	addition
`-`	subtraction
`*`	multiplication
`/`	division

Collections, Lists, Strings:

Operator	Description
`.size()`	size of collection
`.contains(Object o)`	collection membership
`.get(int i)`	get ith list element
`.length(String s)`	length of s
other collection ops	see `Collection` docs
other list ops	see `List` docs
other string ops	see `String` docs

Table 1: Spest Expression Operators.

d. The universal and existential quantifiers have their standard logical meanings, but will be applied in specific ways, as upcoming examples illustrate.

2. The arithmetic operators are used in numeric-valued expressions.
   a. Addition, subtraction, division, and multiplication have their standard mathematical meanings.
   b. Remember that preconditions and postconditions are always boolean valued, so arithmetic must always be performed in the context of a boolean expression.
   c. E.g., `a + b` is not a legal postcondition, but `\result == a + b` is.
   d. Note also that in specifications, we are assuming idealized mathematical arithmetic, without overflow or underflow
   e. If the precision of numeric expressions is an issue in a specification, then it must be dealt with explicit logic.
3. The collection operators are used with values of `java.util.Collection` or `java.util.List`, the latter used to model collections in which order must be specified.
4. All other standard Java operators and library methods can be used in predicate expressions.
5. As always in Java programs, we must be aware of when to use `.equals` versus `==`.
   a. For Spest specifications, `==` should only be used for primitive types `int`, `double`, and `boolean`.

b. For all other class-defined types, including `String`, `.equals` is used for testing equality.

c. For inequality of class types, use `.compareTo`.

D. Further details of the notation are covered in the Java and Spest reference manuals, available in the 308 doc directory.

E. The logic of Spest is comparable to other formal specification languages.

1. A difference between our use of Spest and a number of contemporary languages is collections of instead of mathematical sets.

2. Formally, both collections and sets can be fully axiomatized (i.e., mathematically defined), so there is no lack of formality in the use of collections.

3. In fact, Spest provides definitions of *pure* Java collections, which are defined with fully side-effect-free methods.

4. Overall, the use of collections instead of sets results in little difference in a specification.

a. Set notation makes certain low-level specification easier than with lists, such as operations that can be modeled with set union and difference.

b. On the other hand, collection and list notation makes other forms of specification easier than with sets, such as specification of ordering constraints.

V. "Programming" with predicates.

A. The language of predicates used in pre- and postconditions can be thought of as *non-procedural* programming.

B. The rules for this style of "programming" are different than the procedural kind.

1. We define data, but only in abstract terms and from an end-users "real world" perspective, not from a computer efficiency perspective.

2. We define functions, but only in abstract terms of what the functions do, not how they work.

3. Hence, the only "code" we have are boolean expressions at the beginning and ending of functions, no code bodies.

4. The closest thing we have to traditional control constructs are the two quantifiers `forall` and `exists`.

a. However, these quantifiers are fundamentally different than normal programming language controls.

b. Namely, they only return boolean values, and they don't make anything "happen".

5. Instead of procedural descriptions of how functions work (i.e., what happens *inside* a function), we have only true/false descriptions of what functions do (i.e., what's true *before* and *after* the function happens).

a. Time does not pass within pre- or postconditions, even ones with quantifiers.

b. Rather, pre- and postconditions are simply statements of mathematical fact, that are instantaneously true or false.

c. Hence, even though a `forall` may seem somewhat like a for-loop, it is just a boolean expression that is only true or false.

d. It may be a big boolean expression that is true in a lot of cases, but it's still just a boolean expression.

C. In some cases, it may be necessary to specify certain procedural aspects of a system, specifically the order in which operations occur.

1. However when we do this we need to be careful not to lapse into conventional programming.

2. Therefore, we will specify ordering constraints non-procedurally by writing the precondition of a successor operation to be dependent on the postcondition of a predecessor operation.

a. E.g., if operation B must follow operation A, we write the postcondition of A such that the only way the precondition of B can be true is if A's postcondition is true.

b. In general, this is accomplished by having A's postcondition require some unique value for one or more outputs, and then having B's precondition state that its inputs must have the values required by A.

c. In this way, we require that A must execute before B, if B is ever to happen.

3. As always, we will specify procedural (i.e., step-by-step) behavior only when it is *fundamental* to the way

the user operates.

4. In particular, we need to be careful not to specify procedural details of a particular GUI, when it is only one particular way to access the abstract operations.
5. Here's the way to think about it -- if the user *must* perform a series of operations in a particular order, then we'll specify the order.

VI. An initial example of fully formal specification.

A. For starters with pre- and postconditions, we'll begin with some Calendar tool operations that are simpler than the scheduling and viewing operations we've examined in recent weeks.

B. Specifically, we'll look at operations for adding and finding registered Calendar Tool users and groups.

C. These operations have useful but relatively straightforward specifications.

D. Next week we'll return to the specification of the more involved scheduling a viewing operations.

VII. Synopsis of requirements for user database admin functions.

A. When the user selects the '`Users ...`' item in the '`Admin`' menu, the system displays the screen shown in Figure 1.

1. User `Name` is a free-form string; `Id` is a unique system id of eight characters or less; `Email` address is free-form string; phone `Area` code is three digits, `Number` is seven digits;
2. The `Add` command adds a new user; `Id` field must be unique.
3. The `Find` command finds by `Name` or `Id` or both.
   a. If find is by name and the name is not unique, the system displays list of ids for users of that name.
   b. The user clicks on an item in the list to see the full record for that id.
   c. If no user of the given name or id is found, the system displays a "no users found" pop-up dialog.
4. `Change` works after the user changes the most recently displayed record.
   a. Typically, the user runs `Find` command first, then changes.
   b. The original record is removed, new record is added.
5. `Delete` removes the most recently displayed record, typically located with a `Find` command; the

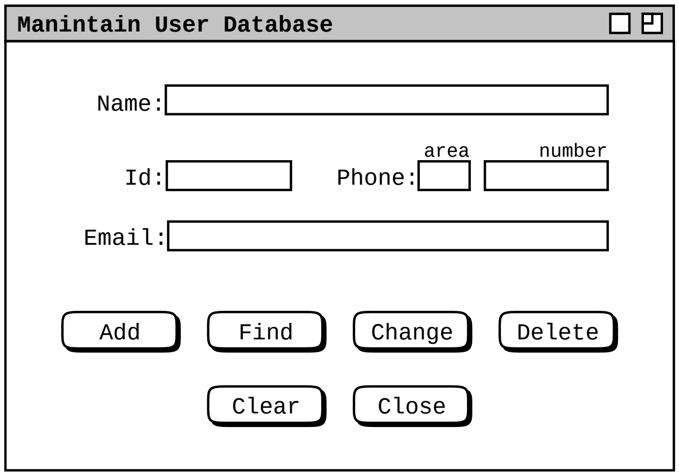


Figure 1: User database maintenance dialog.

system displays an "are you sure" pop-up dialog for confirmation.

B. When the user selects the 'Groups ...' item in the 'Admin' menu, the system displays the screen in shown Figure 2.

1. Group Name is a free-form string that is unique for all groups; leaders and Groups are lists of user Ids for the group leaders and members, respectively; all leaders must be listed as members.
2. The Add command adds a new group; the Name must be unique.
3. The Find command finds a group by name.
4. Change works after the user changes the most recently displayed group record.
   a. Typically, the user runs the Find command first, then changes.
   b. The original record is removed, the new record is added.
5. Delete removes the most recently displayed record, typically located with a Find command; the system displays an "are you sure" pop-up dialog for confirmation.

VIII. Basic definitions for user database objects and operations.

A. Here are the relevant object and operation definitions:

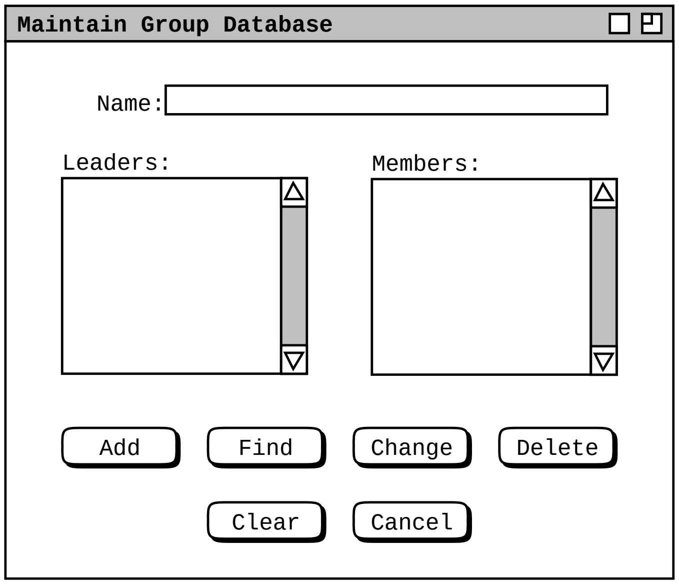


Figure 2: Group database maintenance dialog.

```
import java.util.Collection;

/**
 * UserDB is the repository of registered user information.
 */
abstract class UserDB {

    /**
     * The collection of user data records.
     */
    Collection<UserRecord> data;

    /**
     * Add the given UserRecord to the given UserDB.  The Id of the given user
     * record must not be the same as a user record already in the UserDB.
     * The Id component is required and must be eight characters or less.  The
     * email address is required.  The phone number is optional; if given, the
     * area code and number must be 3 and 7 digits respectively.
     */
    abstract void add(UserRecord ur);

    /**
     * Find a user by unique id.
     */
    abstract UserRecord findById(String id);

    /**
     * Find a user or users by real-world name.  If more than one is found,
     * the output list is sorted by id.
     */
    abstract Collection<UserRecord> findByName(String name);

    /**
     * Change the given old UserRecord to the given new record.  The old and
     * new records must not be the same.  The old record must already be in
     * the input db.  The new record must meet the same conditions as for the
     * input to the AddUser operation.  Typically the user runs the FindUser
     * operation prior to Change to locate an existing record to be changed.
     */
    abstract void change(UserRecord old_ur, UserRecord new_ur);

    /**
     * Delete the given user record from the given UserDB.  The given record
     * must already be in the input db.  Typically the user runs the FindUser
     * operation prior to Delete to locate an existing record to delete.
     */
    abstract void delete(UserRecord ur);

}

/**
 * A UserRecord is the information stored about a registered user of the
 * Calendar Tool.  The Name component is the user‘s real-world name.  The
 * Id is the unique identifier by which the user is known to the Calendar
 * Tool.  The EmailAddress is the electronic mail address used by the
 * Calendar Tool to contact the user when necessary.  The PhoneNumber is
 * for information purposes; it is not used by the Calendar Tool for
 * contacting the user.
 */
abstract class UserRecord {
    String name;
    String id;
    String email;
    PhoneNumber phone;
}
```

```
abstract class PhoneNumber {
    int area;
    int number;
}
```

B. For a little practice with UML, Figure 3 shows diagrams for these definitions, in two equivalent formats.

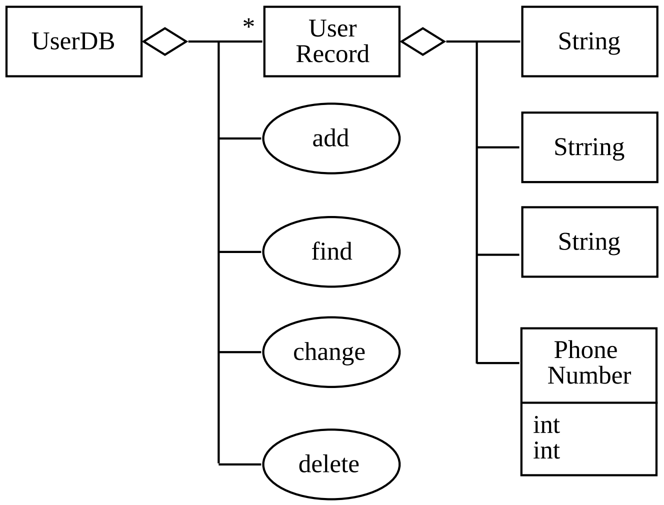
C. The objects and operations were derived from the user-level requirements, per the model derivation process discussed in Lecture Notes 5 last week.

D. The operation signatures are quite representative of those defined for a collection object.

1. `UserDB.add` is a *constructive* operation, with a signature of the general form

```
        class ACollection {
            Collection<AnElement> data;
```

One-part box format:



Equivalent three-part box format (with operation signature details):

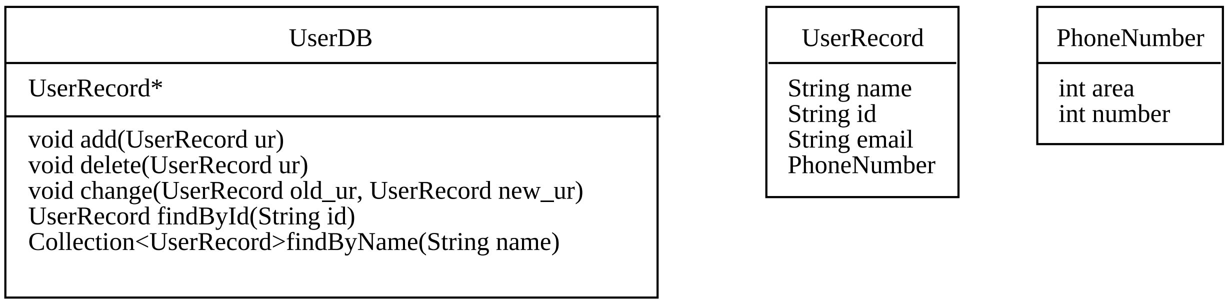

UserDB
UserRecord*
void add(UserRecord ur)
void delete(UserRecord ur)
void change(UserRecord old_ur, UserRecord new_ur)
UserRecord findById(String id)
Collection<UserRecord>findByName(String name)
UserRecord
String name
String id
String email
PhoneNumber
PhoneNumber
int area
int number

Figure 3: UML diagrams for UserDB objects and operations.

```
        void constructiveOp(AnElement);
    }
```

with the effect of adding an element to the data collection.

2. The versions of `UserDB.find` are *selective* operations, with signatures of the general form

```
    class ACollection {
        AnElement selectiveOp(UniqueElementSelector);
        Collection<AnElement> selectiveOp(NonUniqueElementSelector);
    }
```

with the effect of finding zero or more elements in a collection.

a. In both forms, the input is a component of *`AnElement`* used as a search key.

b. In the first form, *`UniqueElementSelector`* is a component whose value is required to be unique among all elements of the collection.

c. In the second form, *`NonUniqueElementSelector`* is a component whose value is not required to be unique among all elements of the collection.

3. `UserDB.delete` is a *destructive* operation, with the same signature form as a constructive operation, but with the effect of removing rather than adding an element.

4. `UserDB.change` is a *modifying* operation (combined constructive and destructive), with a general signature of the form

```
    class ACollection {
        void modifyingOp(AnElement oldElement, AnElement newElement);
    }
```

with the effect of removing the *`OldElement`* and adding the *`NewElement`*.

E. In modeling, it can be useful to overload operation names, for better traceability to the UI.

1. In terms of model accuracy, overloading works well in a case where the same operational widget (e.g., button) can be used with different input values.

2. Hence, we might overload the `find` operation thusly:

```
    abstract UserRecord find(String id);
    abstract Collection<UserRecord> find(String name);
```

3. The problem is, this form of overloading is not supported in Java, since Java requires input signatures to differ.

4. Hence, where necessary, operations need to be disambiguated by name, as in `findById` and `findByName`.

IX. An initial formal definition of `UserDB.add`.

A. For operation pre- and postconditions, we will start by stating a predicate in English, and then refine it into formal logic.

B. As we refine the logic, the English version will be retained as a comment, to aid in the human understanding of the specification.

C. So, here is an initial version of the formal spec for the `UserDB.add` operation:

```
import java.util.Collection;

abstract class UserDB {

    Collection<UserRecord> data;

    /**
     * Add the given UserRecord ur to this.data.  The UserId of the given user
     * record must not be the same as a user record already in this.data.  The
     * UserId component is required and must be eight characters or less.  The
     * email address is required.  The phone number is optional; if given, the
     * area code and number must be 3 and 7 digits respectively.
```

```
       *                                                          <pre>
        pre:
          //
          // The id of the given user record must be unique and less than or
          // equal to 8 characters; the email address must be non-empty; the
          // phone area code and number must be 3 and 7 digits, respectively.
          //
        post:
          //
          // The given user record is in this.data.
          //
        *
        */
      abstract void add(UserRecord ur);

}
```

D. Now let’s formalize the Spest logic.

1. The English comment for the `add` postcondition specifies the most fundamental property of an additive collection operation -- upon completion of the operation, the given element to be added is in the output collection.
2. Formally,

```
import java.util.Collection;

abstract class UserDB {

    Collection<UserRecord> data;

    /**
     * Add the given UserRecord ur to this.data.  The UserId of the given user
     * record must not be the same as a user record already in this.data.  The
     * UserId component is required and must be eight characters or less.  The
     * email address is required.  The phone number is optional; if given, the
     * area code and number must be 3 and 7 digits respectively.
     *                                                          <pre>
      pre:
        //
        // The id of the given user record must be unique and less than or
        // equal to 8 characters; the email address must be non-empty; the
        // phone area code and number must be 3 and 7 digits, respectively.
        //
       // *** Coming soon *** ;

      post:
        //
        // The given user record is in this.data.
        //
        data’.contains(ur);
     *
     */
    abstract void add(UserRecord ur);

}
```

3. The simple expression "`data.contains(ur)’`" is all there is to it.
   a. `contains` is a method defined in `java.util.Collection`.
   b. Its operand is a value of the element type contained in the collection.
   c. I.e., in this case the operand is a `UserRecord`.

E. As it stands, `UserDB.add` still has no precondition formally defined, only a comment indicating what needs to be defined.

1. Having no explicit precondition is equivalent to a precondition of true.

2. In many cases, true preconditions are fine, given that there is no specific condition that must be met before the operation begins.
3. In the case of the `UserDB.add` operation, a default true precondition definitely won't do, since we can see from the requirements that a number of conditions must be met before `UserDB.add` can proceed.
4. We will address these requirements step by step, as we refine the formal definition of `UserDB.add`.

X. Refining the `UserDB.add` postcondition.

A. One of the fundamental questions that must be asked of pre- and postconditions is if they are *strong enough*.

1. In general, adding additional predicate clauses strengthens the conditions.
2. For example, the true precondition for `UserDB.add` is relatively weaker than one that specifies that there is no `UserRecord` of the same id already in the input database.

B. In general, there are two aims to strengthening a specification.

1. Ensuring that all user-level requirements are met (cf. Maxim 1 above).
2. Ensuring that a system implementation works properly (cf. Maxim 2).

C. The former is accomplished via continued consultation with the end user; the latter requires an experienced analyst, who understands the kinds of problems that may arise in a system implementation.

D. In the case of the user and group databases, as well as similar database applications, an area of potential implementation error is the introduction of spurious entries into the database and/or the spurious deletion of entries.

E. To avoid such spurious effects, the specification of `UserDB.add` is strengthened as follows:

```
import java.util.Collection;

abstract class UserDB {

    Collection<UserRecord> data;

    /*
      post:
        //
        // The given user record is in this.data.
        //
        data'.contains(ur)

            &&

        //
        // All the other records in the output db are those from the input db,
        // and only those.
        //
        forall (UserRecord ur_other ; !ur_other.equals(ur) ;
            if (data.contains(ur_other))
                data'.contains(ur_other)
            else
                !data'.contains(ur_other));
     */
    abstract void add(UserRecord ur);

}
```

F. This specification introduces the use of the universal quantification operator, `forall`.

1. Universal quantification in Spest has the same meaning as in standard typed predicate logic.
2. The general format is the following:

`forall (`*`T x`*` ; `*`constraint`*` ; `*`predicate`*`)`

a. This is read "for all values *x* of type *t*, such that *constraint* holds, *predicate* is true."
b. The *constraint* expression is optional.
c. The quantified variable *x* must appear in *constraint* (if present) and *predicate*.

3. In general, universal quantification is used frequently when specifying predicates on collection objects, as upcoming examples illustrate.

G. While this example is a good illustration of specification strengthening, there are easier ways to specify the same meaning logically.

1. For example, the postcondition logic can be simplified to the following:

```
import java.util.Collection;

abstract class UserDB {

    Collection<UserRecord> data;

    /*                                                                  <pre>
      //
      // A user record is in the output data if and only if it is the new
      // record to be added or it is in the input data.
      //
      post:
        forall ( UserRecord ur_other ;
            (data’.contains(ur_other)) <==>
               ur_other.equals(ur) || data.contains(ur_other));
     */
    abstract void add(UserRecord ur);

}
```

2. In general, predicate simplification is beneficial when it helps clarify the specification.
3. Simplification is not necessary, as long as the logic is clear and accurate.

H. Another way to simplify this specification is to use a constructive list operator, as follows:

```
import java.util.Collection;

abstract class UserDB {

    Collection<UserRecord> data;

    /**
     * Add the given UserRecord ur to this.data.  The UserId of the given user
     * record must not be the same as a user record already in this.data.  The
     * UserId component is required and must be eight characters or less.  The
     * email address is required.  The phone number is optional; if given, the
     * area code and number must be 3 and 7 digits respectively.
     */
    /*@
      ensures
        //
        // The given user record is in this.data, per the semantics of
        // Collection.add.
        //
        data’.equals(data.add(ur));

     @*/
    abstract void add(UserRecord ur);
}
```

where `add` in this context is the `java.util.Collection.add` method.

1. A *constructive* specification such as this describes the output of an operation using a constructive operation on the inputs.

2. In contrast, an *analytic* specification (such as the previous spec using the boolean-valued `contains` method) describes output without using constructive operations.
3. In 308, we will define *analytic* specifications whenever possible.
    a. Specifically, we won’t used methods that construct or modify collections.
    b. There is debate among software engineers as to the relative merits of constructive versus non-constructive specification; we will discuss the issues a bit later.

XI. Refining the postconditions for the other `UserDB` operations.

A. Based on the development of the `UserDB.add` specs so far, we can provide a comparable level of formal specification for the other three `UserDB` operations.

B. For example, here is the idea for formalizing the `findById` postcondition:

```
import java.util.Collection;

abstract class UserDB {

    Collection<UserRecord> data;

    /**
     * Find a user by unique id.
     *
     *                                                                   <pre>
      post:
        //
        // If there is a record with the given id in the input db, then the
        // output record is equal to that record, otherwise the output record
        // is empty.
     *
     */
    UserRecord findById(String id);

}
```

C. Here are the initial formal specifications for the `findById`, `findByName`, `ChangeUser`, and `DeleteUser` operations, with the "no spurious data" requirements.

```
import java.util.Collection;

abstract class UserDB {

    Collection<UserRecord> data;

    /*
     * Find a user by unique id.
     *                                                                   <pre>
      pre:  // None yet. ;

      post:
        //
        // If there is a record with the given id in the input data, then the
        // output record is equal to that record, otherwise the output record
        // is null.
        //
        exists (UserRecord ur_found ; data.contains(ur_found) ;
               ur_found.id.equals(id) && ur_found.equals(return))
            ||
        !exists ( UserRecord ur_found ; data.contains(ur_found) ;
               ur_found.id.equals(id)) && return == null;

     *
     */
    abstract UserRecord findById(String id);

    /*
     * Find a user or users by real-world name.  If more than one is found,
     * list is sorted by id.
     *                                                                      <pre>
      pre: // None yet. ;

      post:
        //
        // A record is in the output list if and only it is in the input UserDB
        // and the record name equals the name being searched for.
        //
        forall ( UserRecord ur ;
            return.contains(ur) iff
                data.contains(ur) && ur.name.equals(name));
     *
     */
    abstract Collection<UserRecord> findByName(String name);

    /**
     * Change the given old UserRecord to the given new record.  The old and
     * new records must not be the same.  The old record must already be in
     * the input db.  The new record must meet the same conditions as for the
     * input to the AddUser operation.  Typically the user runs the FindUser
     * operation prior to Change to locate an existing record to be changed.
     */
    /*                                                                      <pre>
      pre: // None yet. ;

      post:
        //
        // A user record is in the output data if and only if it is the new
        // record to be added or it is in the input data, and it is not the old
        // record.
        //
        forall ( UserRecord ur_other ;
            data’.contains(ur_other) iff
                ur_other.equals(new_ur) ||
                    (data.contains(ur_other) &&
                        !ur_other.equals(old_ur)));
     *
     */
    abstract void change(UserRecord old_ur, UserRecord new_ur);

    /**
     * Delete the given user record from the given UserDB.  The given record
     * must already be in the input db.  Typically the user runs the FindUser
     * operation prior to Delete to locate an existing record to delete.
     *                                                                      <pre>
      pre: // None yet. ;

      post:
        //
        // A user record is in the output data if and only if it is not the
        // existing record to be deleted and it is in the input data.
        //
        forall ( UserRecord ur_other ;
            data’.contains(ur_other) iff
                !ur_other.equals(ur) && data.contains(ur_other));
     *
     */
    abstract void delete(UserRecord ur);

}
```

D. Observations.

1. All of the preconditions are commented "`(* None yet. *)`"; we will refine preconditions shortly.
2. The postcondition for `findById` uses the existential quantifier *`exists`*; Table 2 summarizes the Spest formats.
3. The postcondition for `findByName` is missing an important piece of logic vis a vis user-level requirements. What is it? (Hint: see the method's comment.)
4. The postcondition logic for `change` and `delete` are adaptations of the postcondition logic for `UserDB.add`.
   a. This kind of logic is sometimes called the "no junk, no confusion" rule for collection classes.
   b. Namely, when we put something into or take something out of a collection,
      i. we don't put in or take out anything superfluous (no junk),
      ii. we do put in or take out exactly what we intend to (no confusion).
   c. You should study the logic closely to clarify your understanding of it.

XII. On the use of quantifiers.

A. Universal and existential quantification are two ways to state multiple conditions in a single expression.

1. With universal quantification (`forall`), the quantifier expression is true if *all* cases considered are true.
2. With existential quantification (`exists`), the quantifier expression is true if *at least one* of the cases is true.
3. Logically, you can think of `forall` and `exists` as forms of repeated logical `and` and `or`, respectively.
4. There is even a generalized DeMorgan's law that makes the two forms of quantifier interchangeable:

```
forall (T x ; p) <==> !exists (T x ; !p)
    and
!forall (T x ; !p) <==> exists (T x ; p)
```

B. In the software modeling task upon which we're focused, the use of logical quantifiers is focused on two specific objectives:

1. Stating a requirement about all values of a particular type, e.g.,

```
forall (UserRecord ur ; requirement-predicate)
```

2. Stating a requirement that must be true for at least one value of a particular type, e.g.,

```
exists (UserRecord ur ; requirement-predicate)
```

Form	**Reading**
`exists (T x ; predicate)`	There exists `x` of type `T` such that `predicate` is true.
`exists (T x ; constraint ; predicate)`	There exists `x` of type `T`, such that `constraint` is true, and then `predicate` is true.

Table 2: Forms of existential quantification..

C. Constrained forms of qualification provide further focus.

1. Stating a requirement about all values (or at least one value) in a particular data collection, e.g.,

```
forall (UserRecord ur ; data.contains(ur) ; requirement-predicate)
exists (UserRecord ur ; data.contains(ur) ; requirement-predicate)
```

2. Stating a requirement about all values (or at least one value) of a particular type, with some further restrictions on the values. E.g.,

```
forall (int i ; i > 0 ; requirement-predicate)
exists (int i ; i > 0 ; requirement-predicate)
```

D. Keeping these specific focuses in mind will help narrow down when and how to use quantifiers.

XIII. Formally specifying user-level requirements.

A. To this point, we have formalized some basic requirements for our database operations.

B. Specifically, we have focused on postconditions related to the second of our formal specification maxims -- not trusting the programmer.

C. It is now time to consider the formal definition of user-level requirements per the first maxim -- *nothing is obvious*.

D. To start, there are a number of "obvious" user-level requirements, including the following:

1. Duplicate entries are not allowed in the `UserDB`.
2. Input values are checked for validity.
3. If the `findByName` operation outputs more than one record, the output should be sorted in some appropriate order.

E. We have considered these requirements to some extent in the requirements narrative.

1. However, the process of fully formalizing the specification can reveal important details we may have overlooked in the requirements scenarios.
2. For example, in the Milestone 6 scenarios we initially overlooked the sorting requirement for multiple outputs from `findByName`.
3. Such oversights are common, and one of the main reasons we're doing the fully formal level of the spec.

F. An historical note is of interest with regards to such requirements.

1. In software engineering methodologies less formal than what we're using, the process of formalizing a specification can take the form of "firming up" the English prose in which the requirements are stated.
2. For example, the first of the above requirements could be stated "formally" as follows:

   A UserDB shall not contain duplicate entries.

3. While this may not seem to be a substantial improvement to the original statement of the requirement, it represents a seriously-proposed approach to formalization.
   a. With this approach, a number of possible forms of natural language are standardized with a restricted vocabulary.
   b. For example, all formal requirements are expressed using "shall" instead of other comparable English words such as "should", "ought to", or "allowed to".
4. This idea of formalizing English is noteworthy because it has been widely used in practice, and significant documents have been "formalized" in this manner.
5. While such rules can indeed help with the formalization process, they fall well short of a fully formal basis for requirements specification.

XIV. No Duplicates

A. Analysis of the no duplicates requirement provides fine support for the "nothing-is-obvious" maxim.

B. While we may expect reasonable people to understand what "no duplicates" means, there are in fact a number of plausible interpretations here.

C. Three such interpretations are the following:

1. No two `UserRecord`s in a `UserDB` have exactly the same values for all `UserRecord` components.
2. No two `UserRecord`s in a `UserDB` have the same name.
3. No two `UserRecord`s in a `UserDB` have the same id.

D. Which of these interpretations to choose is categorically *not* a matter for a programmer to decide.

1. Rather, it should be decided at the user specification level, by the analyst in consultation with the end users.
2. We could even grant that most programmers are reasonably smart, so in this case we might safely assume that a programmer could make the correct decision, or know enough to consult with the user to resolve the ambiguity.
3. Suppose, however, we were specifying data records in a much more complicated application domain, such as aeronautics.
4. In this domain we might have a data object such as an anomaly list, with record fields like `PreFlight`, `TaxiOut`, `InFlight`, `Approach`, and `Landing`.
   a. What does it mean to disallow duplicates in an anomalies database?
   b. Which field, if any, could be used as a unique key?
5. The point is that such questions need to be answered by end users and/or application domain experts.
6. Such questions should most certainly not be left unanswered when the programmer begins work, since the programmer may well not know how to answer them, or even that they need to be asked.

E. In our `UserDB` case, we have already determined with the customer that the `Id` component of a `UserRecord` is the unique key.

1. This means that `UserRecord`s in the `UserDB` need only differ in the Id value.
2. In particular, there may be multiple `UserRecord`s with the same name.

F. The basic strategy for disallowing duplicates is to define a precondition on `UserDB.add` that checks for an element of the same Id as the `UserRecord` being added.

G. Here is the refined specification for `UserDB.add`; for brevity, the postcondition is omitted:

```
import java.util.Collection;

abstract class UserDB {

    Collection<UserRecord> data;

    /**
     * Same comment as above ... .
     *                                                                  <pre>
      pre:
        //
        // There is no user record in the input UserDB with the same id as the
        // record to be added.
        //
        !exists (UserRecord ur_input ; data.contains(ur_input) ;
            ur_input.id.equals(ur.id));

      post:
        // Same postcondition as above ... ;

     *
```

```
         */
        abstract void add(UserRecord ur);

    }
```

H. A discussion of the exact nature of a precondition is in order here.
   1. By definition, failure of a precondition means that the operation is prevented from executing.
   2. More precisely, precondition failure means that the operation fails.
   3. This abstract meaning of precondition failure does not define how operation failure is perceived by the end user.
      a. Generally, the end-user should see an appropriate error message when an operation fails.
      b. The details of such error messages are typically abstracted out of the formal specification.

XV. Input value checking.

A. Input value constraints for a user record are described in the requirements scenarios as follows:
   1. the Id of a user record is a unique system id of eight characters or less;
   2. the email address is a free-form string;
   3. the phone area code is three digits, the number is seven digits.

B. These constraints are defined formally as follows, with accompanying commentary:

```
import java.util.Collection;

abstract class UserDB {

    Collection<UserRecord> data;

    /*                                                                    <pre>
      pre:
        //
        // There is no user record in the input UserDB with the same id as the
        // record to be added.
        //
        !exists (UserRecord ur_other ;
                data.contains(ur_other) ;
                    ur_other.id.equals(ur.id))

            &&

        //
        // The id of the given user record is not empty and 8 characters or
        // less.
        //
        (ur.id != null) && (ur.id.length() > 0) && (ur.id.length() <= 8)

            &&

        //
        // The email address is not empty.
        //
        (ur.email != null) && (ur.email.length() > 0)

            &&

        //
        // If the phone area code and number are present, they must be 3 digits
        // and 7 digits respectively.
        //
        (if (ur.phone.area != 0)
            Integer.toString(ur.phone.area).length() == 3) &&
        (if (ur.phone.number != 0)
            Integer.toString(ur.phone.number).length() == 7);

      post: // Same as above ;

     *
     */
    abstract void add(UserRecord ur);

}
```

C. Observations

1. The standard way to strengthen a precondition is to `and` on additional clauses.
   a. Here, the previous "no duplicates" clause remains.
   b. The new requirements are added by `and`ing them on.
2. The process of formally specifying these requirements led to the discovery of one unnoticed requirements detail, which will be updated in the scenario narrative.
3. Specifically, in considering the formal specification for the constraint on email address, we were alerted to the question of whether it should be required.
   a. In consultation with the customer, the answer turns out to be "yes", even though we had not originally considered the issue explicitly in the scenarios.
   b. Hence, there is the precondition clause

      ```
      (ur.email != null) && (ur.email.length() > 0)
      ```

   c. This says that while the email address can be a free-form string, it cannot be null or of length 0, i.e., the user cannot leave it empty in the dialog.
      a. Note that we include a standard Java practice of checking for a null reference value before accessing a component of that reference.
      b. Predicates should not throw exceptions, unless they are explicitly dealt with in the specification, which subject we will address next week.
   d. Such are just the kind of details we hope to catch while formalizing.

XVI. Ordering of multi-record output lists.

A. The version of `findByName` input produces a list of `UserRecord`s, since the `name` input is not required to be a unique-valued component of a record.

B. As noted above, the initial requirements scenario overlooked what order the outputs should be in, if there are two or more.

C. The most reasonable choice is to sort the output list by Id field.
1. The scenario narrative will be updated to reflect this decision.
2. As with other such requirements, we should not trust that a programmer will do the right thing in the absence of a formal statement.
3. In this case, the programmer may not even think there is problem if an output list is displayed in some internal order, such as the order `UserRecord`s are stored in a hash table.
4. Such an order is as good as random to most human users, and as such rarely if ever satisfactory.

D. To specify `UserRecord` list ordering, we must strengthen the `findByName` postcondition. Here it is:

```
import java.util.Collection;
import java.util.List;

abstract class UserDB {
```

```
        Collection<UserRecord> data;

        /**
         * Find a user or users by real-world name.  If more than one is found,
         * the output list is sorted by id.
         *                                                                   <pre>

          pre: // Not defined yet. ;

          post:
            //
            // The output list consists of all records of the given name in the
            // input data.
            //
            forall (UserRecord ur ;
                return.contains(ur) ;
                    data.contains(ur) && ur.name.equals(name))

              &&

            //
            // The output list is sorted lexicographically by id, according to the
            // semantics of java.lang.String.compareTo().
            //
            forall (int i ; (i >= 0) && (i < return.size() - 1) ;
                return.get(i).id.compareTo(return.get(i+1).id) < 0);
         *
         */
        abstract List<UserRecord> findByName(String name);

    }
```

E. An English translation of the sorting logic is the following:

"For each position i in the output list, such that i is between the first and the second to the last positions in the list, the ith element of the list is less than the i+1st element of the list."

F. You should study this logic to be satisfied that it specifies sorting satisfactorily.

G. Note that we have used the `java.util.List` interface to define our collection object.

1. We'll use `List` instead of `Collection` in a specification when we need to specify ordering
2. `java.util.Collection` does not have the `get` method for selecting the `ith` element.

XVII. Unbounded quantification.

A. What would happen to the meaning of the sorting predicate if the constraint on the range of i were not present?

B. I.e., if the sorting logic in the postcondition were changed to the following:

```
forall (int i ; \result.get(i).id.compareTo(\result.get(i+1).id) < 0)
```

C. The meaning here is an *unbounded quantification*.

1. That is, the quantifier operates over the unbounded range of all integers.
   a. In pure mathematical terms, unbounded means infinite.
   b. In terms of a Java program, numbers are bounded by the word size of a particular computer architecture, but we are abstracting that out of our specifications at the moment.
2. In principle, there is nothing wrong with unbounded quantification.
3. For example, the original anti-spurious requirements for `UserDB.add` are expressed using unbounded

quantification

a. I.e., `forall (UserRecord ur ...)`

b. The range of the `UserRecord` type is unbounded, since it constrains string components, the values of which are conceptually unbounded, due to their conceptually unbounded length.

4. One might argue for range restrictions on the grounds of efficiency, but as noted earlier, efficiency of this nature is not of concern in an abstract specification.

D. The potential problem with unbounded quantification is that the body of the universal quantifier may not have the correct value in an unbounded range, and hence the value of the entire quantifier expression may be false when we expect it to be true, or may throw an exception, which we do not want.

1. This is in fact the case in the unbounded quantification used in the sorting predicate for `findByName`.

2. Specifically, the evaluation of `\result.get(i)` throws an exception if `i` is outside the bounds of `\result`.

E. The exact outcome of the unbounded quantification depends on the semantics, i.e., formal definition, of a particular specification language.

1. In general, however, unbounded quantification is potentially problematic under any logical semantics.

2. The point is that one needs to be careful when using unbounded quantification to ensure that the body of the quantifier has a well understood value over the entire unbounded range of quantification.

3. This is particularly the case when quantifying over the elements of a list.

XVIII. Using auxiliary functions.

A. The postcondition in the most recent definition of `findByName` is a little lengthy.

1. In practice, predicates significantly longer than this can appear in the specification of a complex operation.

2. When pre- or postconditions become unduly long, it is useful to use *auxiliary functions* to organize the logic.

3. In Spest, an auxiliary function is defined as a boolean-valued method in the class where the function is used in a predicate.

4. The logic of the auxiliary function is given as an `ensures` clause of the form "`\result == ...`", where "`...`" is a boolean expression that appears in one or more predicates.

5. The purpose of an auxiliary function is simply to modularize a piece of logic, give it a mnemonic name, and allow that logic to be invoked in one or more places.

6. I.e., the purpose is to make predicates more readable and understandable.

B. As an example, here is the preceding definition of `findByName` using two auxiliary functions.

```
import java.util.Collection;
import java.util.List;

abstract class UserDB {

    Collection<UserRecord> data;

    /**
     * Find a user or users by real-world name.  If more than one is found,
     * the output list is sorted by id.
     *                                                                    <pre>

      pre: // Not defined yet. ;

      post:
        recordsFound(name, return)
          &&
        sortedById(return);

     *
     */
    abstract List<UserRecord> findByName(String name);


    /**
     * Return true if the given list consists of all records of the given name
     * in this.data.
     *                                                                    <pre>
      post:
        return ==
            forall (UserRecord ur ;
               list.contains(ur) iff
                   data.contains(ur) && ur.name.equals(name));
      *
     */
    abstract boolean recordsFound(String name, Collection<UserRecord> list);

    /**
     * Return true if the given list is sorted lexicographically by id,
     * according to the semantics of java.lang.String.compareTo().
     *                                                                    <pre>
      post:
        return ==
            forall (int i ; (i >= 0) && (i < list.size() - 1) ;
               list.get(i).id.compareTo(list.get(i+1).id) < 0);
     *
     */
    abstract boolean sortedById(List<UserRecord> list);

}
```

XIX. Moving on to the specs for the GroupDB.

A. Figure 2 on page 7 shows the UI for the other user-related database in the Calendar Tool -- the database of user groups.

B. The specs for the GroupDB are quite similar to UserDB.

1. Both databases are clear examples of collection objects with typical collection operations.
2. The specs for GroupDB are slightly simpler, given that there is only one searchable component, the group name, which must be unique among all groups in the database.

C. A significant specification issue does arise in the area of interaction between user database operations with the group database.

1. Specifically, what happens to groups that have as a member a user who is deleted from the user database?
2. Possible ways to deal with this problem include the following:
   a. A deleted user is automatically removed from all groups of which she is a member.
   b. If a deleted user is in one or more groups, a warning message is output indicating what groups the user was in, but the users must be manually deleted from the groups; in the meantime, any unknown users are simply ignored in the group member lists.
   c. The system prevents deletion of a user until she has first been deleted from all groups; to assist the deletion, the system outputs a message indicating the affected groups.

D. This is yet another example of where formalizing the specs has led to the discovery of an important requirements issue.

1. In this case, user consultation results in the automatic removal solution.
2. This in turn leads to another issue, which is what should be done with groups who have no leader, due to

the automatic deletion of a member or was the only leader of a group.

3. This issue is resolved by allowing leaderless groups, but having the system output a warning when the situation arises.

E. All of the issues having been resolved, the resulting complete spec for the user and group databases is as follows:

```
/*
 *
 * This file defines the objects and operations related to maintaining the
 * user, group, and location databases of the calendar system.  See Section 2.6
 * of the Milestone 8 requirements.
 */
import java.util.Collection;
import java.util.List;

/**
 * UserDB is the repository of registered user information.
 */
abstract class UserDB {

    /**
     * The collection of user data records.
     */
    Collection<UserRecord> data;

    /**
     * Reference to GroupDB needed for change and delete methods.
     */
    GroupDB groupDB;

    /**
     * Add the given UserRecord to the given UserDB.  The Id of the given user
     * record must not be the same as a user record already in the UserDB.
     * The Id component is required and must be eight characters or less.  The
     * email address is required.  The phone number is optional; if given, the
     * area code and number must be 3 and 7 digits respectively.
     *                                                                     <pre>
      pre:
        //
        // There is no user record in the input UserDB with the same id as the
        // record to be added.
        //
        !exists (UserRecord ur_other ;
                data.contains(ur_other) ;
                    ur_other.id.equals(ur.id))

            &&

        //
        // The id of the given user record is not empty and 8 characters or
        // less.
        //
        (ur.id != null) && (ur.id.length() > 0) && (ur.id.length() <= 8)

            &&

        //
        // The email address is not empty.
        //
        (ur.email != null) && (ur.email.length() > 0)

            &&

        //
        // If the phone area code and number are present, they must be 3 digits
        // and 7 digits respectively.
        //
        ((ur.phone.area != 0) ==>
            Integer.toString(ur.phone.area).length() == 3) &&
        ((ur.phone.number != 0) ==>
            Integer.toString(ur.phone.number).length() == 7);

      post:
        //
        // A user record is in the output data if and only if it is the new
        // record to be added or it is in the input data.
        //
        forall (UserRecord ur_other ;
            (data'.contains(ur_other)) iff
                ur_other.equals(ur) || data.contains(ur_other));
     *
     */
    abstract void add(UserRecord ur);

    /**
     * Find a user by unique id.
     *                                                                     <pre>
      post:
        //
        // If there is a record with the given id in the input data, then the
        // output record is equal to that record, otherwise the output record
        // is null.
        //
        exists (UserRecord ur_found ; data.contains(ur_found) ;
                ur_found.id.equals(id) && ur_found.equals(return))
            ||
        !exists (UserRecord ur_found ; data.contains(ur_found) ;
                ur_found.id.equals(id)) && return == null;

     *
     */
    abstract UserRecord findById(String id);

    /**
     * Find a user or users by real-world name.  If more than one is found,
     * then the output list is sorted by id.
     *                                                                     <pre>
      post:
        //
        // The output list consists of all records of the given name in the
        // input data.
        //
        forall (UserRecord ur ;
            return.contains(ur) ;
                data.contains(ur) && ur.name.equals(name))

          &&

        //
        // The output list is sorted lexicographically by id, according to the
        // string comparison semantics of java.lang.String.compareTo().
        //
        forall (int i ; (i >= 0) && (i < return.size() - 1) ;
            return.get(i).id.compareTo(return.get(i+1).id) < 0);
      *
     */
    abstract List<UserRecord> findByName(String name);

    /**
     * Change the given old UserRecord to the given new record.  The old and
```

```
* new records must not be the same.  The old record must already be in
* the input db.  The new record must meet the same conditions as for the
* input to the AddUser operation.  Typically the user runs the FindUser
* operation prior to Change to locate an existing record to be changed.
*
* If the user record id is changed, then change all occurrences of the
* old id in the group db to the new id.
*                                                                   <pre>
 pre:
   //
   // The old and new user records are not the same.
   //
   !old_ur.equals(new_ur)

       &&

   //
   // The old record is in this.data.
   //
   data.contains(old_ur)

       &&

   //
   // There is no user record in the input UserDB with the same id as the
   // new record to be added.
   //
   ! exists (UserRecord ur_other ;
           data.contains(ur_other) ;
               ur_other.id.equals(new_ur.id))

       &&

   //
   // The id of the new record is not empty and 8 characters or less.
   //
   (new_ur.id != null) && (new_ur.id.length() > 0) &&
           (new_ur.id.length() <= 8)

       &&

   //
   // The email address is not empty.
   //
   (new_ur.email != null) && (new_ur.email.length() > 0)

       &&

   //
   // If the phone area code and number are present, they must be 3 digits
   // and 7 digits respectively.
   //
   ((new_ur.phone.area != 0) ==>
       Integer.toString(new_ur.phone.area).length() == 3) &&
   ((new_ur.phone.number != 0) ==>
       Integer.toString(new_ur.phone.number).length() == 7);

 post:
   //
   // A user record is in the output data if and only if it is the new
   // record to be added or it is in the input data, and it is not the old
   // record.
   //
   forall (UserRecord ur_other ;
       data'.contains(ur_other) iff
           ur_other.equals(new_ur) ||
                (data.contains(ur_other) &&
                    !ur_other.equals(old_ur)))
        &&

    //
    // If new id is different than old id, then all occurrences of old id
    // in the GroupDB are replaced by new id.
    //
    !old_ur.id.equals(new_ur.id) ==> true
        // Logic left as exercise for the reader
            ;
  *
 */
abstract void change(
    UserRecord old_ur, UserRecord new_ur);

/**
 * Delete the given user record from the given UserDB.  The given record
 * must already be in the input db.  Typically the user runs the FindUser
 * operation prior to Delete to locate an existing record to delete.
 *
 * In addition, delete the user from all groups of which the user is a
 * member.  If the deleted user is the only leader of a one more groups,
 * output a warning indicating that those groups have become leaderless.
 *                                                                   <pre>
  pre:
    //
    // The given user record is in this.data.
    //
    data.contains(ur);

  post:
    //
    // A user record is in the output data if and only if it is not the
    // existing record to be deleted and it is in the input data.
    //
    forall (UserRecord ur_other ;
        data'.contains(ur_other) iff
            !ur_other.equals(ur) && data.contains(ur_other))

        &&

    //
    // The id of the deleted user is not in the leader or member lists of
    // any group in the output GroupDB.  (NOTE: This clause is not as
    // strong as a complete "no junk, no confusion" spec.  Why not?  Should
    // it be?)
    //
    forall (GroupRecord gr ; groupDB.data.contains(gr) ;
        !gr.leaders.contains(ur.id) && !gr.members.contains(ur.id))

        &&

    //
    // The LeaderlessGroupsWarning list contains the ids of all groups
    // whose only leader was the user who has just been deleted.
    //
    forall (GroupRecord gr ; groupDB.data.contains(gr) ;
        forall (String id ;
            (return.groupNames.contains(id) iff
                gr.leaders.size() == 1) &&
                    (gr.leaders.get(0).equals(ur.id))));
 *
 */
abstract LeaderlessGroupsWarning delete(UserRecord ur);
```

```
}


/**
 * A UserRecord is the information stored about a registered user of the
 * Calendar Tool.  The Name component is the user‘s real-world name.  The
 * Id is the unique identifier by which the user is known to the Calendar
 * Tool.  The EmailAddress is the electronic mail address used by the
 * Calendar Tool to contact the user when necessary.  The PhoneNumber is
 * for information purposes; it is not used by the Calendar Tool for
 * contacting the user.
 */
abstract class UserRecord {
    String name;
    String id;
    String email;
    PhoneNumber phone;
}

abstract class PhoneNumber {
    int area;
    int number;
}

/**
  * LeaderlessGroupsWarning is a secondary output of the UserDB.change and
  * UserDB.delete operations, indicating the names of zero or more groups that
  * have become leaderless as the result of a user having been deleted.
  */
abstract class LeaderlessGroupsWarning {
    Collection<String> groupNames;
}

/**
 * GroupDB is the repository of user group information.
 */
abstract class GroupDB {

    /**
     * The collection of group data records.
     */
    Collection<GroupRecord> data;

    /**
     * Reference to GroupDB needed for change and delete methods.
     */
    UserDB userDB;

    /**
      * Add the given GroupRecord to the given GroupDB.  The name of the given
      * group must not be the same as a group already in the GroupDB.  All
      * group members must be registered users.  The leader(s) of the group
      * must be members of it.
      *                                                                    <pre>
      pre:
        //
        // All group members are registered users.
        //
        forall (String id ; gr.members.contains(id) ;
                exists (UserRecord ur ; userDB.data.contains(ur) ;
                    ur.id.equals(id)))

            &&

        //
        // All group leaders are members of the group.
        //
        forall (String id ; gr.leaders.contains(id) ;
            gr.members.contains(id));

      post:
        //
        // A group record is in the output db if and only if it is the new
        // record to be added or it is in the input db.
        //
        forall (GroupRecord gr_other ;
            data’.contains(gr_other) iff
                gr_other.equals(gr) || data.contains(gr_other));
      *
     */
    abstract void add(GroupRecord gr);

    /**
     * Delete the given group record from the given GroupDB.  The given record
     * must already be in the input db.  Typically the user runs the FindGroup
     * operation prior to Delete to locate an existing record to delete.
     *                                                                    <pre>
      pre:
        //
        // The given GroupRecord is in the given GroupDB.
        //
        data.contains(gr);

      post:
        //
        // A group record is in the output db if and only if it is not the
        // existing record to be deleted and it is in the input db.
        //
        forall (GroupRecord gr_other ;
            data’.contains(gr_other) iff
                !gr_other.equals(gr) && data.contains(gr_other));
     *
     */
    abstract void delete(GroupRecord gr);

    /**
     * Change the given old GroupRecord to the given new record.  The old and
     * new records must not be the same.  The old record must already be in
     * the input db.  The new record must meet the same conditions as for the
     * input to the AddGroup operation.  Typically the user runs the FindGroup
     * operation prior to Change to locate an existing record to be changed.
     *                                                                    <pre>
      pre:
        //
        // The old and new group records are not the same.
        //
        !old_gr.equals(new_gr)

            &&

        //
        // All group members are registered users.
        //
        forall (String id ; new_gr.members.contains(id) ;
                exists (UserRecord ur ; userDB.data.contains(ur) &&
                     ur.id.equals(id)))

            &&

        //
        // All group leaders are members of the group.
        //
```

```
          forall ( String id ; new_gr.leaders.contains(id) ;
              new_gr.members.contains(id));

        post:
          //
          // A group record is in the output db if and only if it is the new
          // record to be added or it is in the input db, and it is not the old
          // record.
          //
          forall (GroupRecord gr_other ;
              data'.contains(gr_other) iff
                  gr_other.equals(new_gr) ||
                      data.contains(gr_other) &&
                          !gr_other.equals(old_gr));
       *
       */
      abstract void change(GroupRecord old_gr, GroupRecord new_gr);

      /**
       * Find a group by unique name.
       *                                                                   <pre>
        post:
          //
          // If there is a record with the given name in the input db, then the
          // output record is equal to that record, otherwise the output record
          // is empty.
          //
          exists (GroupRecord gr_found ; data.contains(gr_found) ;
                  gr_found.name.equals(id) && gr_found.equals(return))
              ||
          !exists (GroupRecord gr_found ; data.contains(gr_found) ;
                  gr_found.name.equals(id) && return == null);
       *
       */
      abstract GroupRecord findById(String id);

  }

  /**
    * A GroupRecord is the information stored about a user group.  The Name
    * component is a unique group name of any length.  Leaders is a list of zero
    * or more users designated as group leader.  Members is the list of group
    * members, including the leaders.  Both lists consist of user id's.  Normally
    * a group is required to have at least one leader.  The only case that a
    * group becomes leaderless is when its only leader is deleted as a registered
    * user.
    */
  abstract class GroupRecord {
      String name;
      List<String> leaders;
      List<String> members;
  }

  /**
   * The LocationDB contains the location records that provide information about
   * the locations at which items are scheduled.
   */
  abstract class LocationDB {
      Collection<LocationRecord> data;
  }

  /**
   * A LocationRecord has a name and number which serve to identify where
   * the location is.  Both fields are free-form strings and the Calendar
   * Tool enforces no constraints on their values.  The Bookings component
   * is a list of the titles of the items that are scheduled in the
```

```
 * location.  The Remarks component is a free-form text that can be used
 * to describe any other pertinent information about the room.
 */
abstract class LocationRecord {

    String name;
    String number;
    Bookings bookings;
    Remarks remarks;
}

abstract class Bookings { /* ... */ }
abstract class Remarks { /* ... */ }
```