Functional Testing Details

Specification-Based Testing

Unit Testing: Dealing with Scale

- **Best practice** is to test individual ***units*** or ***components*** of software
  - Test one class's operation at a time
  - This is known as ***unit testing***

Unit Testing:

And the unit being tested is known as the *unit under test*

- **Best practice** is to te dividual ***units*** or ***components*** of softw e
  - Test one class's opera ion at a time
  - This is known as ***unit testing***

Testing Functional Correctness

- What does it mean for a program unit to be ***correct***?

Testing Functional Correctness

- What does it mean for a program unit to be ***correct***?

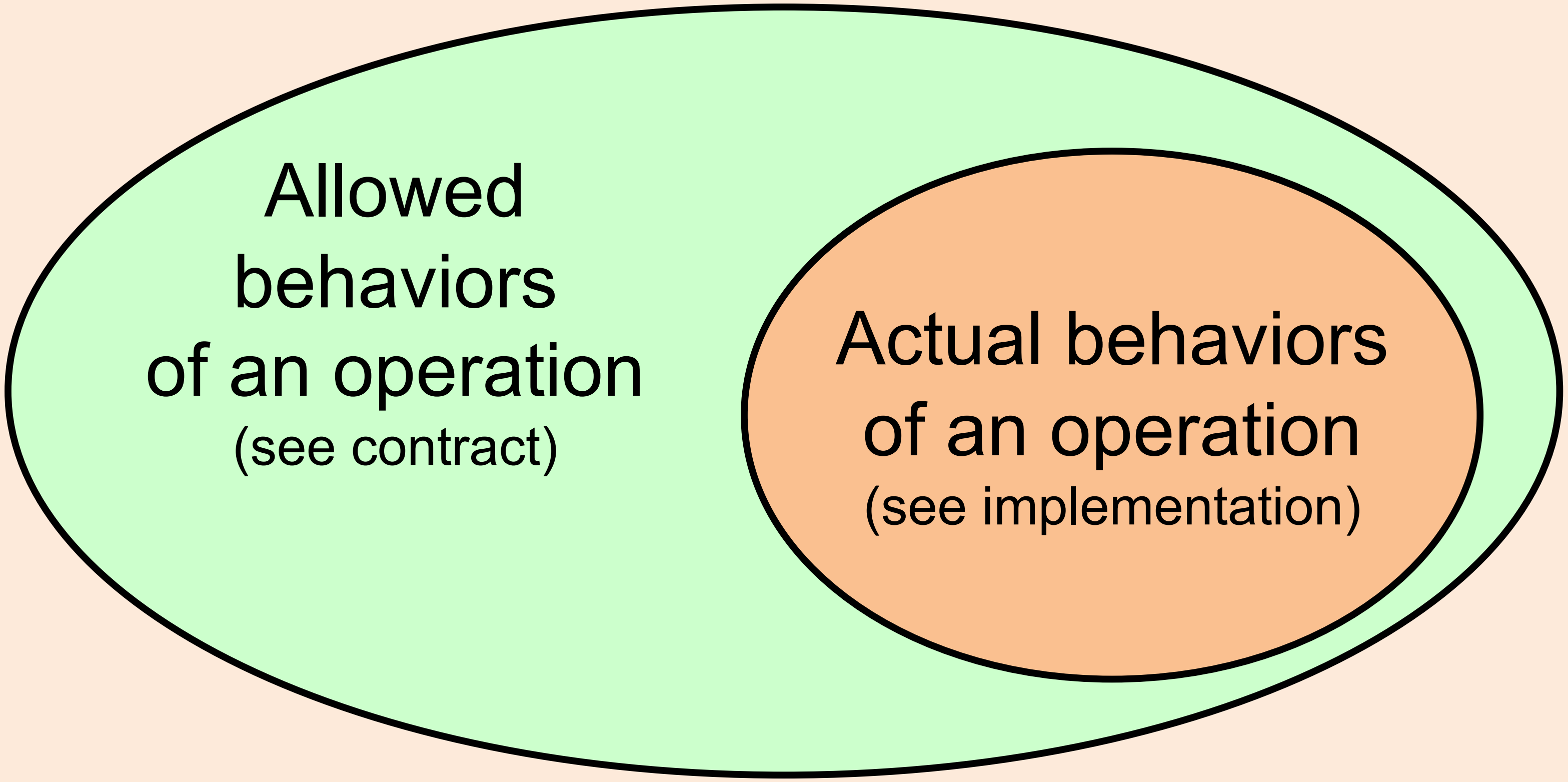
- The following answers are vague
  - It does what it is supposed to do
  - It doesn't do what it is not supposed to do

“Supposed To Do”?

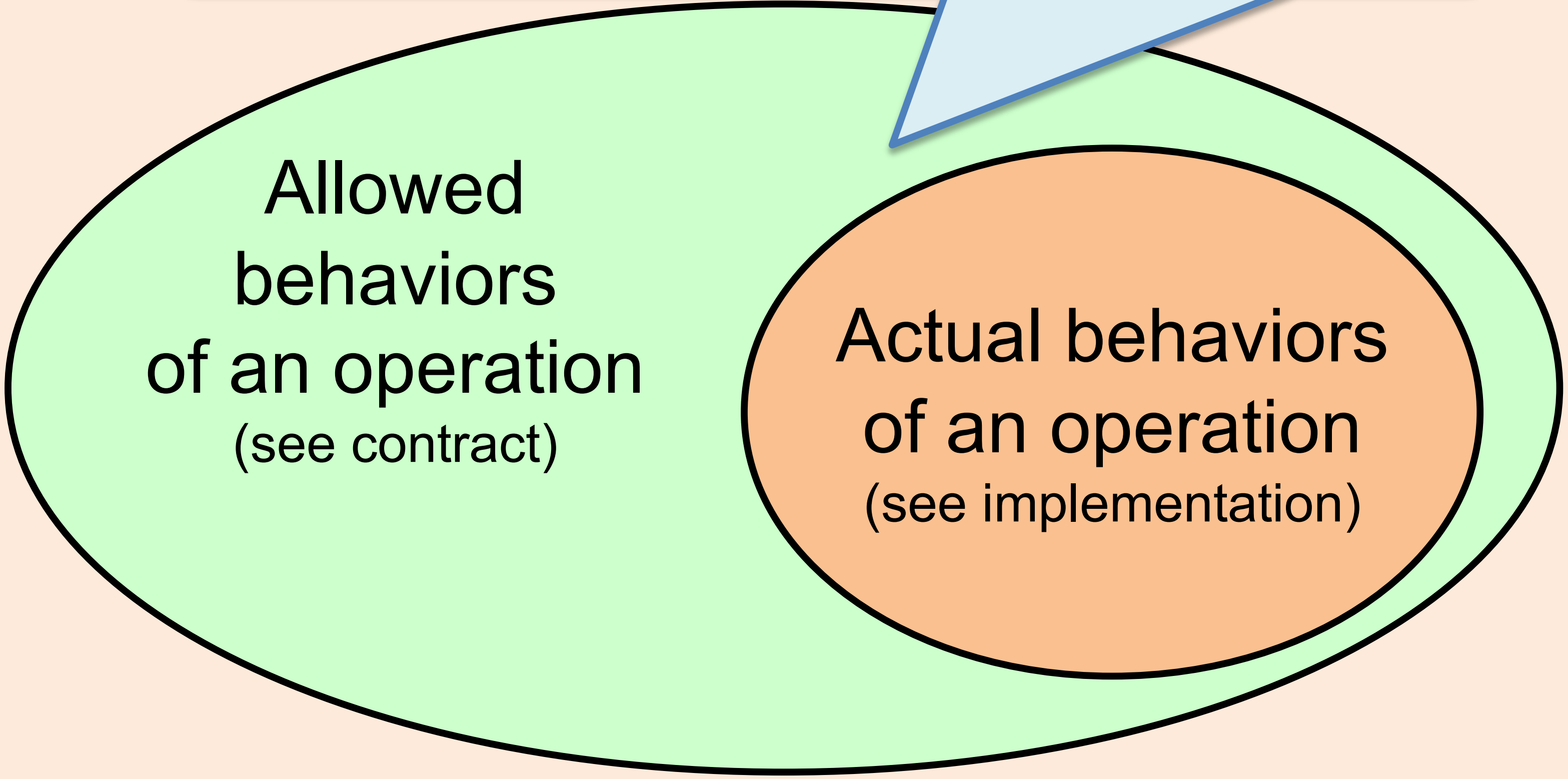
- How do we know what an operation *is supposed to do*, and what it is *not supposed to do*?
- Answer:
  - We look at the operation’s ***contract***, which is a ***specification*** of its ***intended behavior***

```
void enqueue(T& x);
   //! updates self
   //! clears x
   //! ensures: self = #self * <#x>
```

Allowed & Actual Behaviors


Allowed behaviors of an operation
(see contract)
Actual behaviors of an operation
(see implementation)

Each point in this space is a ***legal input*** with a corresponding ***allowable result***.
Represented as 2-tuples:
(legal input, allowable result)


Allowed behaviors of an operation (see contract)
Actual behaviors of an operation (see implementation)

Example: Queue's *length* Contract

```
Integer length(void);
   //! restores self
   //! ensures: length = |self|
```

Example: Queue's *length* Contract

```
Integer length(void);
    //! restores self
    //! ensures: length = |self|
```

This means:
"*length* returns a count of the number of items currently in the queue"

Example: Client of Queue

```
#include "Wrapper.h”
#include "Queue\Queue1.hpp”

typedef Queue1<Integer> QueueOfInteger;

int main(int argc, char* argv[])
{
   QueueOfInteger q1;

   cout << q1.length();
}
```

Example: Client of Queue

```
#include "Wrapper.h”
#include "Queue\Queue1.hpp”

typedef Queue1<Integer> QueueOfInteger;

int main(int argc, char* argv[])
{
   QueueOfInteger q1;

   cout << q1.length();
}
```

Instantiate Queue1 with Integer to create QueueOfInteger

Example: Client of Queue

```
#include "Wrapper.h”
#include "Queue\Queue1.hpp”

typedef Queue1<Integer> QueueOfInteger;

int main(int argc, char* argv[])
{
   QueueOfInteger q1;

   cout << q1.length();
}
```

Declare variable q1 from QueueOfInteger

Example: Client of Queue

```
#include "Wrapper.h”
#include "Queue\Queue1.hpp”

typedef Queue1<Integer> QueueOfInteger;

int main(int argc, char* argv[])
{
   QueueOfInteger q1;

   cout << q1.length();
}
```

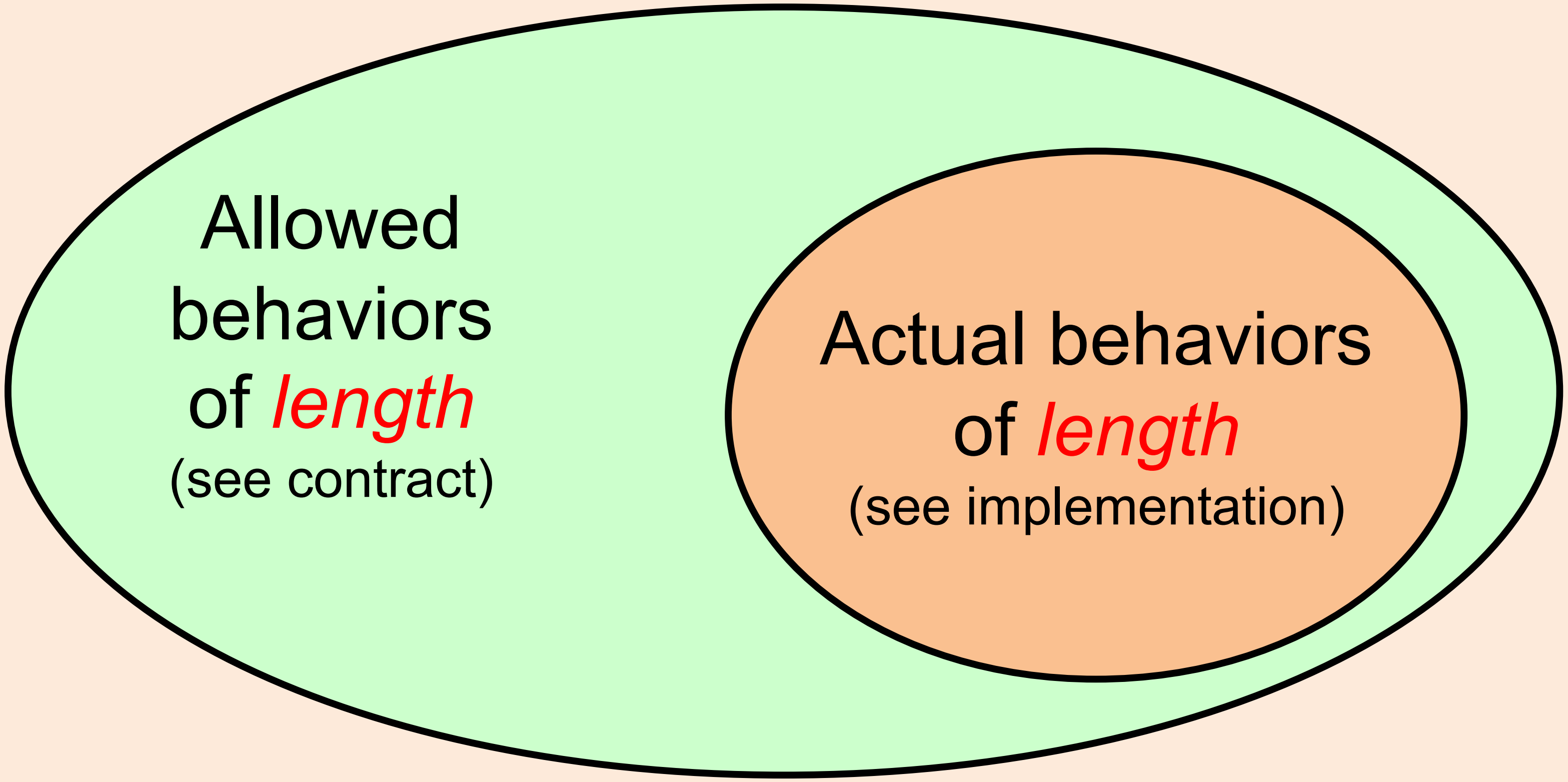
Ensures clause of Queue’s constructor initializes q1 = <>

Example: Client of Queue

```
#include "Wrapper.h”
#include "Queue\Queue1.hpp”

typedef Queue1<Integer> QueueOfInteger;

int main(int argc, char* argv[])
{
   QueueOfInteger q1;

   cout << q1.length();
}
```

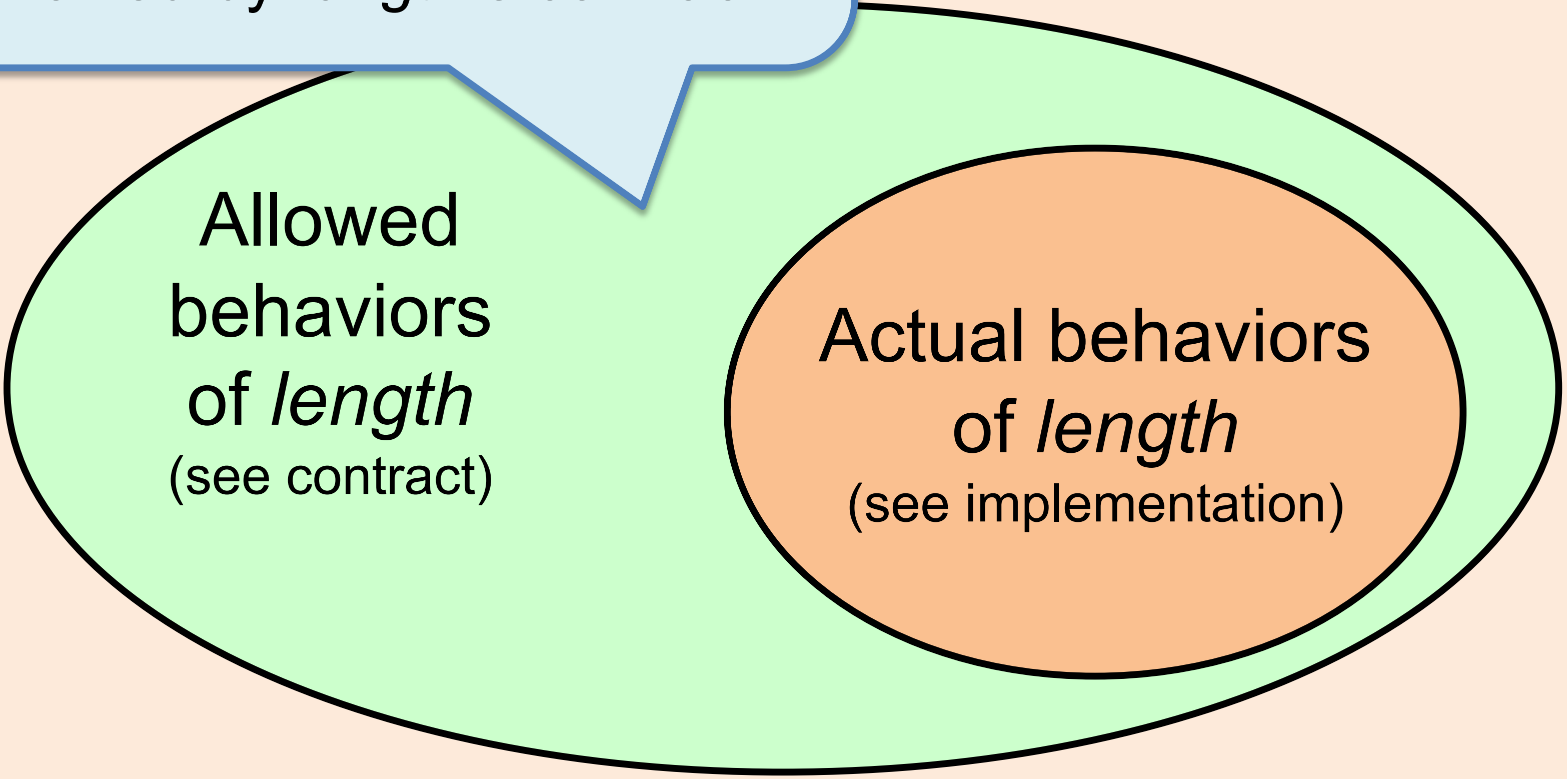
Ensures clause of Queue’s length is: length = |q1|

Example: *length's* Behavior



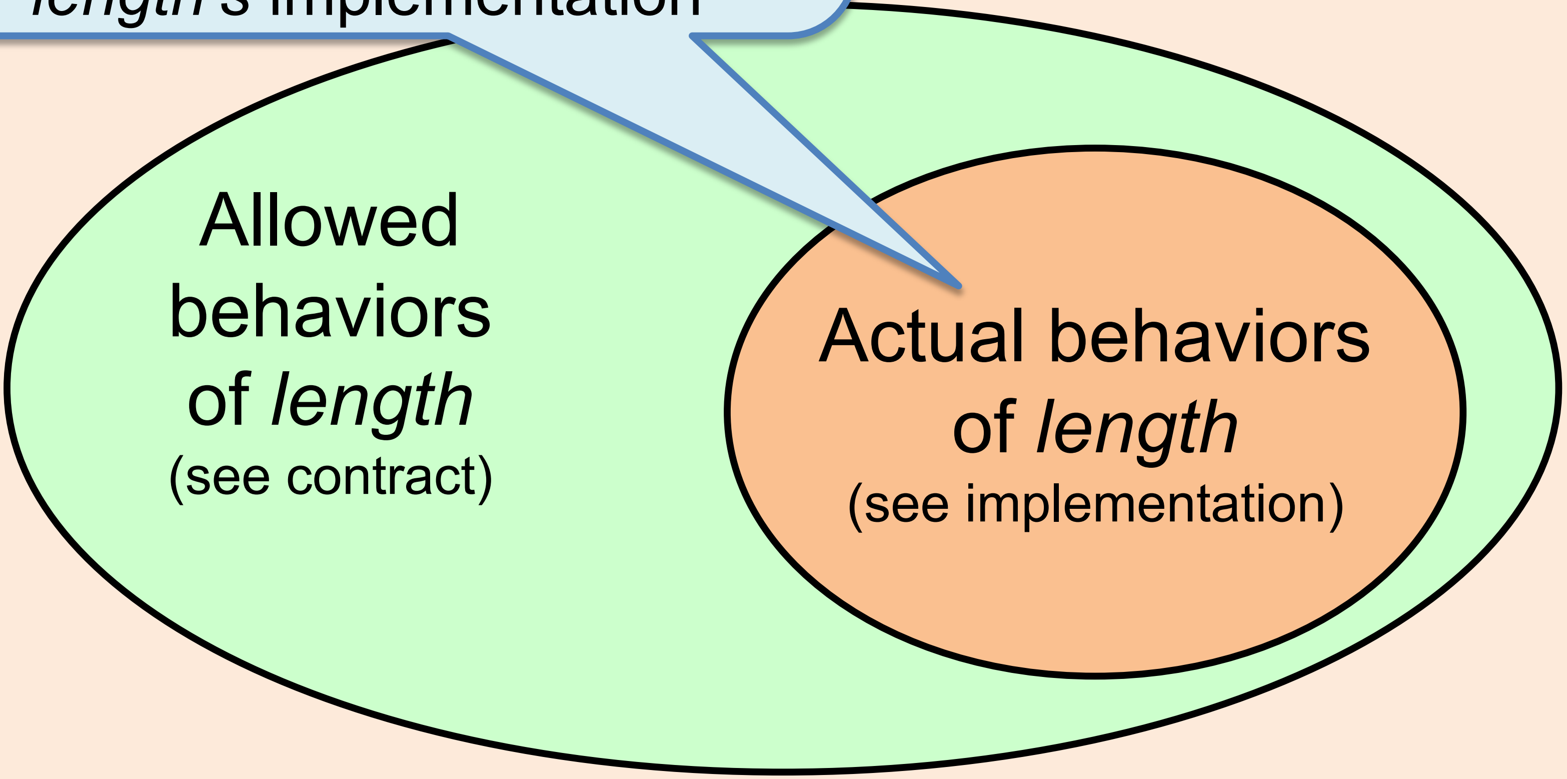
ehavior

Appearing in this part of the Venn diagram are 2-tuples representing behaviors allowed by *length's* contract


Allowed behaviors of *length* (see contract)
Actual behaviors of *length* (see implementation)

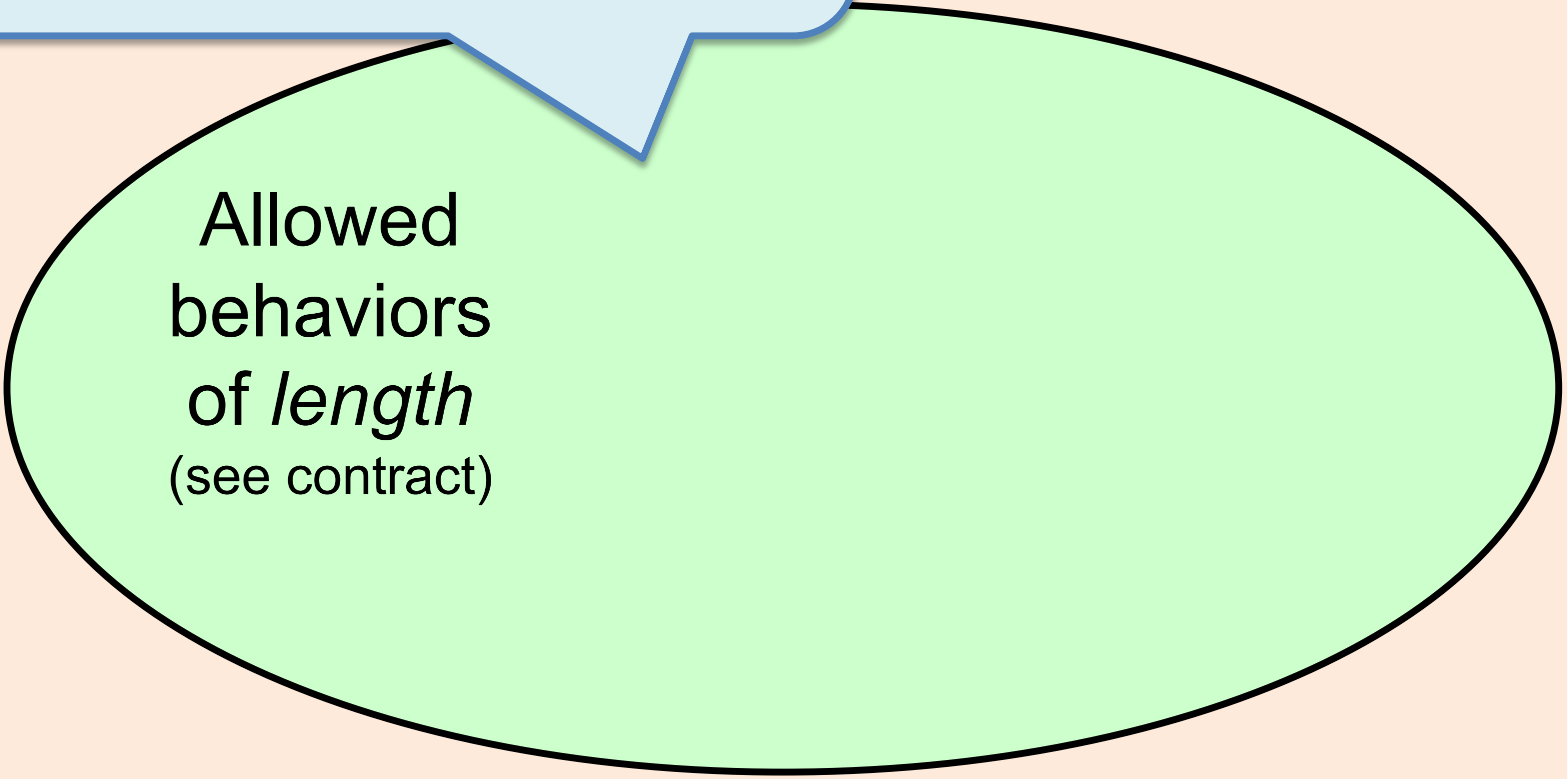
ehavior

Appearing in this part of the Venn diagram are 2-tuples representing behaviors actually exhibited by *length's* implementation


Allowed behaviors of *length* (see contract)
Actual behaviors of *length* (see implementation)

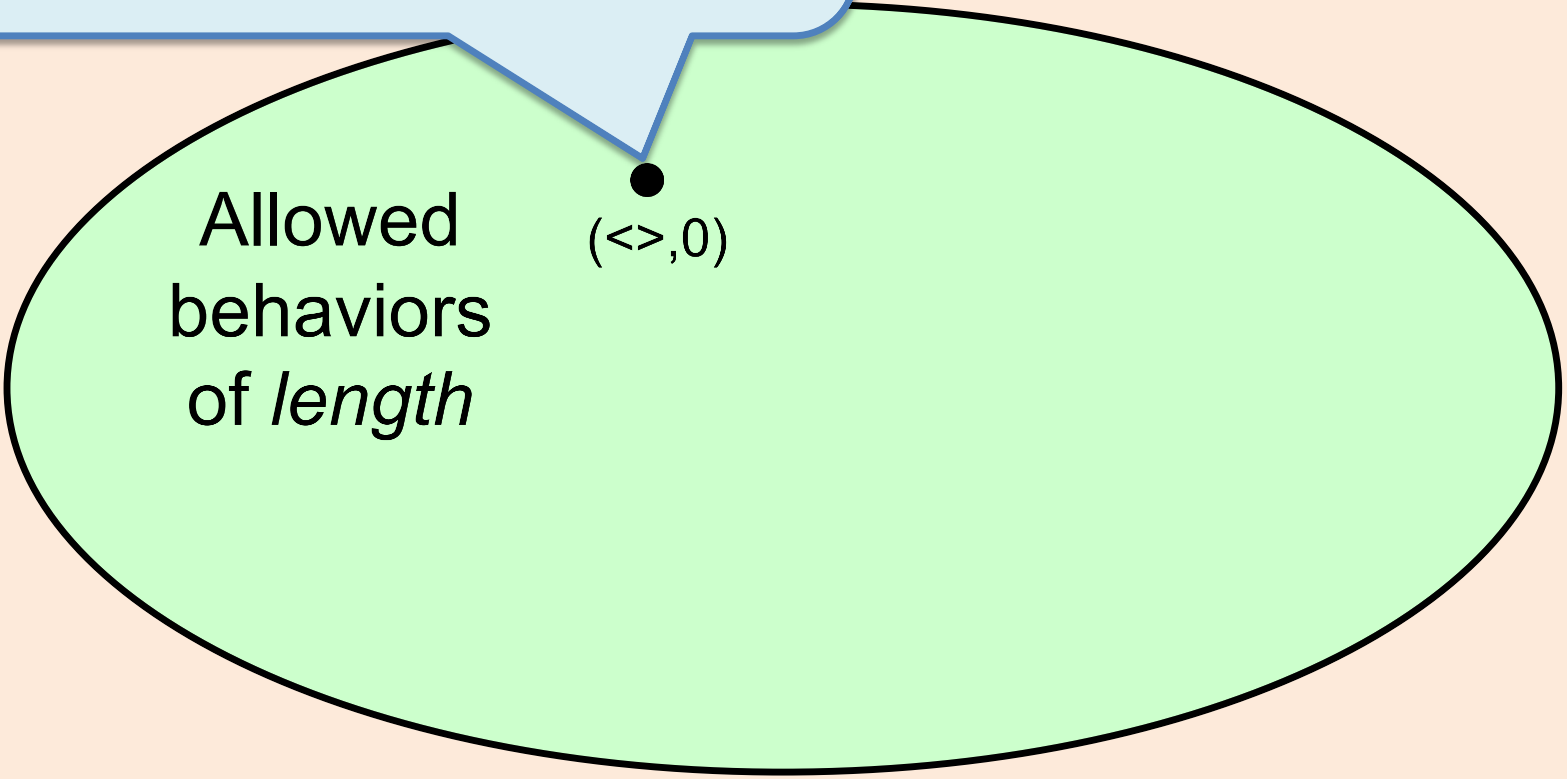
ehavior

For the moment, let's focus on the behaviors allowed by *length's* contract

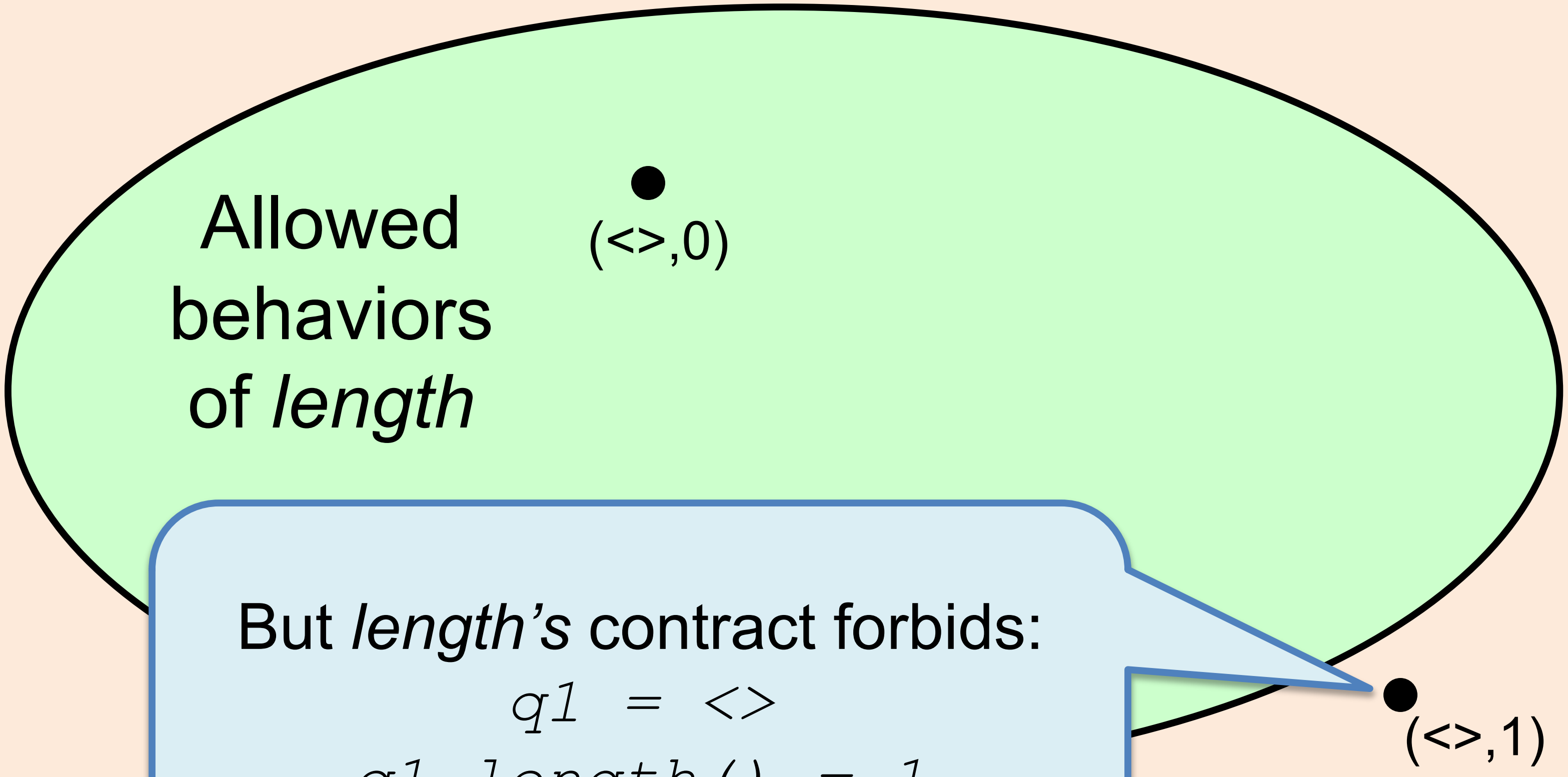


ehavior

By *length's* contract:
if `q1 = <>`
then `q1.length() = 0`



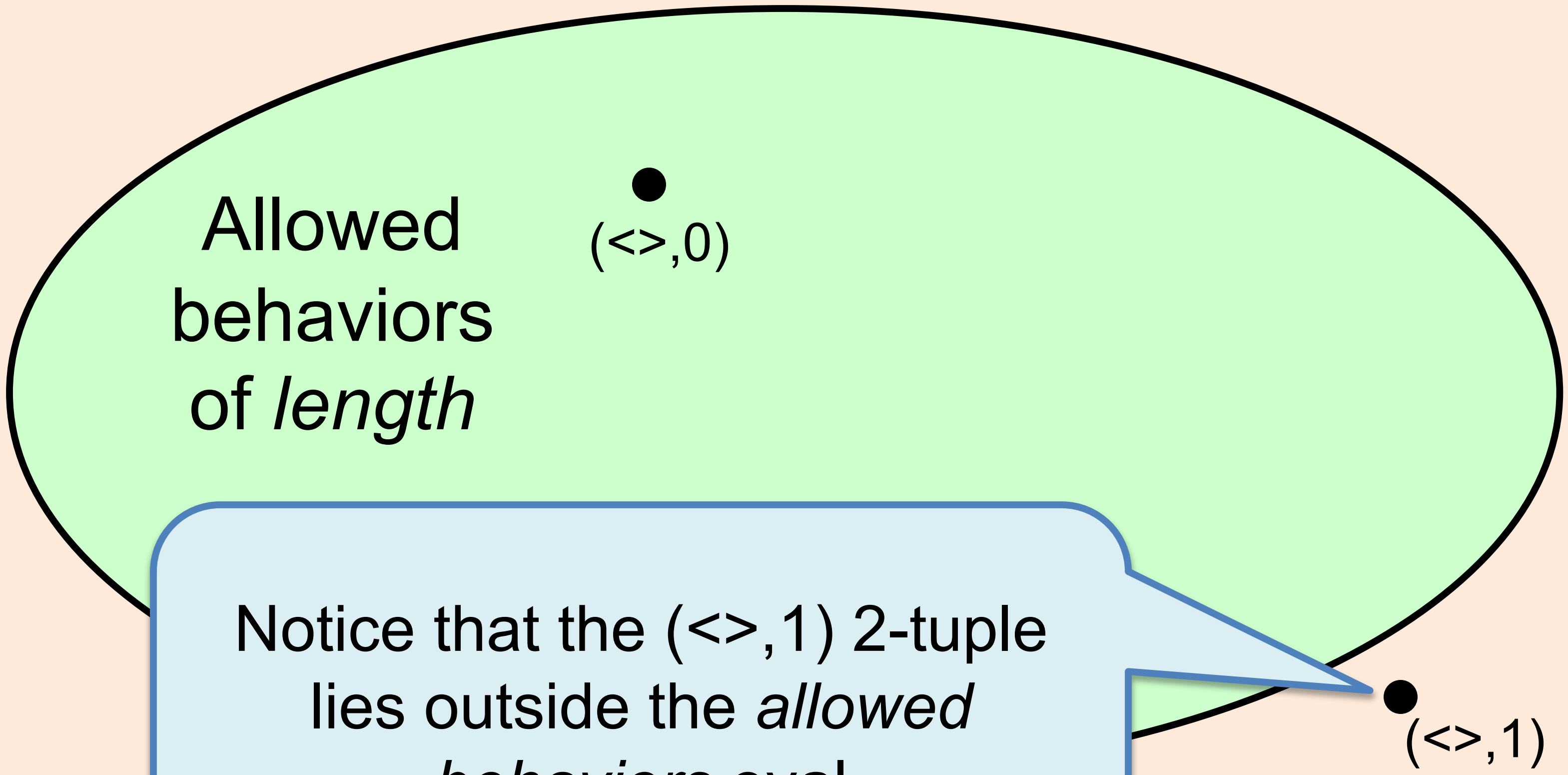
length's Behavior



But *length's* contract forbids:

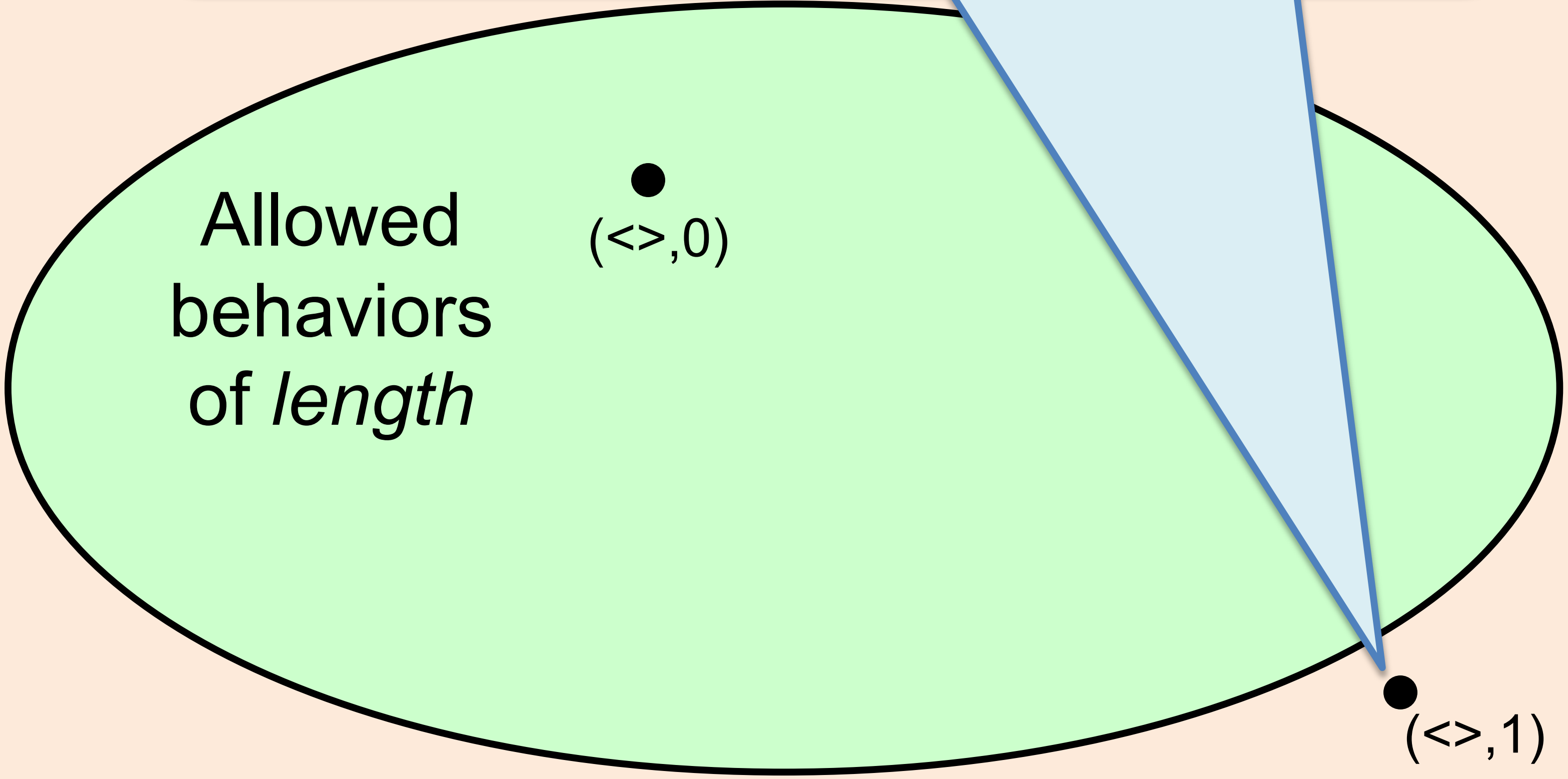
```
q1 = <>
q1.length() = 1
```

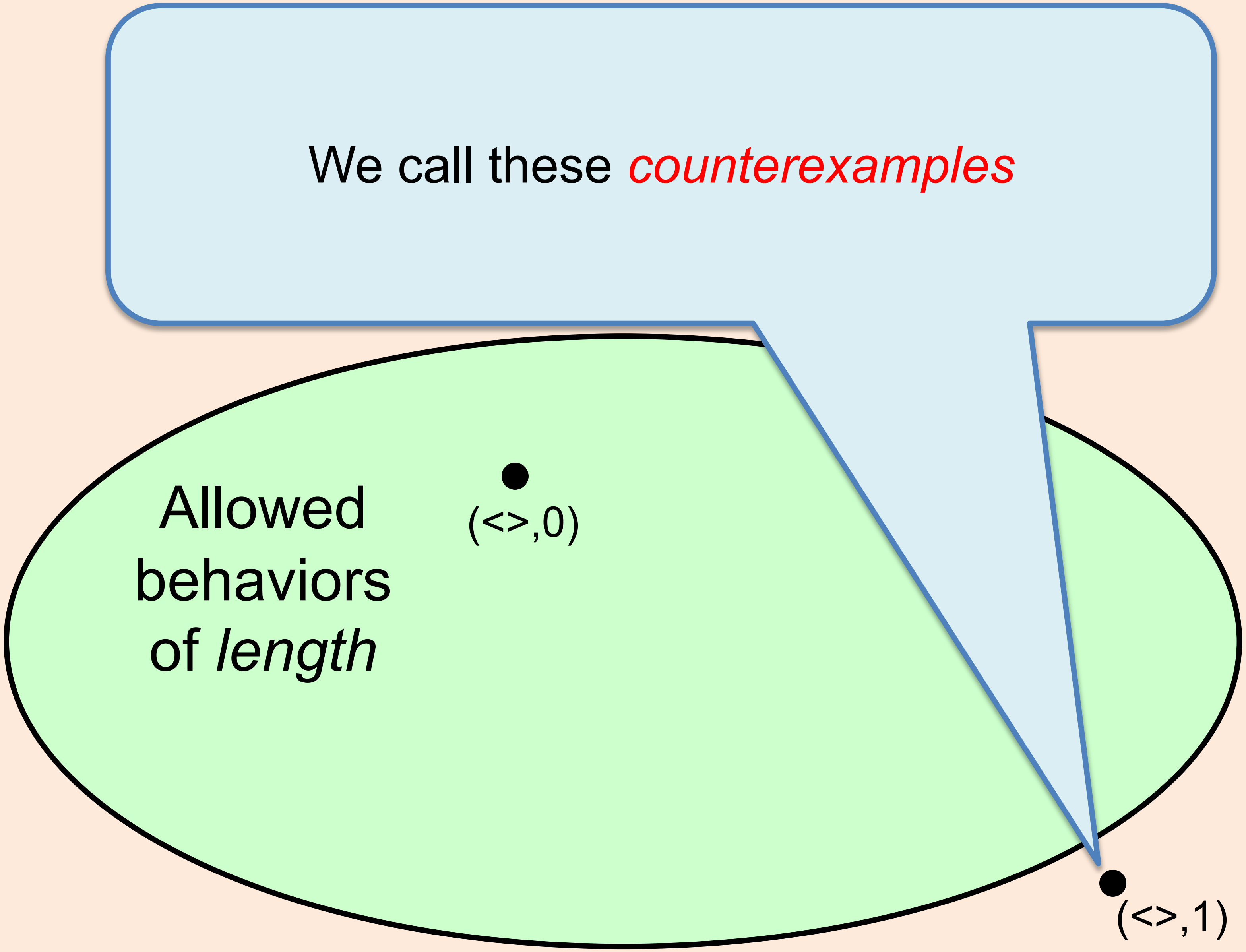
length's Behavior



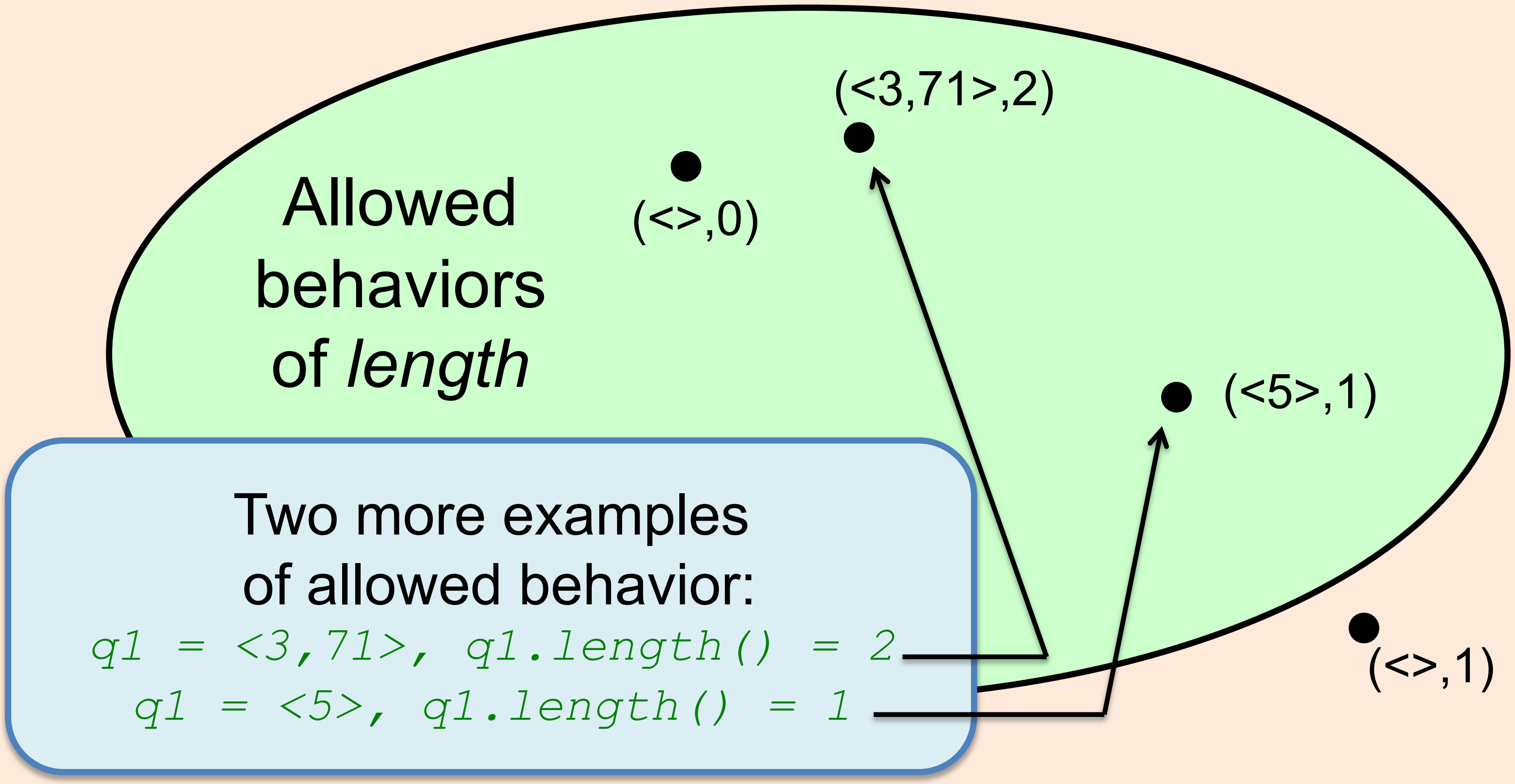
Notice that the (<>,1) 2-tuple lies outside the *allowed behaviors* oval

Each point outside the oval is a ***legal input*** with a corresponding ***not allowable result***. These are also represented as 2-tuples: (legal input, not allowable result)




We call these *counterexamples*
Allowed behaviors of *length*
(<>,0)
(<>,1)

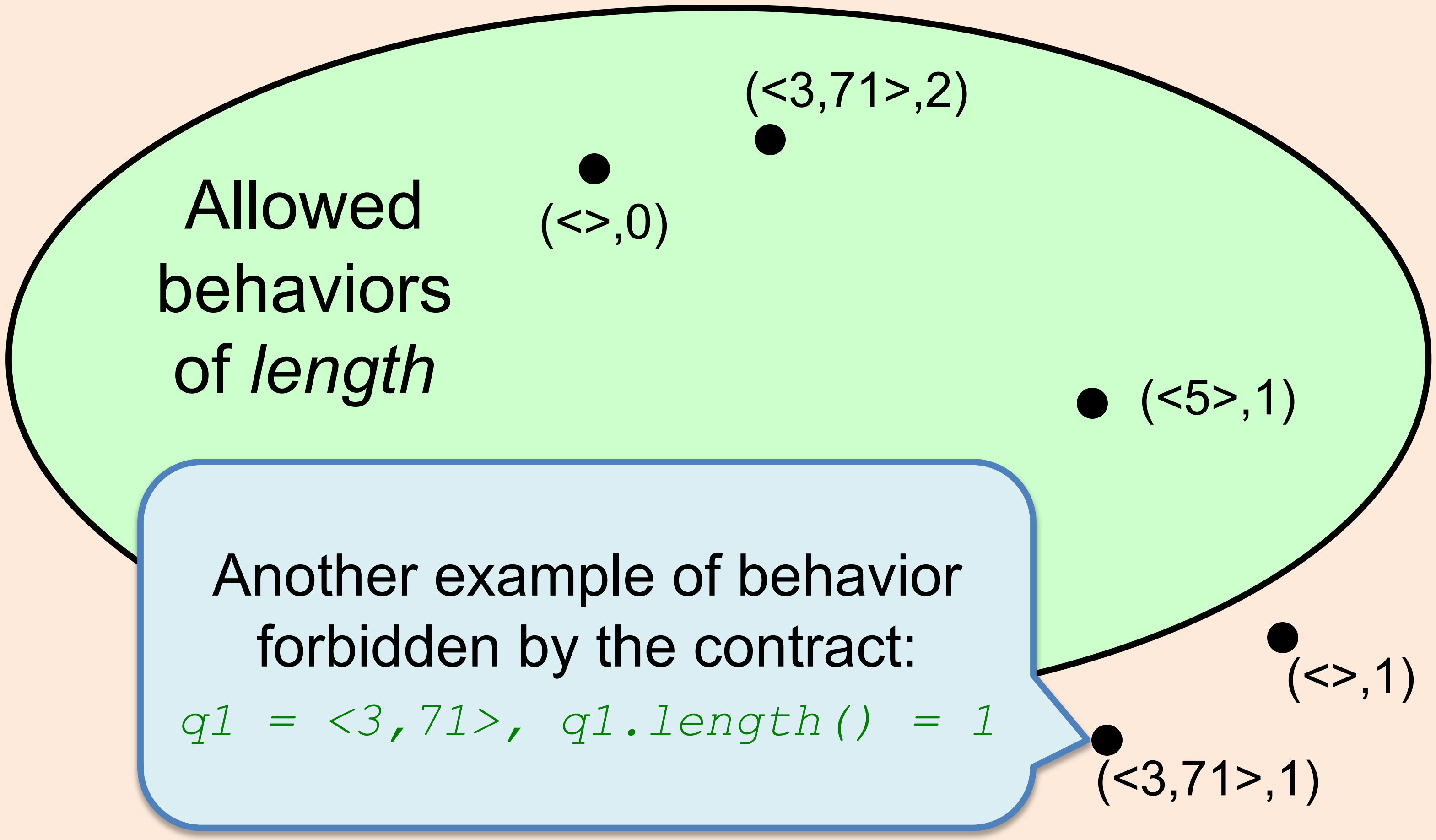
length's Behavior



Two more examples of allowed behavior:

```
q1 = <3,71>, q1.length() = 2
  q1 = <5>, q1.length() = 1
```

length's Behavior

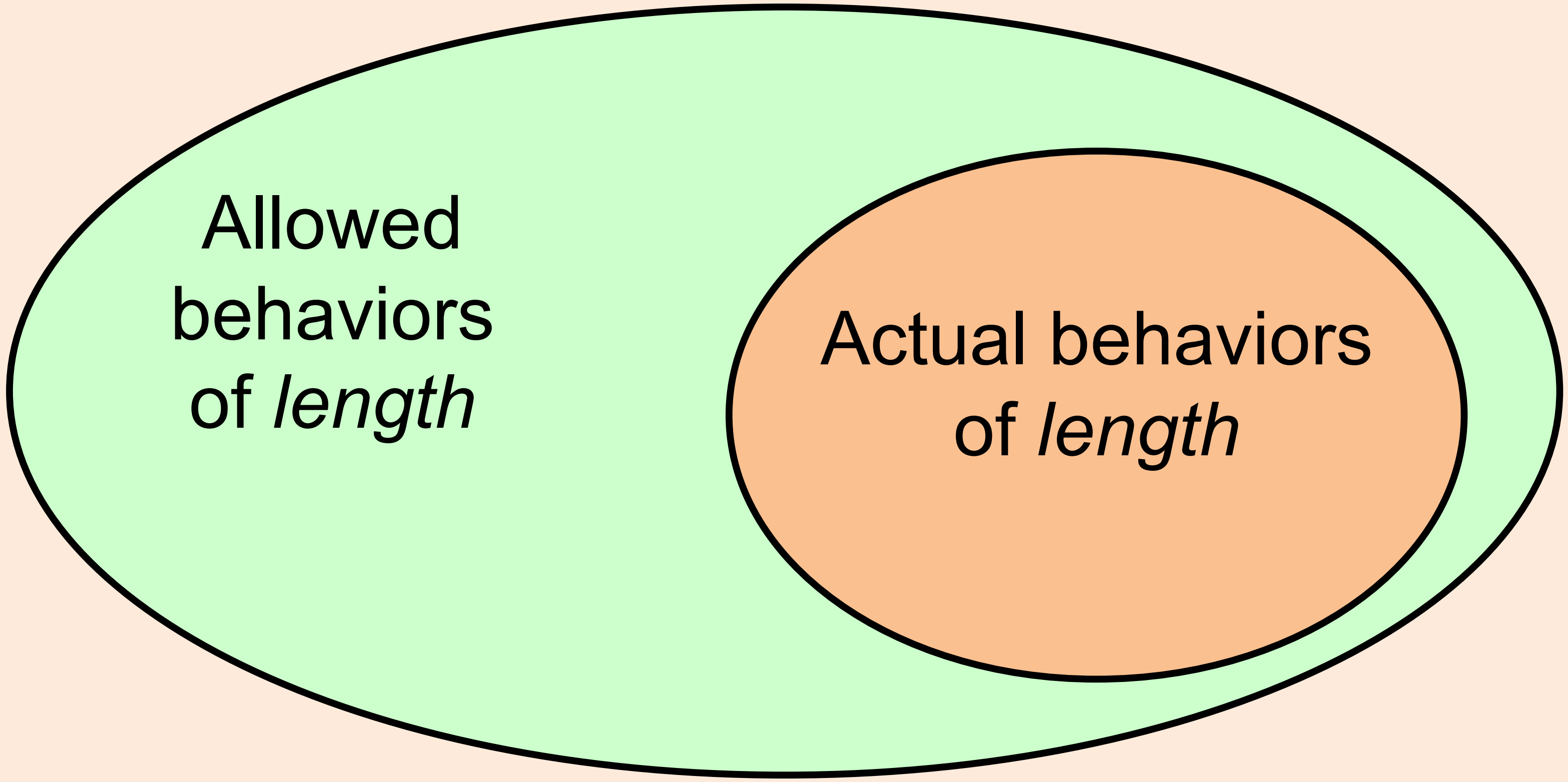


Another example of behavior forbidden by the contract:

`q1 = <3,71>, q1.length() = 1`

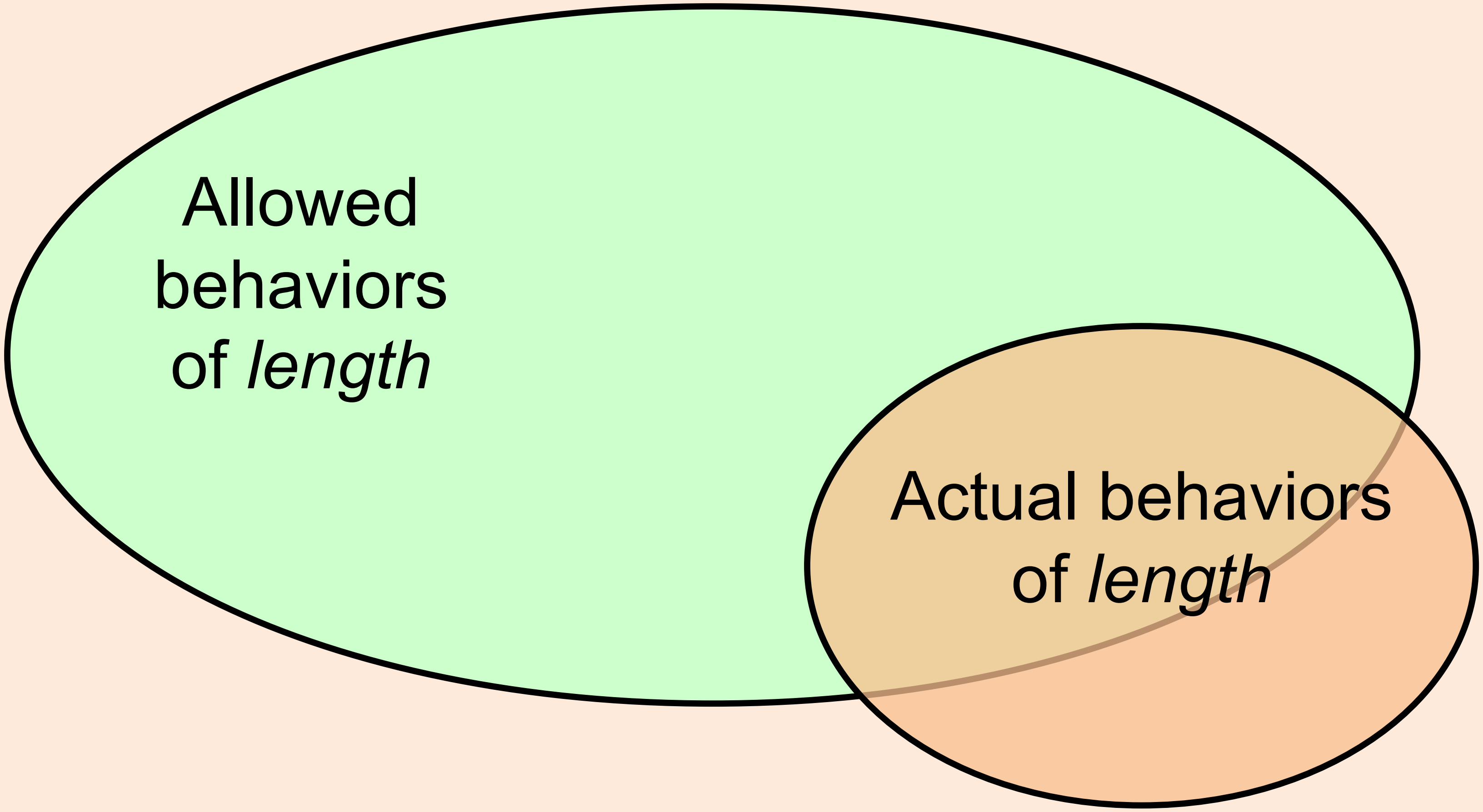
Definition of Correctness

- The implementation is ***correct*** if *actual* is a subset of *allowed*.



Definition of Defective Code

- The implementation is ***incorrect*** (or defective) if *actual* is not a subset of *allowed*.



A Possible Implementation of Queue's *length*

```
Integer length(void)
{
  return 1;
} // length
```

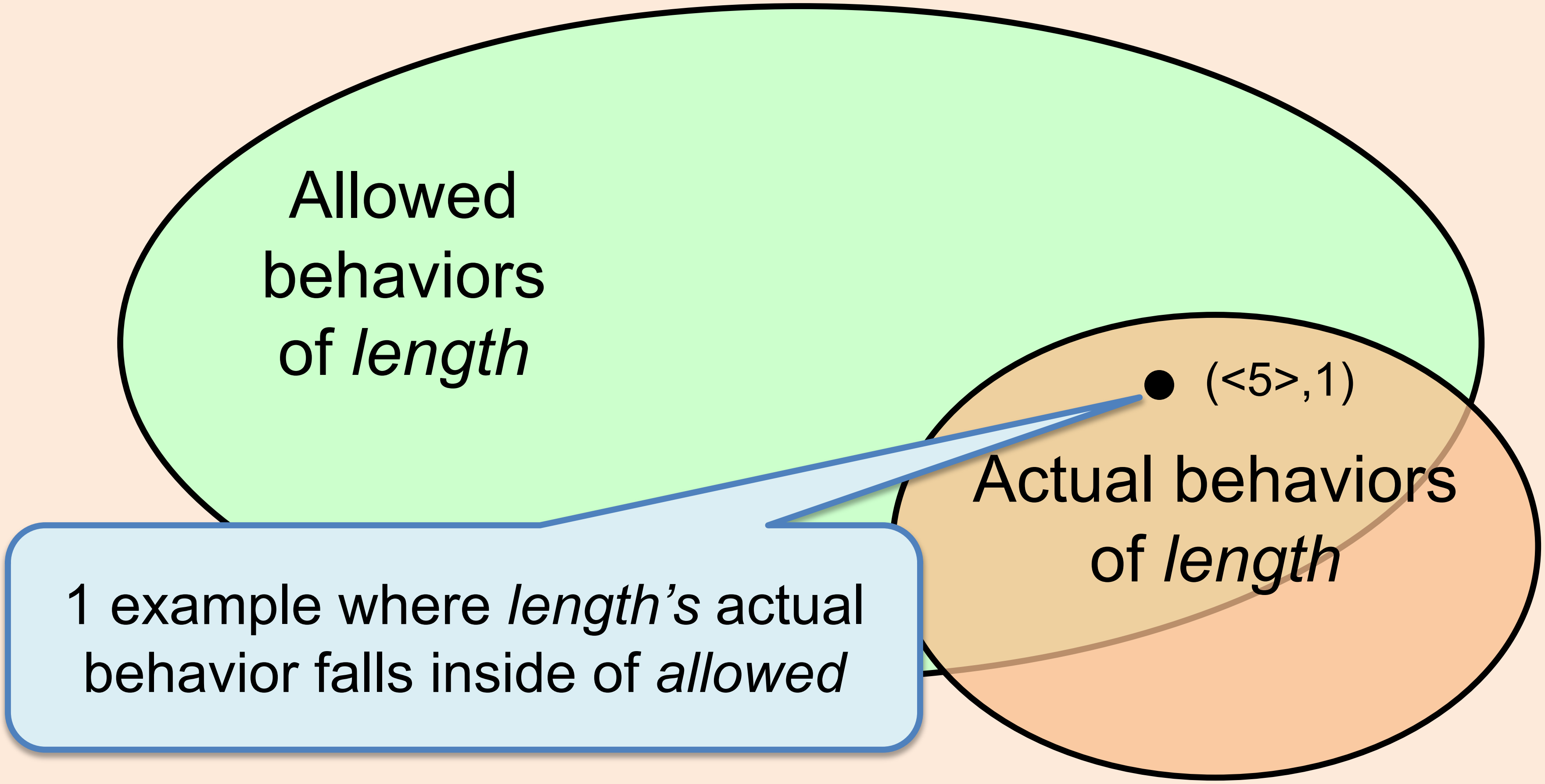
A Possible Implementation of Queue's *length*

```
Integer length(void)
{
  return 1;
} // length
```

This implementation always returns 1

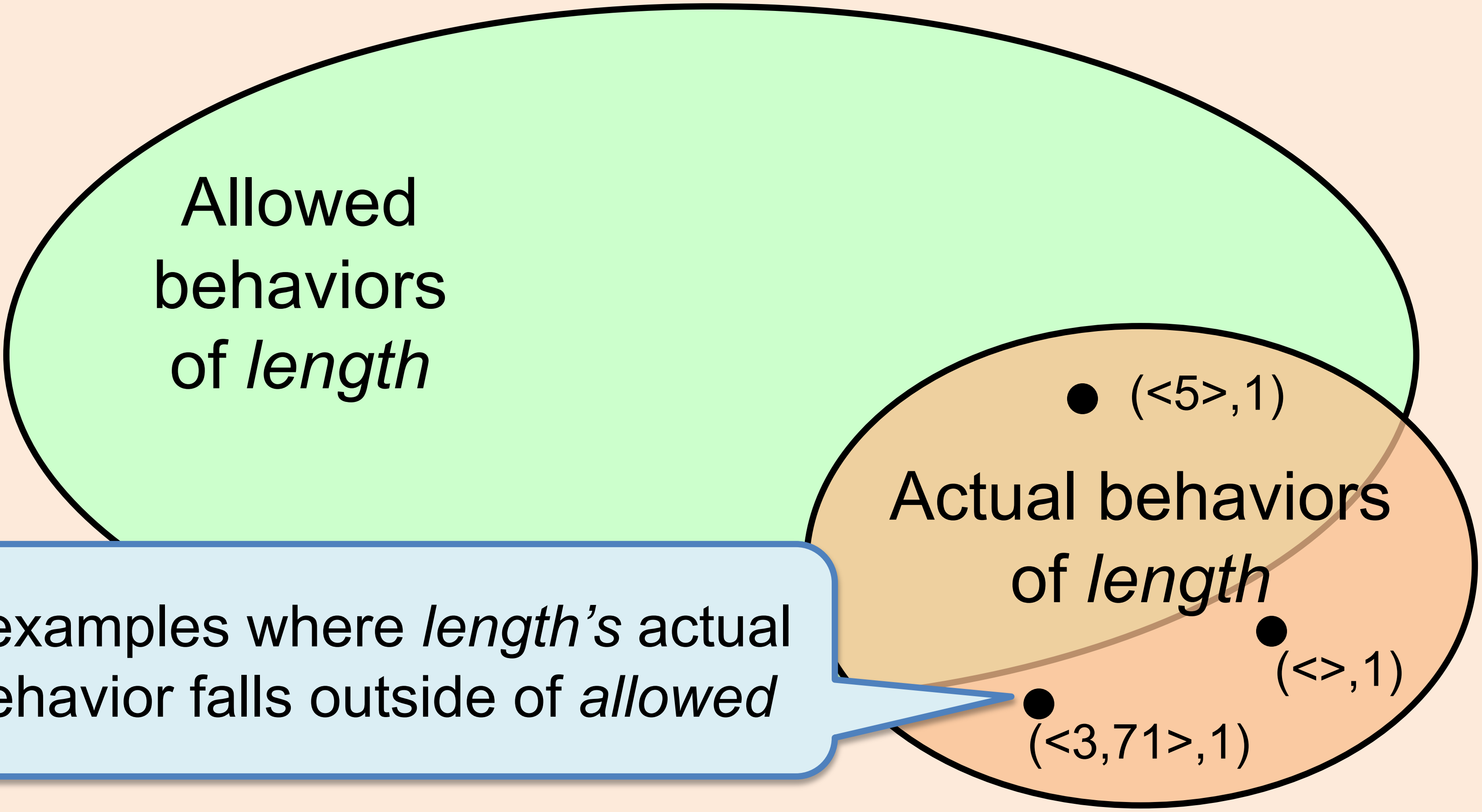
Is this implementation correct?

Defective Implementation



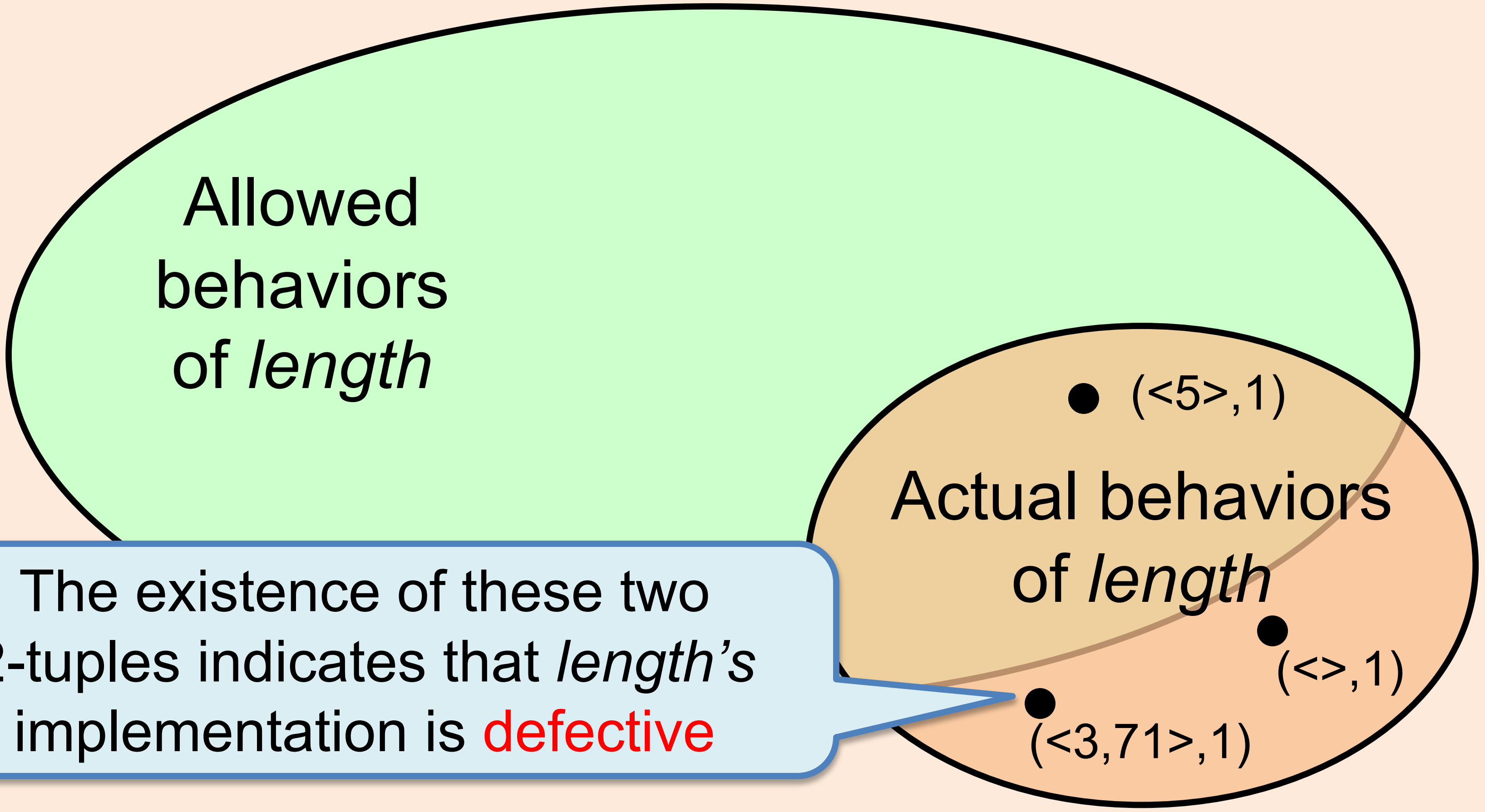
1 example where *length's* actual behavior falls inside of *allowed*

Defective Implementation



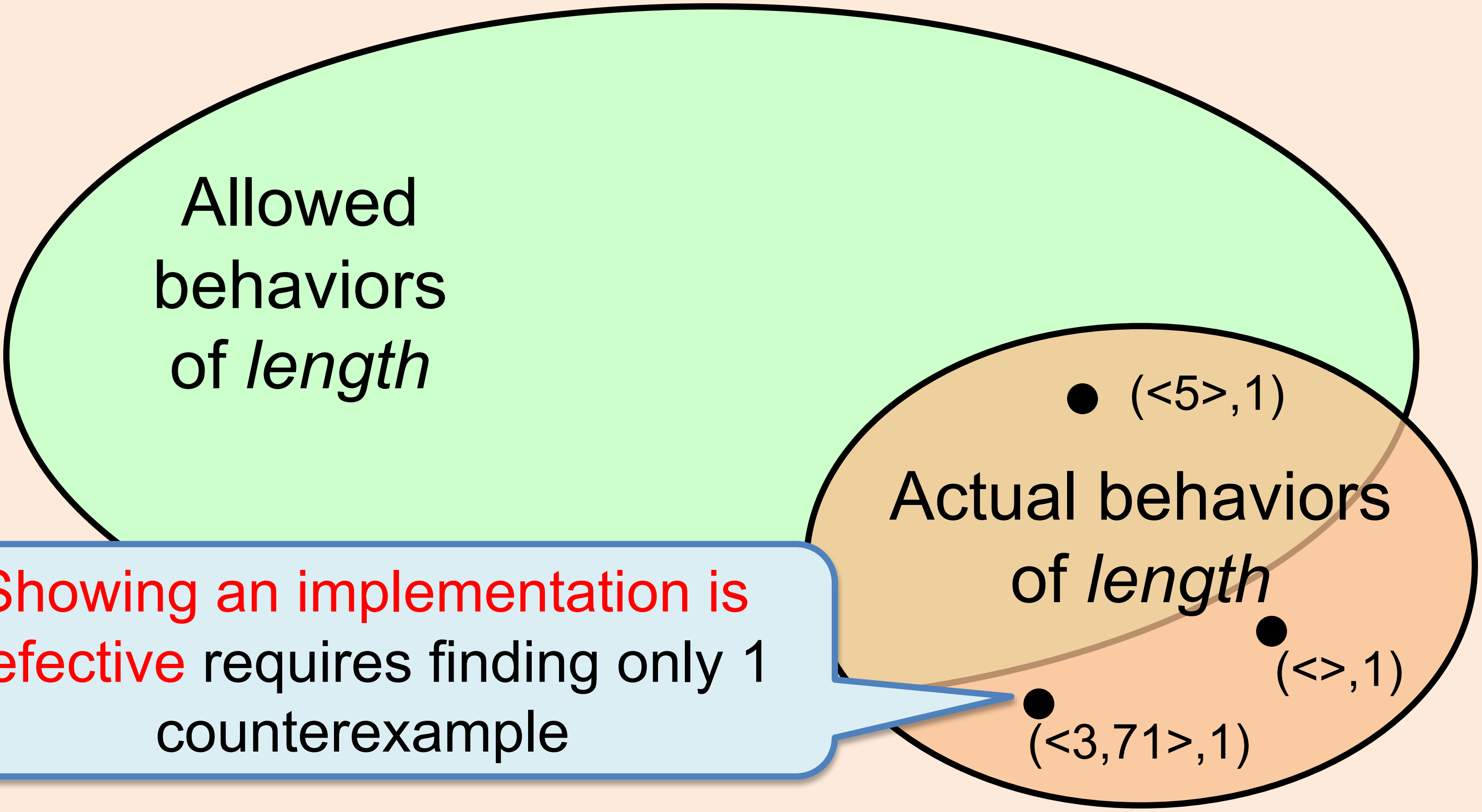
2 examples where *length's* actual behavior falls outside of *allowed*

Defective Implementation



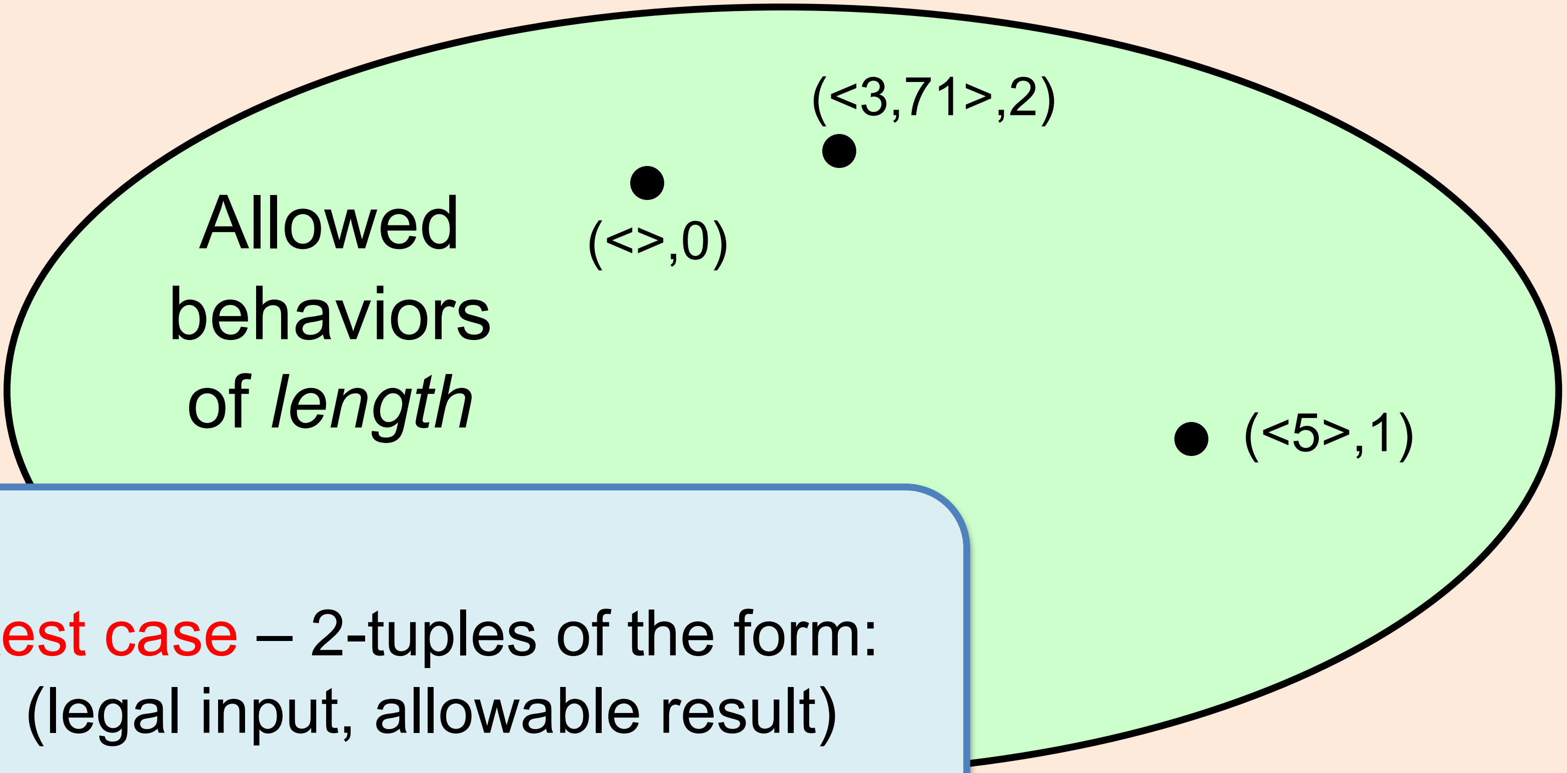
The existence of these two 2-tuples indicates that *length's* implementation is defective

Defective Implementation



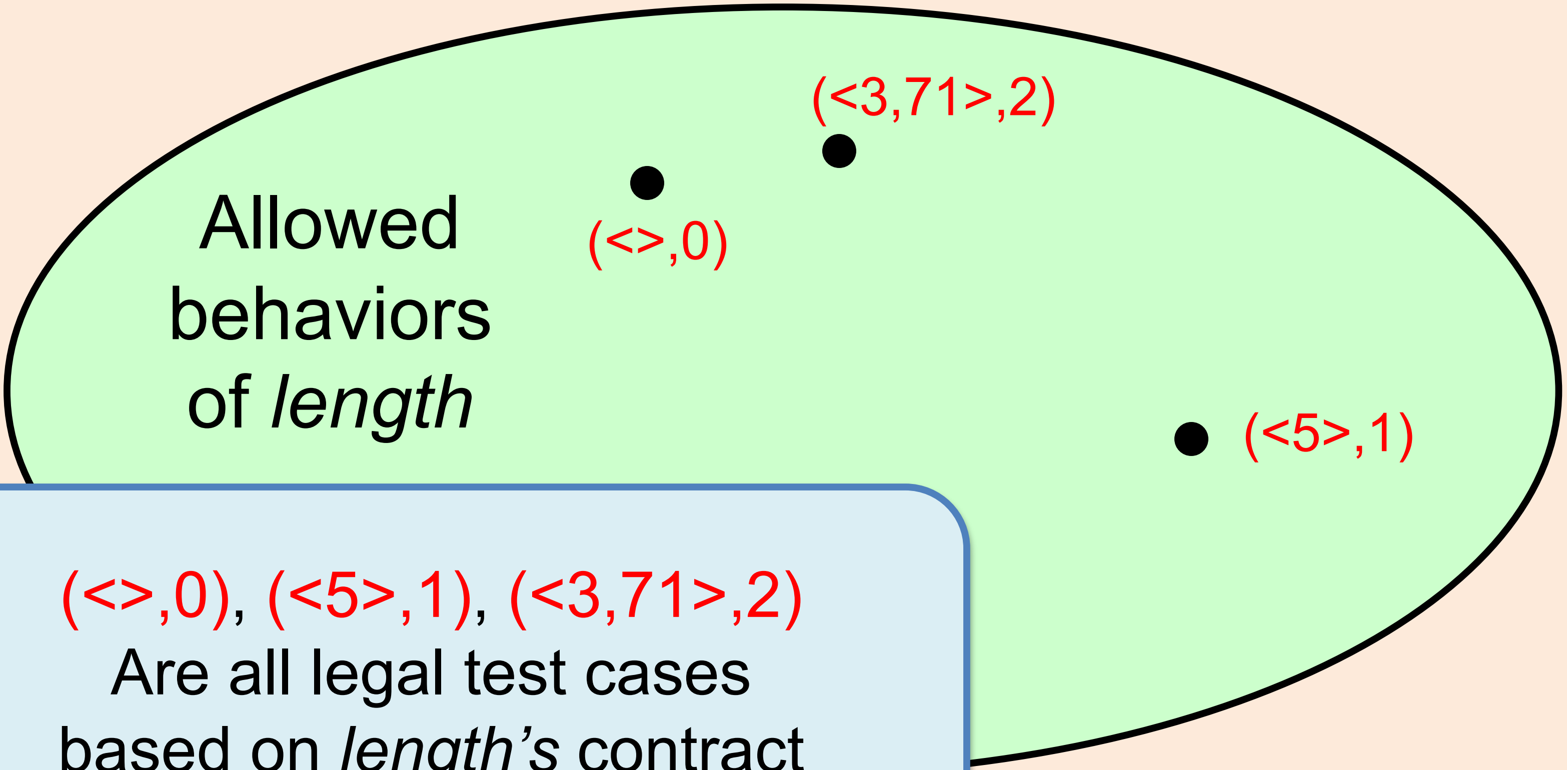
Showing an implementation is defective requires finding only 1 counterexample

Test Cases



test case – 2-tuples of the form: (legal input, allowable result)

Test Cases



(<>,0), (<5>,1), (<3,71>,2)
Are all legal test cases based on *length's* contract

Testing Concepts

- ***actual behavior space*** – consists of all 2-tuples of the form (legal input, allowable result) and (legal input, not allowable result)
- ***allowable result*** – an output from an operation’s implementation satisfying the operation’s ensures clause
- ***allowed behavior space*** – consists of 2-tuples of the form (legal input, allowable result)
- ***correct implementation*** – when the actual behavior space is a subset of the allowed behavior space
- ***counterexample*** – consists of a 2-tuple of the form (legal input, not allowable result)
- ***defective implementation*** – when the actual behavior space is not a subset of the allowed behavior space
- ***integration testing*** – when a subsystem comprising multiple classes are under test
- ***legal input*** – an input to an operation satisfying the operation’s requires clause
- ***not allowable result*** – an output from an operation’s implementation (on a legal input) that does not satisfy the operation’s ensures clause
- ***showing an implementation is defective*** – requires finding only one counterexample
- ***system testing*** – when the entire end-user system is under test
- ***test case*** – consists of a 2-tuple of the form (legal input, allowable result) based on the unit under test’s contract
- ***unit testing*** – testing one operation at a time
- ***unit under test*** – the operation being tested

Credits

- These slides were adapted from slides obtained from Dr. Bruce W. Weide and Dr. Paolo Bucci.

- Drs. Weide & Bucci are members of the Resolve/Reusable Software Research Group (RSRG) which is part of the Software Engineering Group in the Department of Computer Science and Engineering at The Ohio State University.