Section 7: Midterm

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(with material from Alex Mariakakis, Kellen Donohue, David Mailhot, and Hal Perkins)
Midterm review
Midterm topics

Reasoning about code
Specification vs. Implementation
Abstract Data Types (ADTs)
Testing

Subtypes & subclasses
Exceptions & assertions
Identity & equality
Reasoning about code 1

Using backwards reasoning, find the weakest precondition for each sequence of statements and postcondition below. Insert appropriate assertions in each blank line. You should simplify your answers if possible.

{_______________}
z = x + y;
{_______________}
y = z - 3;
{x > y}
Using backwards reasoning, find the weakest precondition for each sequence of statements and postcondition below. Insert appropriate assertions in each blank line. You should simplify your answers if possible.

\[
\begin{align*}
\{ & \text{_______________} \} \\
z &= x + y; \\
\{ & x > z - 3 \} \\
y &= z - 3; \\
\{ & x > y \}
\end{align*}
\]
Reasoning about code 1

Using backwards reasoning, find the weakest precondition for each sequence of statements and postcondition below. Insert appropriate assertions in each blank line. You should simplify your answers if possible.

{x > x + y - 3 => y < 3}
z = x + y;
{x > z - 3}
y = z - 3;
{x > y}
Reasoning about code 1

Using backwards reasoning, find the weakest precondition for each sequence of statements and postcondition below. Insert appropriate assertions in each blank line. You should simplify your answers if possible.

\[
\{ \quad \}
\text{p = a + b;}
\{ \quad \}
\text{q = a - b;}
\{ p + q = 42 \}
Reasoning about code 1

Using backwards reasoning, find the weakest precondition for each sequence of statements and postcondition below. Insert appropriate assertions in each blank line. You should simplify your answers if possible.

```
{_______________}
p = a + b;
{p + a - b = 42}
q = a - b;
{p + q = 42}
```
Reasoning about code 1

Using backwards reasoning, find the weakest precondition for each sequence of statements and postcondition below. Insert appropriate assertions in each blank line. You should simplify your answers if possible.

\{a + b + a - b = 42 \Rightarrow a = 21\}

\(p = a + b;\)

\{p + a - b = 42\}

\(q = a - b;\)

\{p + q = 42\}
Specification vs. Implementation

Suppose we have a BankAccount class with instance variable balance. Consider the following specifications:

A. @effects decreases balance by amount
B. @requires amount >= 0 and amount <= balance
   @effects decreases balance by amount
C. @throws InsufficientFundsException
   if balance < amount
   @effects decreases balance by amount

Which specifications does this implementation meet?

I. void withdraw(int amount) {
   balance -= amount;
}

Another way to ask the question:

If the client does not know the implementation, will the method do what the client expects it to do based on the specification?
Specification vs. Implementation

Suppose we have a **BankAccount** class with instance variable **balance**. Consider the following specifications:

A. ```
   @effects decreases balance by amount
   ```
   does exactly what the spec says

B. ```
   @requires amount >= 0 and amount <= balance
   @effects decreases balance by amount
   ```

C. ```
   @throws InsufficientFundsException
     if balance < amount
   @effects decreases balance by amount
   ```

Which specifications does this implementation meet?

I. ```
   void withdraw(int amount) {
     balance -= amount;
   }
   ```
Specification vs. Implementation

Suppose we have a BankAccount class with instance variable balance. Consider the following specifications:

A. @effects decreases balance by amount  
   does exactly what the spec says

B. @requires amount >= 0 and amount <= balance  
   @effects decreases balance by amount  
   If the client follows the @requires precondition, the code will execute as expected

C. @throws InsufficientFundsException  
   if balance < amount  
   @effects decreases balance by amount

Which specifications does this implementation meet?

I. void withdraw(int amount) {
   balance -= amount;
}


Specification vs. Implementation

Suppose we have a BankAccount class with instance variable balance. Consider the following specifications:

A. @effects decreases balance by amount  
   does exactly what the spec says

B. @requires amount \(\geq 0\) and amount \(\leq\) balance
   @effects decreases balance by amount
   If the client follows the @requires precondition, the code will execute as expected

C. @throws InsufficientFundsException
   if balance \(<\) amount
   @effects decreases balance by amount  
   ✘ Method never throws an exception

Which specifications does this implementation meet?

I. void withdraw(int amount) {
   balance -= amount;
   }


Specification vs. Implementation

Suppose we have a `BankAccount` class with instance variable `balance`. Consider the following specifications:

A. @effects decreases balance by amount
B. @requires amount >= 0 and amount <= balance
   @effects decreases balance by amount
C. @throws InsufficientFundsException
   if balance < amount
   @effects decreases balance by amount

Which specifications does this implementation meet?

II. void withdraw(int amount) {
    if (balance >= amount) balance -= amount;
}
Specification vs. Implementation

Suppose we have a `BankAccount` class with instance variable `balance`. Consider the following specifications:

A. @effects decreases balance by amount  \( \times \) balance does not always decrease
B. @requires amount >= 0 and amount <= balance  
   @effects decreases balance by amount
C. @throws InsufficientFundsException  
   if balance < amount  
   @effects decreases balance by amount

Which specifications does this implementation meet?

II. void withdraw(int amount) {
       if (balance >= amount) balance -= amount;
   }
### Specification vs. Implementation

Suppose we have a `BankAccount` class with instance variable `balance`. Consider the following specifications:

A. `@effects decreases balance by amount`  
   `✘` balance does not always decrease

B. `@requires amount >= 0 and amount <= balance @effects decreases balance by amount`

C. `@throws InsufficientFundsException if balance < amount @effects decreases balance by amount`

Which specifications does this implementation meet?

II. `void withdraw(int amount) {
       if (balance >= amount) balance -= amount;
   }`

If the client follows the `@requires` precondition, the code will execute as expected.
Specification vs. Implementation

Suppose we have a `BankAccount` class with instance variable `balance`. Consider the following specifications:

A. @effects decreases balance by amount  ❌ balance does not always decrease

B. @requires amount >= 0 and amount <= balance
   @effects decreases balance by amount
   If the client follows the @requires precondition, the code will execute as expected

C. @throws InsufficientFundsException
   if balance < amount
   @effects decreases balance by amount  ❌ Method never throws an exception

Which specifications does this implementation meet?

II. void withdraw(int amount) {
    if (balance >= amount) balance -= amount;
}
Specification vs. Implementation

Suppose we have a BankAccount class with instance variable balance. Consider the following specifications:

A. @effects decreases balance by amount

B. @requires amount ≥ 0 and amount ≤ balance
   @effects decreases balance by amount

C. @throws InsufficientFundsException
   if balance < amount
   @effects decreases balance by amount

Which specifications does this implementation meet?

III. void withdraw(int amount) {
    if (amount < 0) throw new IllegalArgumentException();
    balance -= amount;
}
Specification vs. Implementation

Suppose we have a BankAccount class with instance variable balance. Consider the following specifications:

A. @effects decreases balance by amount   **✗** balance does not always decrease

B. @requires amount >= 0 and amount <= balance
   @effects decreases balance by amount

C. @throws InsufficientFundsException
   if balance < amount
   @effects decreases balance by amount

Which specifications does this implementation meet?

III. void withdraw(int amount) {
     if (amount < 0) throw new IllegalArgumentException();
     balance -= amount;
 }
Specification vs. Implementation

Suppose we have a `BankAccount` class with instance variable `balance`. Consider the following specifications:

A. @effects decreases balance by amount  ❌ balance does not always decrease

B. @requires amount >= 0 and amount <= balance
   @effects decreases balance by amount
   If the client follows the @requires precondition, the code will execute as expected

C. @throws InsufficientFundsException
   if balance < amount
   @effects decreases balance by amount

Which specifications does this implementation meet?

III. `void withdraw(int amount) {`
    if (amount < 0) throw new IllegalArgumentException();
    balance -= amount;
    }
Suppose we have a `BankAccount` class with instance variable `balance`. Consider the following specifications:

A. `@effects decreases balance by amount`  ✗ balance does not always decrease

B. `@requires amount >= 0 and amount <= balance`  
   `@effects decreases balance by amount`  
   If the client follows the `@requires` precondition, the code will execute as expected

C. `@throws InsufficientFundsException`  
   if balance < amount  
   `@effects decreases balance by amount`  ✗ Method throws wrong exception for wrong reason

Which specifications does this implementation meet?

```java
void withdraw(int amount) {
    if (amount < 0) throw new IllegalArgumentException();
    balance -= amount;
}
```
Specification vs. Implementation

Suppose we have a BankAccount class with instance variable balance. Consider the following specifications:

A. @effects decreases balance by amount
B. @requires amount >= 0 and amount <= balance
   @effects decreases balance by amount
C. @throws InsufficientFundsException
   if balance < amount
   @effects decreases balance by amount

Which specifications does this implementation meet?

IV. void withdraw(int amount) throws InsufficientFundsException {
    if (balance < amount) throw new InsufficientFundsException();
    balance -= amount;
}
Specification vs. Implementation

Suppose we have a `BankAccount` class with instance variable `balance`. Consider the following specifications:

A. @effects decreases balance by amount  ✗ balance does not always decrease

B. @requires amount >= 0 and amount <= balance @effects decreases balance by amount

C. @throws InsufficientFundsException
   if balance < amount @effects decreases balance by amount

Which specifications does this implementation meet?

IV. `void withdraw(int amount) throws InsufficientFundsException {
       if (balance < amount) throw new InsufficientFundsException();
       balance -= amount;
   }`
Specification vs. Implementation

Suppose we have a BankAccount class with instance variable balance. Consider the following specifications:

A. @effects decreases balance by amount  \( \times \) balance does not always decrease
B. @requires amount \( \geq 0 \) and amount \( \leq \) balance
   @effects decreases balance by amount
C. @throws InsufficientFundsException
   if balance < amount
   @effects decreases balance by amount

Which specifications does this implementation meet?

IV. void withdraw(int amount) throws InsufficientFundsException {
   if (balance < amount) throw new InsufficientFundsException();
   balance -= amount;
}
Specification vs. Implementation

Suppose we have a BankAccount class with instance variable balance. Consider the following specifications:

A. @effects decreases balance by amount  ❌ balance does not always decrease
B. @requires amount >= 0 and amount <= balance  
   @effects decreases balance by amount  
   If the client follows the @requires precondition, the code will execute as expected
C. @throws InsufficientFundsException  
   if balance < amount  
   @effects decreases balance by amount  
   Method does what the spec says

Which specifications does this implementation meet?

IV. void withdraw(int amount) throws InsufficientFundsException {
    if (balance < amount) throw new InsufficientFundsException();
    balance -= amount;
}
Specifications 2

/**
 * An IntPoly is an immutable, integer-valued polynomial with integer coefficients. A typical IntPoly value
 * is a_0 + a_1*x + a_2*x^2 + ... + a_n*x^n. An IntPoly with degree n has coefficient a_n != 0, except that the
 * zero polynomial is represented as a polynomial of degree 0 and a_0 = 0 in that case.
 */

public class IntPoly {
    int a[];
    // AF(this) = a has n+1 entries, and for each entry,
    // a[i] = coefficient a_i of the polynomial.
}
Specifications 2

/**
 * Return a new IntPoly that is the sum of this and other
 * @requires
 * @modifies
 * @effects
 * @return
 * @throws
 */
public IntPoly add(IntPoly other)
Specifications 2

/**
 * Return a new IntPoly that is the sum of this and other
 * @requires other != null
 * @modifies none
 * @effects none
 * @return a new IntPoly representing the sum of this and other
 * @throws none
 */
public IntPoly add(IntPoly other)
Specifications 2

/**
 * Return a new IntPoly that is the sum of this and other
 * @requires other != null
 * @modifies none
 * @effects none
 * @return a new IntPoly representing the sum of this and other
 * @throws none
 */

public IntPoly add(IntPoly other) {
  // Implementation
}
One of your colleagues is worried that this creates a potential representation exposure problem. Another colleague says there’s no problem since an `IntPoly` is immutable. Is there a problem? Give a brief justification for your answer.

```java
public class IntPoly {
    int a[];
    // AF(this) = a has n+1 entries, and for each entry,
    // a[i] = coefficient a_i of the polynomial.

    // Return the coefficients of this IntPoly
    public int[] getCoeffs() {
        return a;
    }
}
```
Representation invariants

One of your colleagues is worried that this creates a potential representation exposure problem. Another colleague says there’s no problem since an IntPoly is immutable. Is there a problem? Give a brief justification for your answer.

```java
public class IntPoly {
    int a[];
    // AF(this) = a has n+1 entries, and for each entry,
    // a[i] = coefficient a_i of the polynomial.
    
    // Return the coefficients of this IntPoly
    public int[] getCoeffs() {
        return a;  // The return value is a reference to the same coefficient
        array stored in the IntPoly and the client code could
        alter those coefficients.
    }
}
```
Representation invariants

If there is a representation exposure problem, give a new or repaired implementation of `getCoeffs` that fixes the problem but still returns the coefficients of the `IntPoly` to the client. If it saves time you can give a precise description of the changes needed instead of writing the detailed Java code.

```java
public class IntPoly {
    int a[];
    // AF(this) = a has n+1 entries, and for each entry,
    // a[i] = coefficient a_i of the polynomial.

    // Return the coefficients of this IntPoly
    public int[] getCoeffs() {
        return a;
    }
}
```
Representation invariants

If there is a representation exposure problem, give a new or repaired implementation of `getCoeffs` that fixes the problem but still returns the coefficients of the `IntPoly` to the client. If it saves time you can give a precise description of the changes needed instead of writing the detailed Java code.

```java
public int[] getCoeffs() {
    int[] copyA = new int[a.length];
    for (int i = 0; i < copyA.length; i++) {
        copyA[i] = a[i]
    }
    return copyA
}
```
Representation invariants

If there is a representation exposure problem, give a new or repaired implementation of `getCoeffs` that fixes the problem but still returns the coefficients of the `IntPoly` to the client. If it saves time you can give a precise description of the changes needed instead of writing the detailed Java code.

```java
public int[] getCoeffs() {
    int[] copyA = new int[a.length];
    for (int i = 0; i < copyA.length; i++) {
        copyA[i] = a[i]
    }
    return copyA
}
```

1. Make a copy
2. Return the copy
We would like to add a method to this class that evaluates the \texttt{IntPoly} at a particular value \textit{x}. In other words, given a value \textit{x}, the method \texttt{valueAt(x)} should return $a_0 + a_1x + a_2x^2 + ... + a_nx^n$, where $a_0$ through $a_n$ are the coefficients of this \texttt{IntPoly}.

For this problem, develop an implementation of this method and prove that your implementation is correct.

(see starter code on next slide)
Reasoning about code 2

/** Return the value of this IntPoly at point x */
public int valueAt(int x) {
    int val = a[0];
    int xk = 1;
    int k = 0;
    int n = a.length-1; // degree of this, n >=0
    while (k != n) {
        xk = xk * x;
        val = val + a[k+1]*xk;
        k = k + 1;
    }
    return val;
}
Reasoning about code 2

/** Return the value of this IntPoly at point x */
public int valueAt(int x) {
    int val = a[0];
    int xk = 1;
    int k = 0;
    int n = a.length-1; // degree of this, n >=0
    {inv: xk = x^k && val = a[0] + a[1]*x + ... + a[k]*x^k}
    while (k != n) {
        {_____}
        xk = xk * x;
        {_____}
        val = val + a[k+1]*xk;
        {_____}
        k = k + 1;
        {_____}
    }
    {_____}
    return val;
}
Reasoning about code 2

/** Return the value of this IntPoly at point x */
public int valueAt(int x) {
    int val = a[0];
    int xk = 1;
    int k = 0;
    int n = a.length-1; // degree of this, n >=0
    {inv: xk = x^k && val = a[0] + a[1]*x + ... + a[k]*x^k}
    while (k != n) {
        {inv && k != n}
        xk = xk * x;
        {_____}
        val = val + a[k+1]*xk;
        {_____}
        k = k + 1;
        {_____}
    }
    {_____}
    return val;
}
Reasoning about code 2

/** Return the value of this IntPoly at point x */
public int valueAt(int x) {
    int val = a[0];
    int xk = 1;
    int k = 0;
    int n = a.length-1; // degree of this, n >=0
    {inv: xk = x^k && val = a[0] + a[1]*x + ... + a[k]*x^k}
    while (k != n) {
        {inv && k != n}
        xk = xk * x;
        {xk = x^(k+1) && val = a[0] + a[1]*x + ... + a[k]*x^k}
        val = val + a[k+1]*xk;
        {_____}
        k = k + 1;
        {_____}
    }
    {_____}
    return val;
}
Reasoning about code 2

/** Return the value of this IntPoly at point x */
public int valueAt(int x) {
    int val = a[0];
    int xk = 1;
    int k = 0;
    int n = a.length-1; // degree of this, n >=0
    {inv: xk = x^k && val = a[0] + a[1]*x + ... + a[k]*x^k}
    while (k != n) {
        {inv && k != n}
        xk = xk * x;
        {xk = x^(k+1) && val = a[0] + a[1]*x + ... + a[k]*x^k}
        val = val + a[k+1]*xk;
        {xk = x^(k+1) && val = a[0] + a[1]*x + ... + a[k+1]*x^(k+1)}
        k = k + 1;
        {_____}
    }
    {_____}
    return val;
}
Reasoning about code 2

/** Return the value of this IntPoly at point x */
public int valueAt(int x) {
    int val = a[0];
    int xk = 1;
    int k = 0;
    int n = a.length-1; // degree of this, n >=0
    {inv: xk = x^k && val = a[0] + a[1]*x + ... + a[k]*x^k}
    while (k != n) {
        {inv && k != n}
        xk = xk * x;
        {xk = x^(k+1) && val = a[0] + a[1]*x + ... + a[k]*x^k}
        val = val + a[k+1]*xk;
        {xk = x^(k+1) && val = a[0] + a[1]*x + ... + a[k+1]*x^(k+1)}
        k = k + 1;
        {inv}
    }
    ______
    return val;
Reasoning about code 2

/** Return the value of this IntPoly at point x */
public int valueAt(int x) {
    int val = a[0];
    int xk = 1;
    int k = 0;
    int n = a.length-1; // degree of this, n >=0
{inv: xk = x^k && val = a[0] + a[1]*x + ... + a[k]*x^k}
    while (k != n) {
        {inv && k != n}
        xk = xk * x;
        {xk = x^(k+1) && val = a[0] + a[1]*x + ... + a[k]*x^k}
        val = val + a[k+1]*xk;
        {xk = x^(k+1) && val = a[0] + a[1]*x + ... + a[k+1]*x^(k+1)}
        k = k + 1;
        {inv}
    }
{inv && k = n ⇒ val = a[0] + a[1]*x + ... + a[n]*x^n} 
    return val;
}
Equality

Suppose we are defining a class `StockItem` to represent items stocked by an online grocery store. Here is the start of the class definition, including the class name and instance variables:

```java
public class StockItem {
    String name;
    String size;
    String description;
    int quantity;

    /* Construct a new StockItem */
    public StockItem(...);
}
```
A summer intern was asked to implement an `equals` function for this class that treats two `StockItem` objects as equal if their `name` and `size` fields match. Here’s the result:

```java
/** return true if the name and size fields match */
public boolean equals(StockItem other) {
    return name.equals(other.name) && size.equals(other.size);
}
```

This `equals` method seems to work sometimes but not always. Give an example showing a situation when it fails.
Equality

A summer intern was asked to implement an `equals` function for this class that treats two `StockItem` objects as equal if their `name` and `size` fields match. Here’s the result:

```java
/** return true if the name and size fields match */
public boolean equals(StockItem other) {
    return name.equals(other.name) && size.equals(other.size);
}
```

This `equals` method seems to work sometimes but not always. Give an example showing a situation when it fails.

```java
Object s1 = new StockItem("thing", 1, "stuff", 1);
Object s2 = new StockItem("thing", 1, "stuff", 1);
System.out.println(s1.equals(s2));
```
A summer intern was asked to implement an *equals* function for this class that treats two *StockItem* objects as equal if their *name* and *size* fields match. Here’s the result:

```java
/** return true if the name and size fields match */
public boolean equals(StockItem other) {
    // equals is overloaded, not overridden
    return name.equals(other.name) && size.equals(other.size);
}
```

This *equals* method seems to work sometimes but not always. Give an example showing a situation when it fails.

```java
Object s1 = new StockItem("thing", 1, "stuff", 1);
Object s2 = new StockItem("thing", 1, "stuff", 1);
System.out.println(s1.equals(s2));
```
Equality

Show how you would fix the `equals` method so it works properly (StockItems are equal if their names and sizes are equal)

/** return true if the name and size fields match */
Show how you would fix the `equals` method so it works properly (`StockItems` are equal if their names and sizes are equal)

```java
/** return true if the name and size fields match */
@Override
public boolean equals(Object o) {
    if (!(o instanceof StockItem)) {
        return false;
    }
    StockItem other = (StockItem) o;
    return name.equals(other.name) && size.equals(other.size);
}
```
hashCode

Which of the following implementations of `hashCode()` for the `StockItem` class are legal:

1. `return name.hashCode();`
2. `return name.hashCode() * 17 + size.hashCode();`
3. `return name.hashCode() * 17 + quantity;`
4. `return quantity;`
hashCode

Which of the following implementations of hashCode() for the StockItem class are legal:

1. return name.hashCode();  legal
2. return name.hashCode() * 17 + size.hashCode();
3. return name.hashCode() * 17 + quantity;
4. return quantity;
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3. `return name.hashCode() * 17 + quantity;`
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Which of the following implementations of `hashCode()` for the `StockItem` class are legal:

1. return name.hashCode();  legal
2. return name.hashCode() * 17 + size.hashCode();  legal
3. return name.hashCode() * 17 + quantity; ✘ illegal!
4. return quantity;
Which of the following implementations of `hashCode()` for the `StockItem` class are legal:

1. `return name.hashCode();`  **legal**
2. `return name.hashCode() * 17 + size.hashCode();`  **legal**
3. `return name.hashCode() * 17 + quantity;`  ✗ illegal!
4. `return quantity;`  ✗ illegal!
hashCode

Which of the following implementations of `hashCode()` for the `StockItem` class are legal:

1. return name.hashCode();  legal
2. return name.hashCode() * 17 + size.hashCode();  legal
3. return name.hashCode() * 17 + quantity;  ✘ illegal!
4. return quantity;  ✘ illegal!

The `equals` method does not care about `quantity`

In #3 and #4 two `StockItem` objects that were equal could have different hashcodes, which is invalid
HashCode

Which implementation do you prefer?

```java
public int hashCode() {
    return name.hashCode();
}
```

```java
public int hashCode() {
    return name.hashCode()*17 + size.hashCode();
}
```
Which implementation do you prefer?

public int hashCode() {
    return name.hashCode();
}

public int hashCode() {
    return name.hashCode()*17 + size.hashCode();
}

(ii) will likely do the best job since it takes into account both the size and name fields. (i) is also legal but it gives the same hashCode for StockItems that have different sizes as long as they have the same name, so it doesn’t differentiate between different StockItems as well as (ii).
Suppose we are specifying a method and we have a choice between either requiring a precondition (e.g., @requires: n > 0) or specifying that the method throws an exception under some circumstances (e.g., @throws IllegalArgumentException if n <= 0).

Assuming that neither version will be significantly more expensive to implement than the other and that we do not expect the precondition to be violated or the exception to be thrown in normal use, is there any reason to prefer one of these to the other, and, if so, which one?
Suppose we are specifying a method and we have a choice between either requiring a precondition (e.g., `@requires: n > 0`) or specifying that the method throws an exception under some circumstances (e.g., `@throws IllegalArgumentException if n <= 0`).

Assuming that neither version will be significantly more expensive to implement than the other and that we do not expect the precondition to be violated or the exception to be thrown in normal use, is there any reason to prefer one of these to the other, and, if so, which one?

It would be better to specify the exception. That reduces the domain of inputs for which the behavior of the method is unspecified. It also will cause the method to fail fast for incorrect input, which should make the software more robust – or at least less likely to continue execution with erroneous data.
Suppose we are specifying a method and we have a choice between either requiring a precondition (e.g., \texttt{@requires: n > 0}) or specifying that the method throws an exception under some circumstances (e.g., \texttt{@throws IllegalArgumentException if n <= 0}).

Assuming that neither version will be significantly more expensive to implement than the other and that we do not expect the precondition to be violated or the exception to be thrown in normal use, is there any reason to prefer one of these to the other, and, if so, which one?

It would be better to specify the exception. That reduces the domain of inputs for which the behavior of the method is unspecified. It also will cause the method to fail fast for incorrect input, which should make the software more robust – or at least less likely to continue execution with erroneous data.

Note: You could just as easily argue the other way. It may be better to specify the precondition because once the exception is in the specification, it has to stay there because the client may expect it.
Suppose we are trying to choose between two possible specifications for a method. One of the specifications $S$ is stronger than the other specification $W$, but both include the behavior needed by clients. In practice, should we always pick the stronger specification $S$, always pick the weaker one $W$, or is it possible that either one might be the suitable choice? Give a brief justification of your answer, including a brief list of the main criteria to be used in making the decision.
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Neither is necessarily better. What is important is picking a specification that is simple, promotes modularity and reuse, and can be implemented efficiently.

(Many answers focused narrowly on which would be easier to implement. While that is important – we don’t want a specification that is impossible to build – it isn’t the main thing that determines whether a system design is good or bad.)