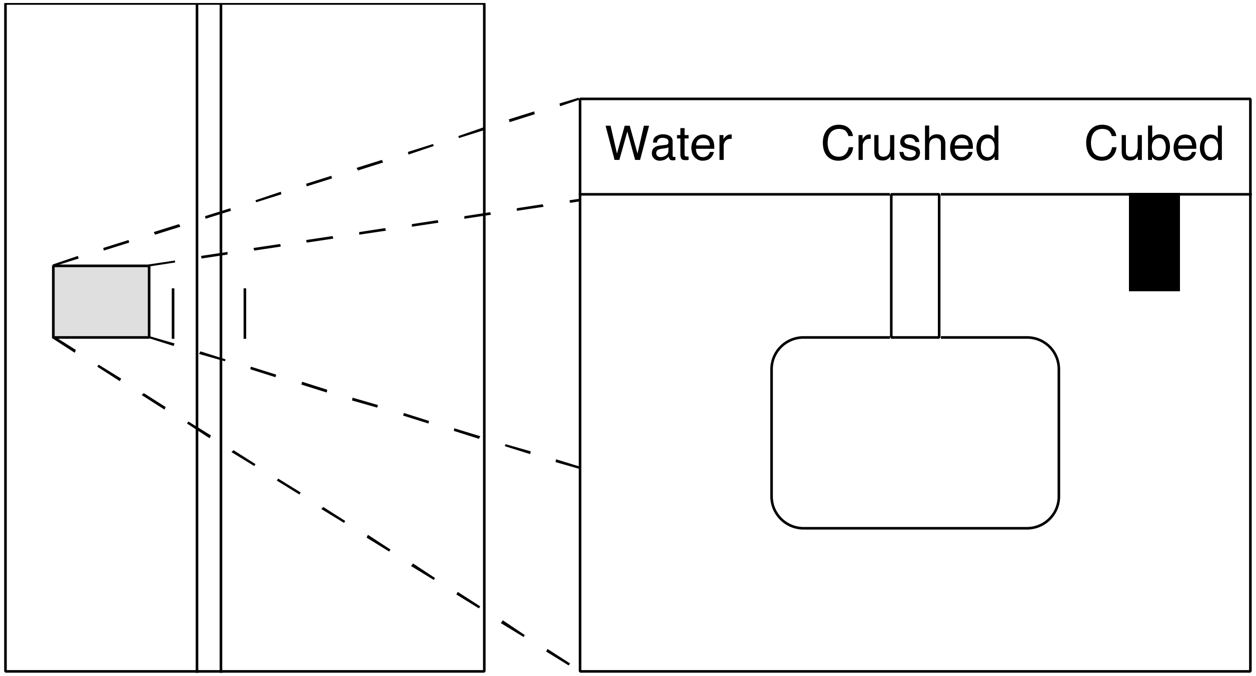
Design-by-Contract

Systems Thinking

- A ***system*** is any part of anything that you want to think about as an indivisible unit
- An ***interface*** is a description of the "boundary" between a system and everything else, that also describes how to think about that system as a unit
- A ***subsystem*** (***component***) is a system that is used inside, i.e., as a part of, another system — a relative notion!

Example: Ice/Water Dispenser



Select water, crushed ice, or cubed ice.
Place a glass against the pad and push.

People’s Roles wrt Systems

- A ***client*** is a person (or a role played by some agent) viewing a system “from the outside” as an indivisible unit
- An ***implementer*** is a person (or a role played by some agent) viewing a system “from the inside” as an assembly of subsystems/components

Describing Behavior: Part 1

- One side of the coin: ***information hiding*** is a technique for describing system behavior in which you *intentionally leave out* "internal implementation details" of the system

Describing Behavior: Part 2

- Other side of the coin (and a necessary consequence of information hiding): ***abstraction*** is a technique in which you create a *valid cover story* to counteract the effects of hiding some internal implementation details
  - Presumably the hidden information is relevant to the system behavior, so even if you hide it you still need to account for its presence!

Overview of Design-by-Contract

- Also known as ***programming-to-the-interface***
- Articulated clearly only in the 1980s
- Design-by-contract has become *the standard policy* governing "separation of concerns" across modern software engineering
- This is how software components are really used…

Recall: Mathematical Models

- Each ***variable*** in the program has a ***type***
  - Examples: `int`, `double`, …
- Each program type has a ***mathematical type*** that ***models*** it: you should think of any variable of that program type as having a value from its mathematical model's mathematical space/domain
  - Examples (respectively): ***`integer`***, ***`real`***, …

Informal Models

- Models are not always ***formal*** mathematical models like integers, real numbers, etc., but can be based on ***informal*** concepts from other situations
- Example of an *anthropomorphic* description of behavior:
  - "This TV *remembers* the last channel you watched."
- More examples to come…

Structure of a Method Contract

- Each method has:
  - A ***precondition*** (***requires clause***) that characterizes the responsibility of the program that ***calls*** (***uses***) that method (client code)
  - A ***postcondition*** (***ensures clause***) that characterizes the responsibility of the program that ***implements*** that method (implementation code in the method body)

Meaning of a Method Contract

- If its precondition is true when a method is called, then the method will ***terminate*** — return to the calling program — and the postcondition will be true when it does return
- If its precondition is not true when a method is called, then the method may do anything (including not terminate)

Responsibilities and Rewards

- Responsibility: Making sure the ***precondition*** is true when a method is called is the responsibility of the ***client***
- Reward: The client may assume the postcondition is true when the method returns

Responsibilities and Rewards

- Responsibility: Making sure the ***postcondition*** is true when a method returns is the responsibility of the ***implementer***
- Reward: The implementer may assume the precondition is true when the method is called

Recall: Static (Class) Methods

- A ***static method*** (***class method***) is one that:
  - Has zero or more ***formal parameters*** of various types — placeholders for the ***arguments*** that appear in the call between (…)
  - Returns a value of a particular ***return type*** to the calling program; or, returns nothing, denoted by a return type of `void`
    - Example of a call and its ***arguments***:

```
double a, b;
…
double c = sqrt (a*a + b*b, 0.001);
```

Recall: Static (Class) Methods

- A ***static method*** (***clas***
  - Has zero or more ***form*** types — placeholders f in the call between (…)
  - Returns a value of a partic ***eturn type*** to the calling program; or, returr hing, denoted by a return type of **`void`**
    - Example of a call and it ***guments***:

```
double a, b;
…
double c = sqrt (a*a + b*b, 0.001);
```

What does this method do?
How do you know?

Example of a Contract

```
/**
 * ...
 * @param x number to take the square root of
 * @param epsilon allowed relative error
 * @return the approximate square root of x
 * @requires
 * x > 0  and  epsilon > 0
 * @ensures <pre>
 * sqrt >= 0  and
 * [sqrt is within relative error epsilon
 *  of the actual square root of x]
 * </pre>
 */
private static double sqrt(double x,
    double epsilon)
```

Example of a Contract

```
/**
 * ...
 * @param x numbe
 * @param epsilon allow
 * @return the approximate
 * @requires
 * x > 0  and  epsilon >
 * @ensures <pre>
 * sqrt >= 0  and
 * [sqrt is within relative error epsilon
 *  of the actual square root of x]
 * </pre>
 */
private static double sqrt(double x,
    double epsilon)
```

A Java comment that starts with the symbols

`/**`

is called a ***Javadoc comment***; it goes before the method header.

Javadoc

- The standard documentation technique for Java is called ***Javadoc***
- You place special ***Javadoc comments*** enclosed in `/** … */` in your code, and the ***javadoc tool*** generates nicely formatted web-based documentation from them

APIs

- The resulting documentation is known as the ***API (application programming interface)*** for the Java code to which the Javadoc tags are attached
- The API for the OSU CSE components is at:

  http://web.cse.ohio-state.edu/software/common/doc/

APIs

- The resulting documentation is known as the ***API (application programming interface)*** for the Java code to which the Javadoc tags are attached
- The API fo at:

  http://web.cse.ohi

The word ***interface*** has two related but distinct meanings:

- a unit of Java code that contains Javadoc comments used to produce documentation
- the resulting documentation

Example of a Contract

```
/**
 * ...
 * @param x number to take the square root of
 * @param epsilon allowed relative error
 * @return th  approximate square root of x
 * @requires
 * x > 0  and  epsi     > 0
 * @ensures <pre>
 * sqrt >= 0  and
 * [sqrt is within relati
 *  of the actual square
 * </pre>
 */
private static double sqrt(double x,
    double epsilon)
```

The ***Javadoc tag*** `@param` is needed for each formal parameter; you describe the parameter's role in the method.

Example of a Contract

```
/**
 * ...
 * @param x number to take the square root of
 * @param epsilon allowed relative error
 * @return the approximate square root of x
 * @requires
 * x > 0  and  ep      n > 0
 * @ensures <pre>
 * sqrt >= 0  and
 * [sqrt is within relati
 *  of the actual square
 * </pre>
 */
private static double sqrt(double x,
    double epsilon)
```

The ***Javadoc tag*** `@return` is needed if the method returns a value; you describe the returned value.

Example o

```
/**
 * ...
 * @param x number to ta
 * @param epsilon all
 * @return the ar     ximate
 * @requires
 * x > 0  and  epsilon > 0
 * @ensures <pre>
 * sqrt >= 0  and
 * [sqrt is within relative error epsilon
 *  of the actual square root of x]
 * </pre>
 */
private static double sqrt(double x,
    double epsilon)
```

The ***Javadoc tag*** `@requires` introduces the precondition for the `sqrt` method.

Example o

```
/**
 * ...
 * @param x number to ta
 * @param epsilon allo
 * @return the appr
 * @requires
 * x > 0  and  epsilon > 0
 * @ensures <pre>
 * sqrt >= 0  and
 * [sqrt is within relative error epsilon
 *  of the actual square root of x]
 * </pre>
 */
private static double sqrt(double x,
    double epsilon)
```

The ***Javadoc tag*** `@ensures` introduces the postcondition for the `sqrt` method.

Example o

```
/**
 * ...
 * @param x number to tak
 * @param epsilon allowe
 * @return the approxi
 * @requires
 * x > 0  and  epsilon > 0
 * @ensures <pre>
 * sqrt >= 0  and
 * [sqrt is within relative error epsilon
 *  of the actual square root of x]
 * </pre>
 */
private static double sqrt(double x,
    double epsilon)
```

Javadoc comments may contain HTML-like tags; e.g., `<pre> … </pre>` means spacing and line-breaks are retained in generated documentation.

Abbreviated Javadoc

- For this course:
  - Any actual code you see *in *.java files* will have the full Javadoc comments, as above
  - Some code you see *in these slides* will *not* have the Javadoc tags @param, @return, and formatting tags <pre>; plus, “keywords” in the Javadoc and mathematics will be bold-faced for easy reading
    - This allows you to focus on the contract content: the requires and ensures clauses themselves

Example Contract (Abbreviated)

```
/**
 * ...
 * @requires
 * x > 0  and  epsilon > 0
 * @ensures
 * sqrt >= 0  and
 * [sqrt is within relative error epsilon
 *  of the actual square root of x]
 */
private static double sqrt(double x,
    double epsilon)
```

Example Contract (Abbreviated)

```
/**
 * ...
 * @requires
 * x > 0  and  epsilon > 0
 * @ensures
 * sqrt >= 0
 * [sqrt is wi
 *  of the act
 */
private static
    double epsilon)
```

This is the precondition, indicating that the *arguments* passed in for the *formal parameters* `x` and `epsilon` both must be positive before a client may call `sqrt`.

Example Contract (Abbreviated)

```
/**
 * ...
 * @requires
 * x > 0  and  epsilon > 0
 * @ensures
 * sqrt >= 0
 * [sqrt is wi
 *   of the act
 */
private static
    double epsilon)
```

The precondition is *a statement about the models of the arguments*; here, it is a *formal* mathematical statement about mathematical ***real***s.

Example Contract (Abbreviated)

```
/**
 * ...
 * @requires
 * x > 0  and
 * @ensures
 * sqrt >= 0  and
 * [sqrt is within relative error epsilon
 *  of the actual square root of x]
 */
private static double sqrt(double x,
    double epsilon)
```

This is the postcondition, indicating that the *return value* from `sqrt` is non-negative and … what does the rest say?

Example Contract (Abbreviated)

```
/**
 * ...
 * @requires
 * x > 0  and
 * @ensures
 * sqrt >= 0  and
 * [sqrt is within relative error epsilon
 *  of the actual square root of x]
 */
private static double sqrt(double x,
    double epsilon)
```

The first part of the postcondition here is written in *mathematical* notation; it is not program code! The second part — inside *[…]* — is written in English.

Using a Method Contract

- A static method's contract refers to its formal parameters, and (only if it returns a value, not **`void`**) to the name of the method (which stands for the return value)
- To determine whether the precondition and postcondition are true for a particular client call:
  - The model values of the *arguments* are substituted for the respective formal parameters
  - The model value of the *result returned by the method* is substituted for the method name

Reasoning: Tracing Tables

Code	***State***
	y = 76.9
`y = sqrt(4.0, 0.01);`	
	y = 2.0

Reasoning: Tracing Tables

Code	***State***
	y = 76.9 *z = 4.0*
`y = sqrt(z, 0.01);`	
	y = 2.0 *z = 4.0*

Reasoning: Tracing Tables

From the contract of `sqrt`,
do we know that
`y = 2.0`
instead of
`y = -2.0`?

	State
	`= 76.9` `z = 4.0`
`y = sqrt(z, 0.01);`	
	`y = 2.0` `z = 4.0`

Reasoning: Tracing Tables

From the contract of `sqrt`,
do we know that
`y = 2.0`
instead of
`y = 1.9996`?

	State
	`= 76.9` `z = 4.0`
`y = sqrt(z, 0.01);`	
	`y = 2.0` `z = 4.0`

A Partly Informal Contract

```
/**
 * ...
 * @requires
 * x > 0  and  epsilon > 0
 * @ensures
 * sqrt >= 0  and
 * [sqrt is within relative error epsilon
 *  of the actual square root of x]
 */
private static double sqrt(double x,
    double epsilon)
```

A Formal Contract

```
/**
 * ...
 * @requires
 * x > 0  and  epsilon > 0
 * @ensures
 * sqrt >= 0  and
 * |sqrt - x^(1/2)| / x^(1/2) <= epsilon
 */
private static double sqrt(double x,
    double epsilon)
```

A

We can, in this formal setting, easily substitute `4.0` for `x`, `0.01` for `epsilon`, and either `2.0` or `1.9996` for `sqrt` ... and is the postcondition true in either case? Yes!

```
/**
 * ...
 * @requires
 * x > 0  and  ep          0
 * @ensures
 * sqrt >= 0  and
 * |sqrt - x^(1/2)| / x^(1/2) <= epsilon
 */
private static double sqrt(double x,
    double epsilon)
```

A Method Body

```
private static double sqrt(double x,
    double epsilon) {
  assert x > 0.0 :
    "Violation of: x > 0";
  assert epsilon > 0.0 :
    "Violation of: epsilon > 0";
  // rest of body: compute the square root
}
```

A Method Body

```
private static double sqrt(double x,
    double epsilon) {
  assert x > 0.0 :
    "Violation of: x > 0";
  assert epsilon > 0.0 :
    "Violation of: epsilon > 0";
  // rest o  bod
}
```

The `assert` statement in Java checks whether a condition (an ***assertion***) is true; if it is not, it stops execution and reports the message after the colon.

A Method Body

```
private static double sqrt(double x,
    double epsilon) {
  assert x > 0.0 :
    "Violation of: x > 0";
  assert epsilon > 0.0 :
    "Violation of: epsilon > 0";
  // rest o  bod
}
```

But why are there `assert` statements in this method body to *check* what the implementer is supposed to *assume*?

Checking a Precondition

- During ***software development***, it is a **best practice** to check assumptions with **`assert`** when it is easy to do so
  - This checking can be turned on and off (on by using the “-ea” argument to the JVM)
  - When turned off, **`assert`** is documentation
- Preconditions generally are easy to check; postconditions generally are not easy to check

A Misconception

- A common misconception is that using `assert` statements to check preconditions contradicts design-by-contract principles
- It does not, because the advice is not to ***deliver*** software with assertion-checking turned on, but rather to ***develop*** software with assertion-checking turned on — to help catch *your* mistakes, not the client's!

Resources

- Wikipedia: Design by Contract
  - http://en.wikipedia.org/wiki/Design_by_contract