Programming with Contracts in C++20

Björn Fahller

What is a contract?

contract

noun con·tract | \ˈkän-ˌtrakt \

Definition of contract

(Entry 1 of 3)

1:

a: binding agreement between two or more persons or parties - especially : one legally enforceable
// If he breaks the contract, he'll be sued.

b: a business arrangement for the supply of goods or services at a fixed price
// make parts on contract

c: the act of marriage or an agreement to marry

2: a document describing the terms of a contract
// Have you signed the contract yet?

3: the final bid to win a specified number of tricks in bridge

4: an order or arrangement for a hired assassin to kill someone
// His enemies put out a contract on him.

`https://www.merriam-webster.com/dictionary/contract`

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In SW design:

A formalised agreement, regarding program correctness, between a user and the implementation of a component.

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A formalised agreement, **regarding program correctness**, between a user and the implementation of a component.

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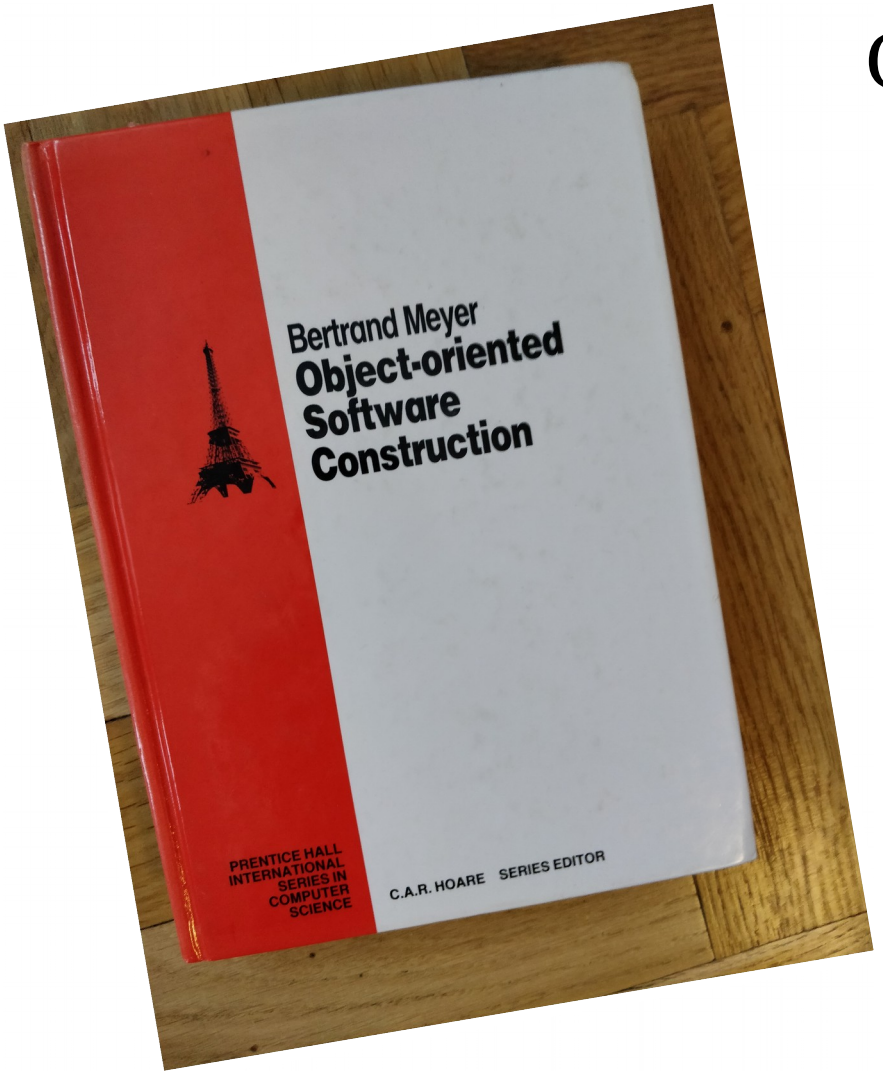
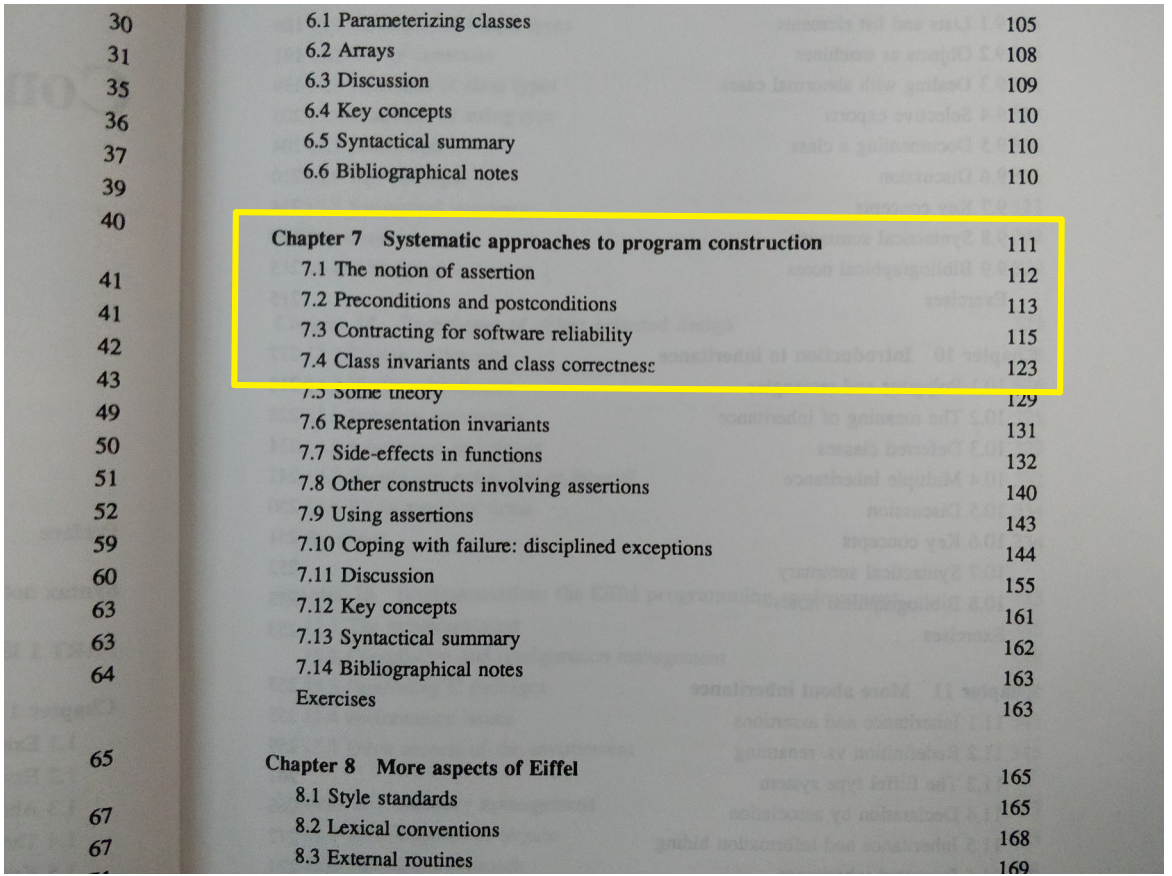


Contracts

- Object-oriented Software Construction
  - Bertrand Meyer - 1988
  - ISBN 978-0136290490

Contracts

- Preconditions
- Postconditions
- Class invariants



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Ringbuffer example

```
ringbuffer <int,12> b;
b.push_back(1);
b.push_back(2);
b.push_back(5);
b.pop_front(); // 1
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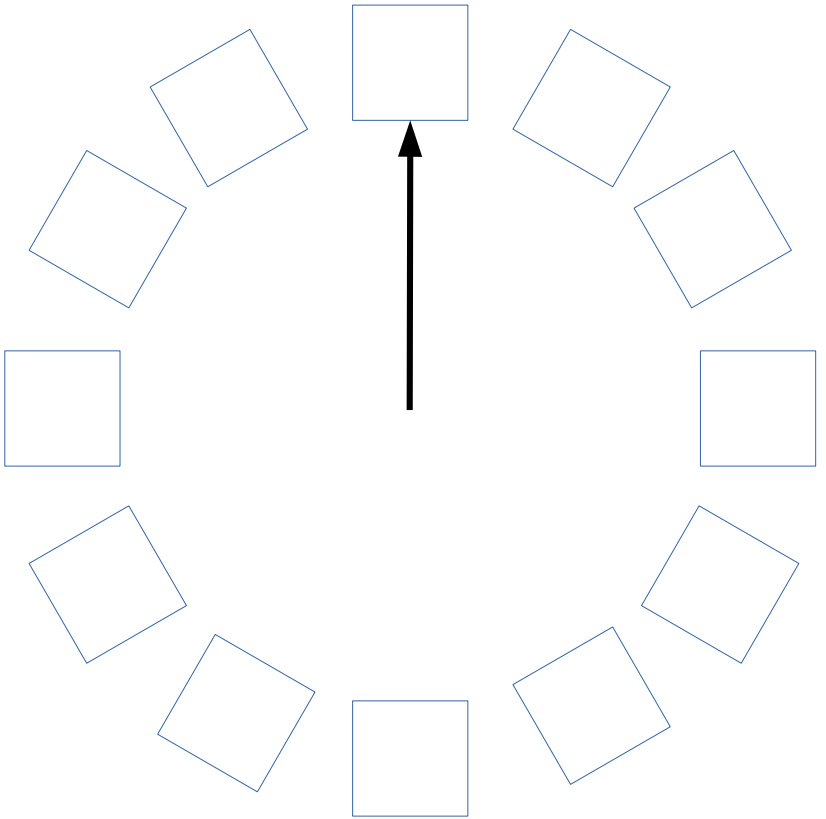

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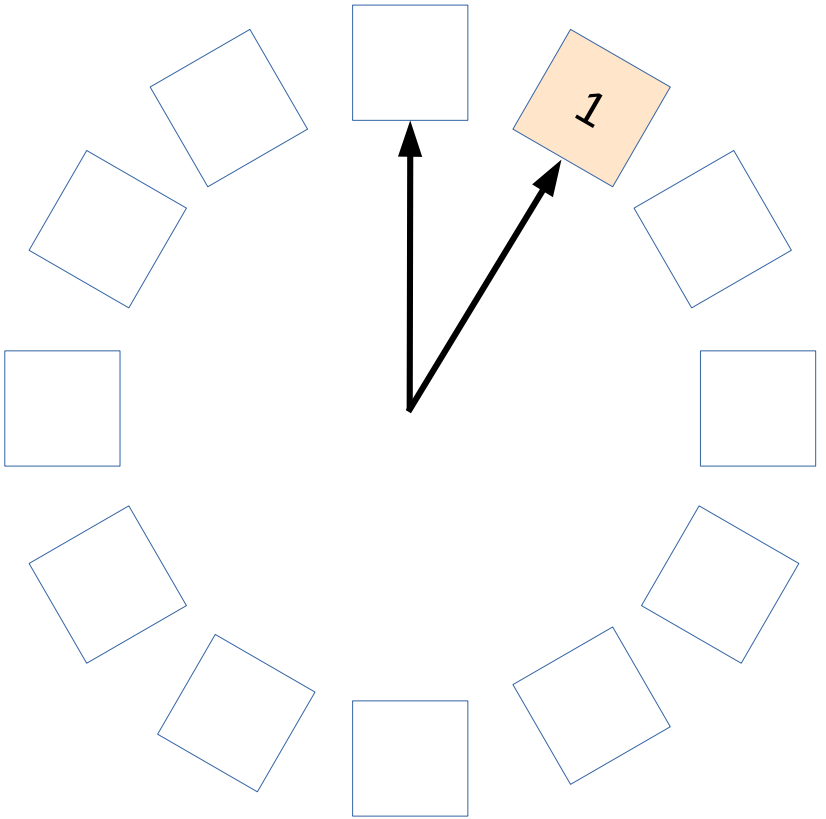

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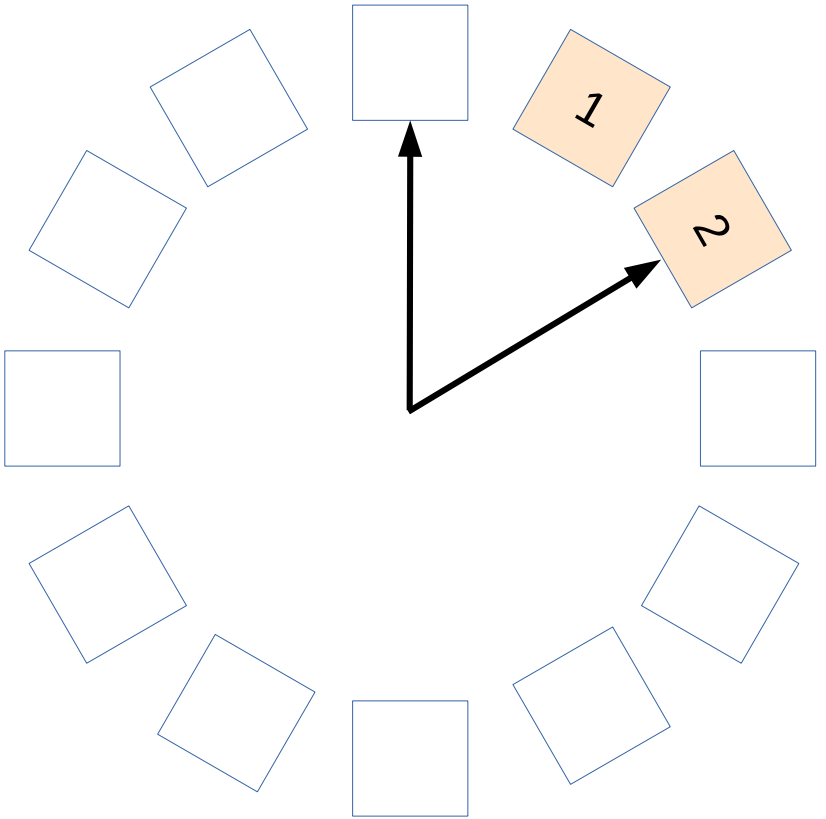

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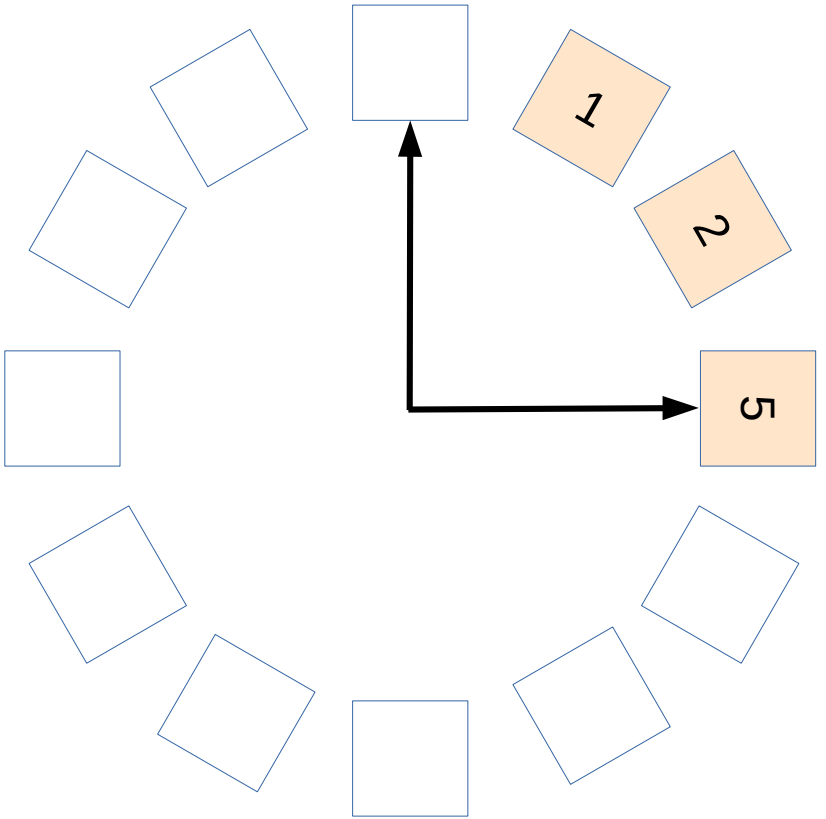

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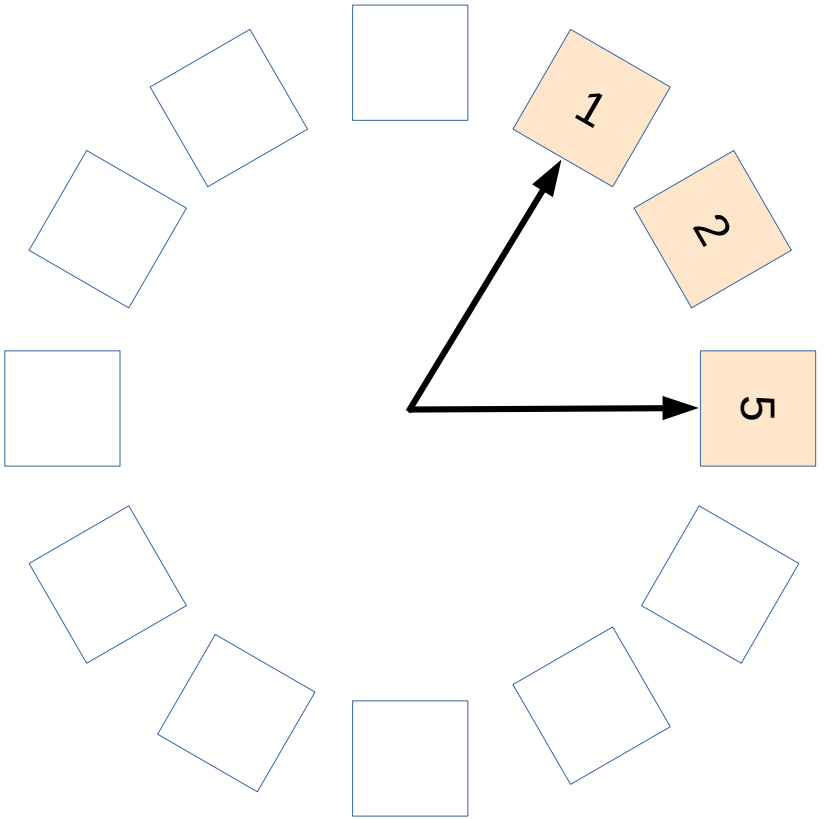

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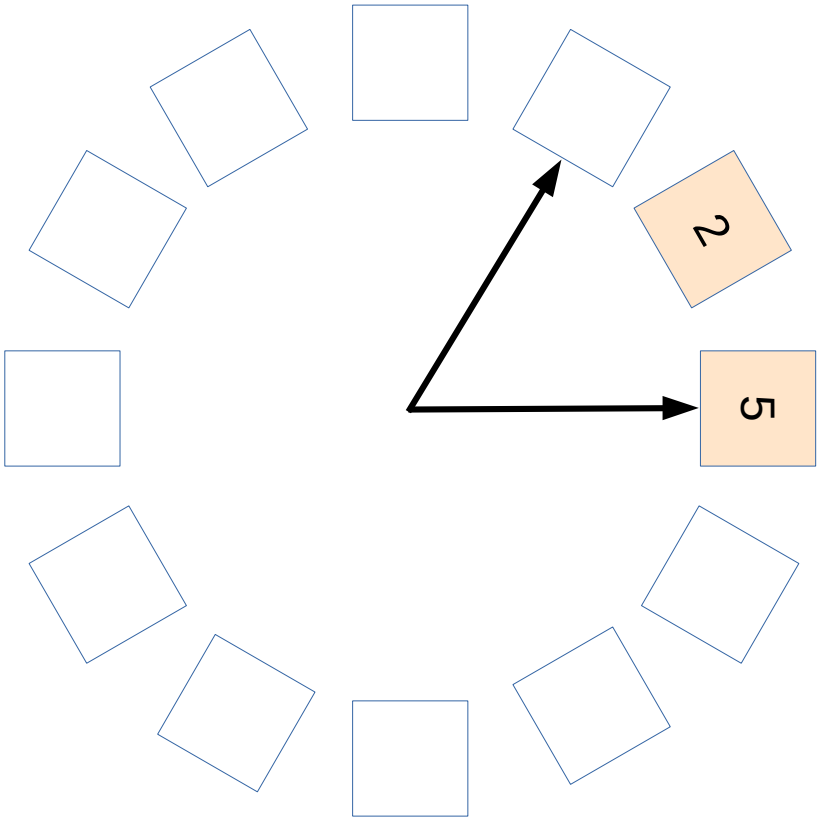

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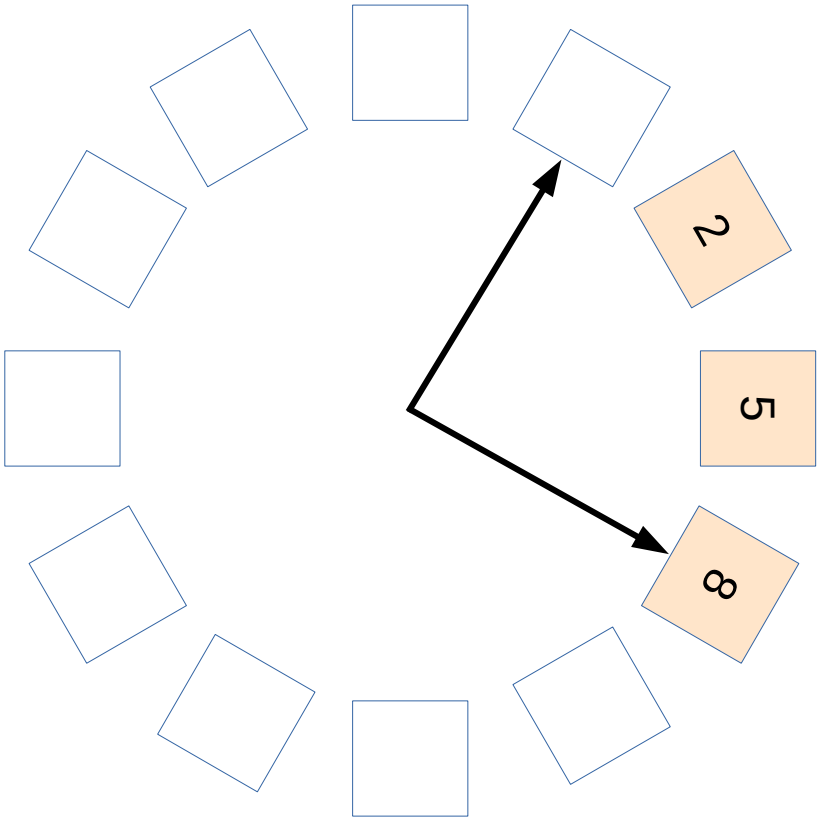

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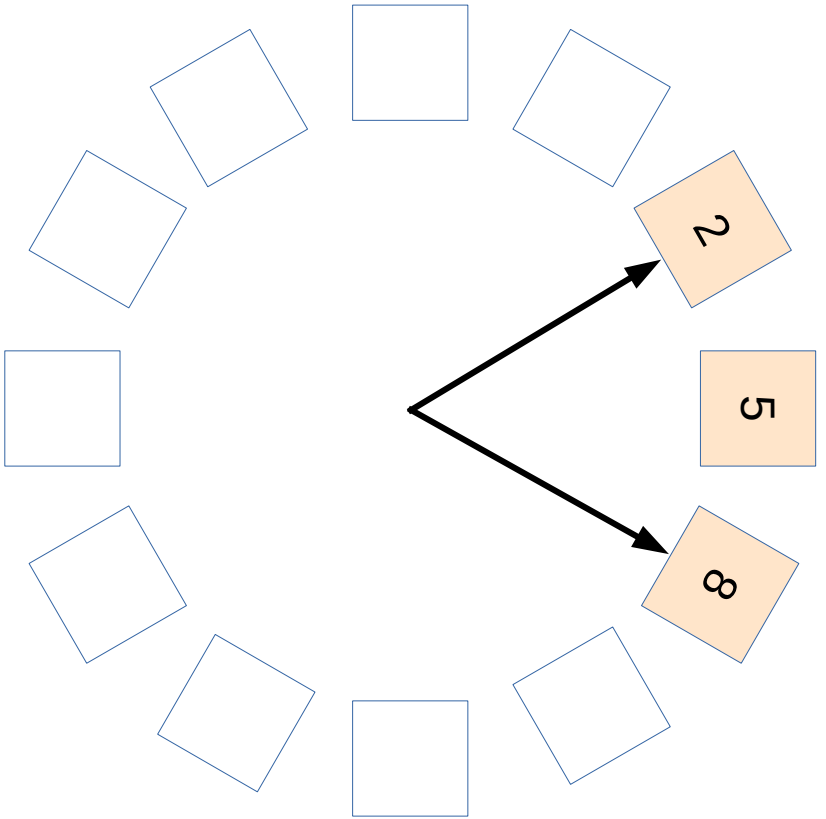

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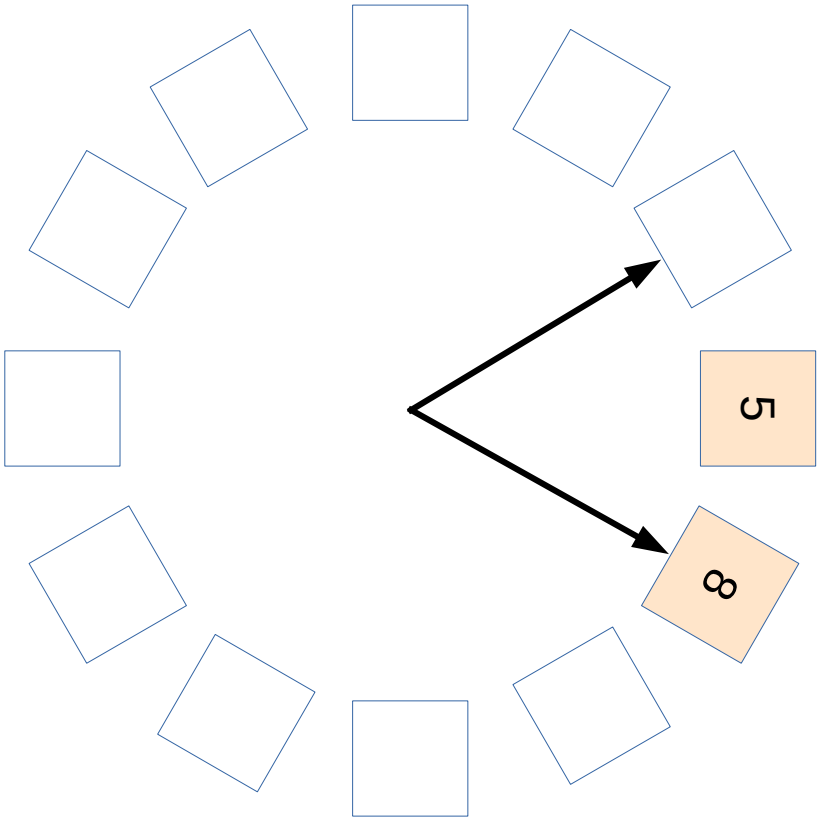

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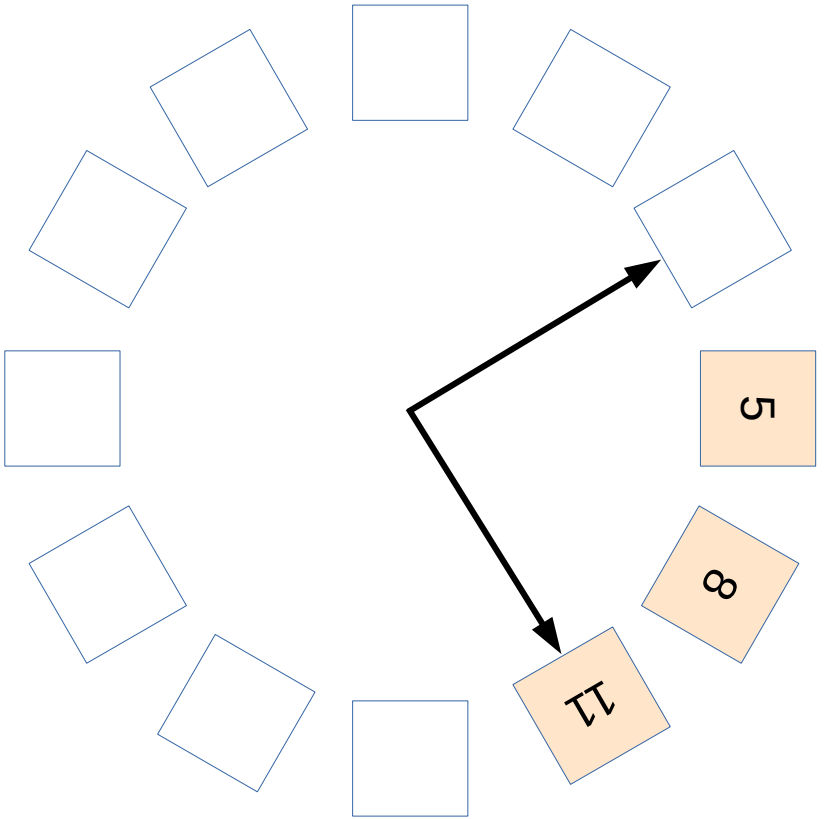

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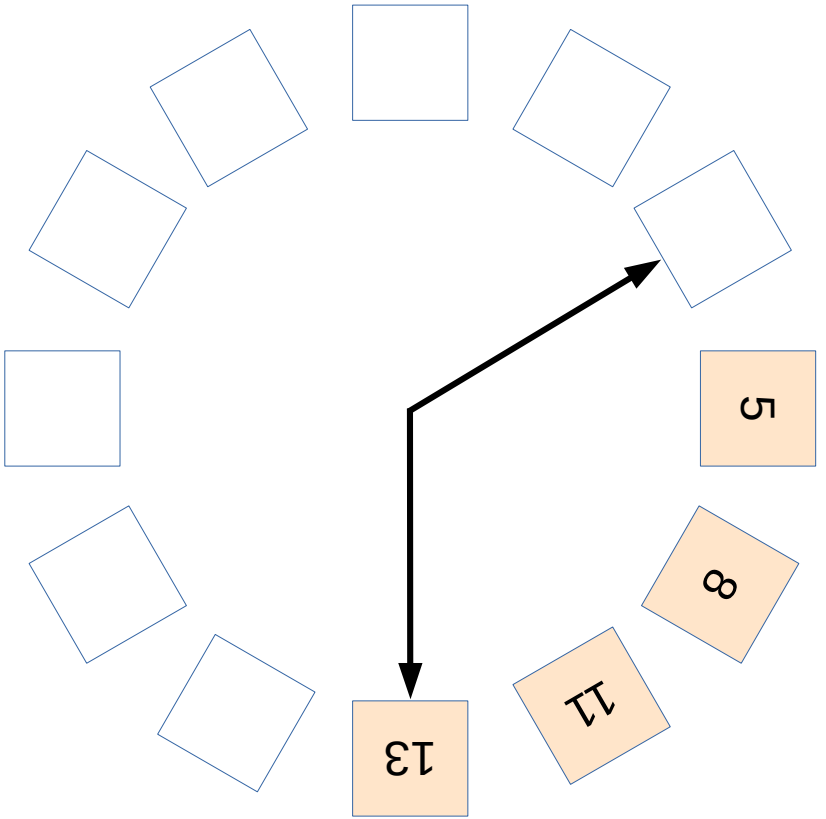

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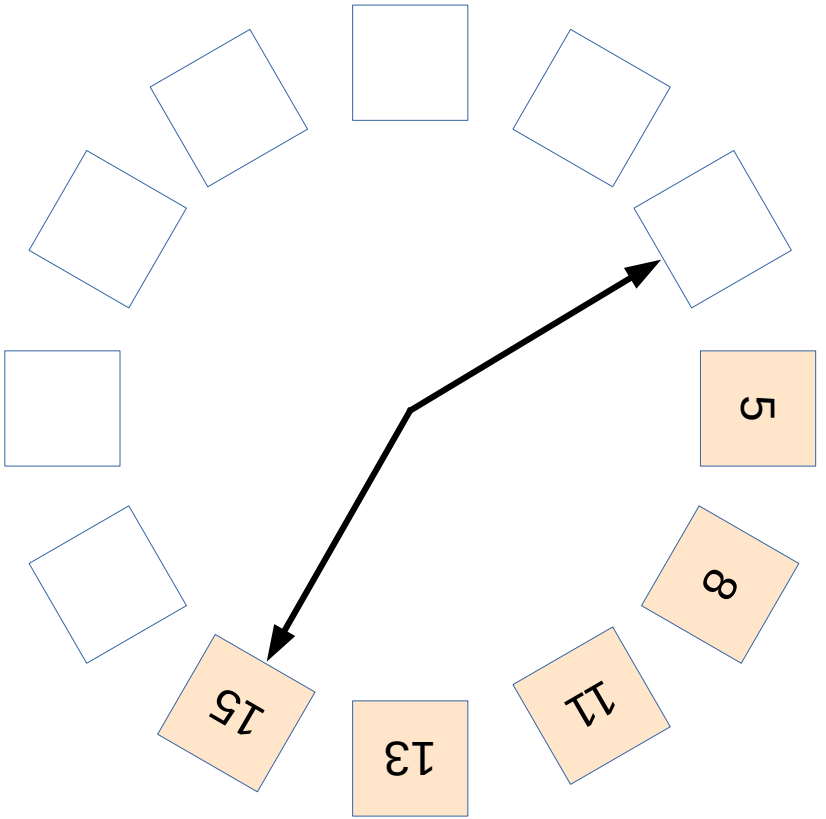

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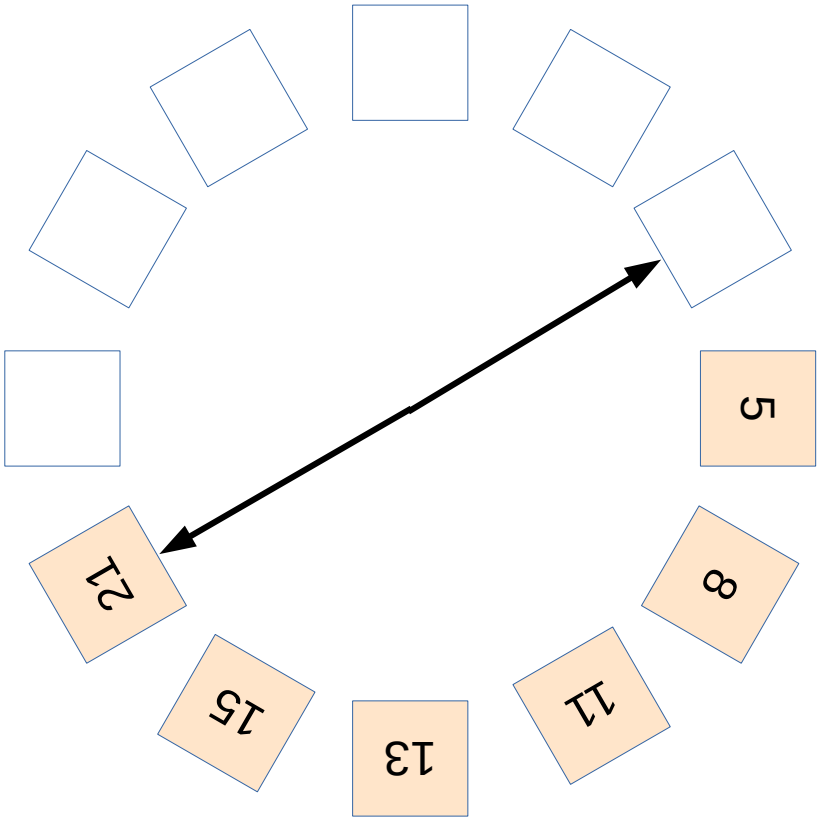

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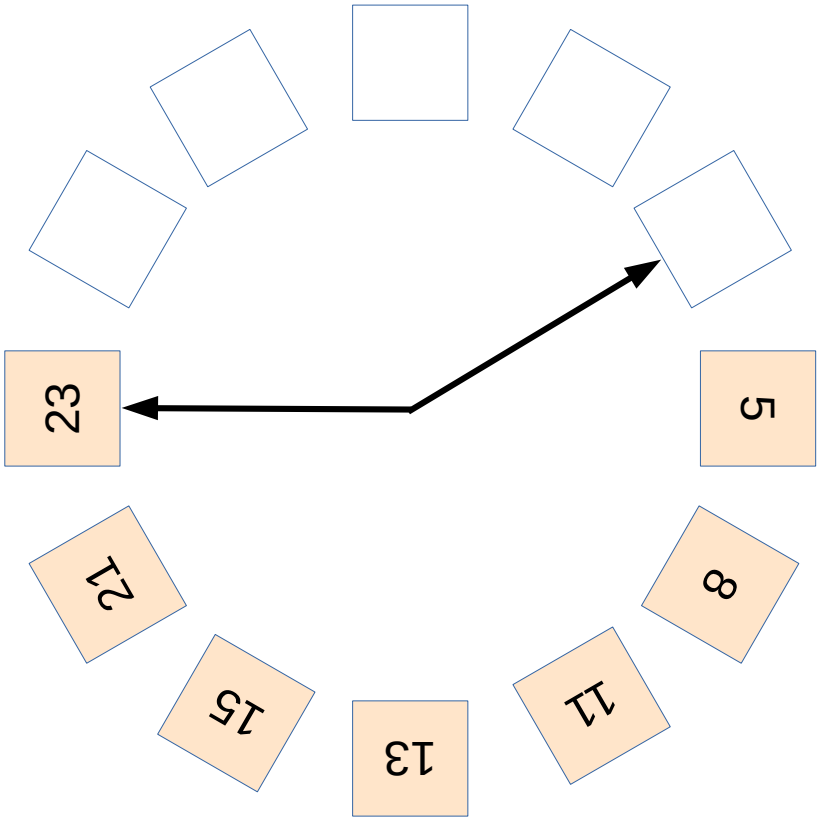

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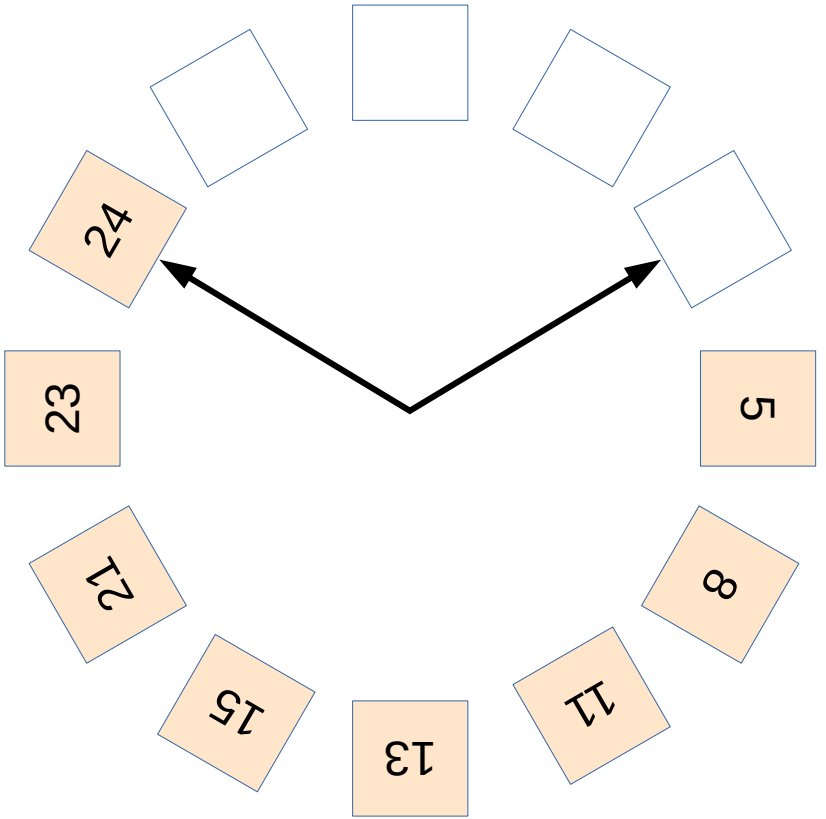


Ringbuffer example

```
template <typename T, int N>
class ringbuffer {
public:

  ringbuffer();

  int size() const;



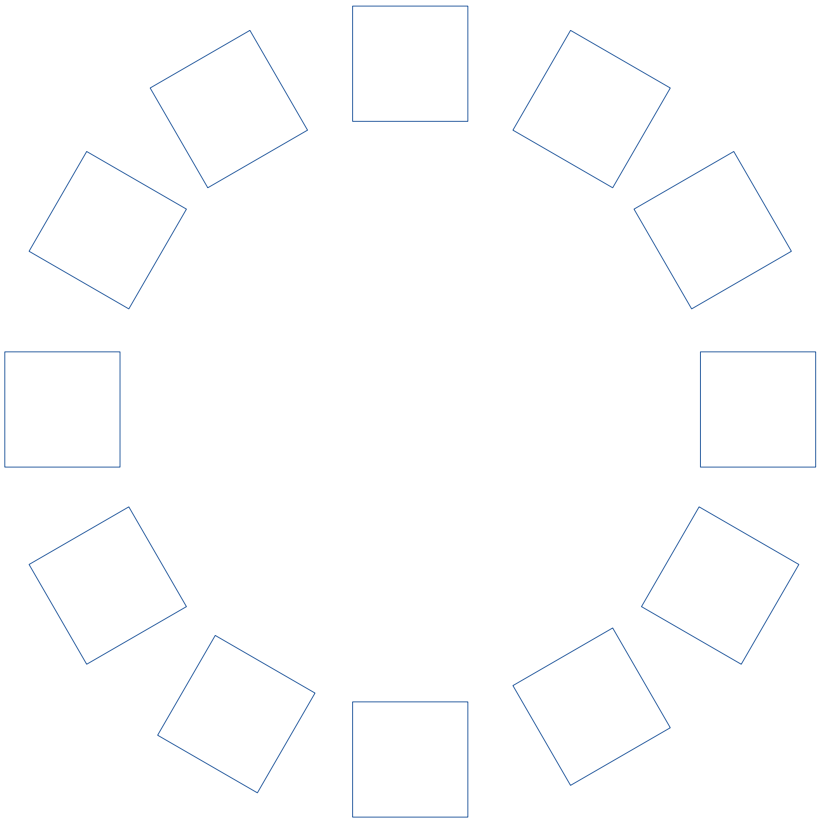

  void push_back(T);



  T pop_front();



};
```



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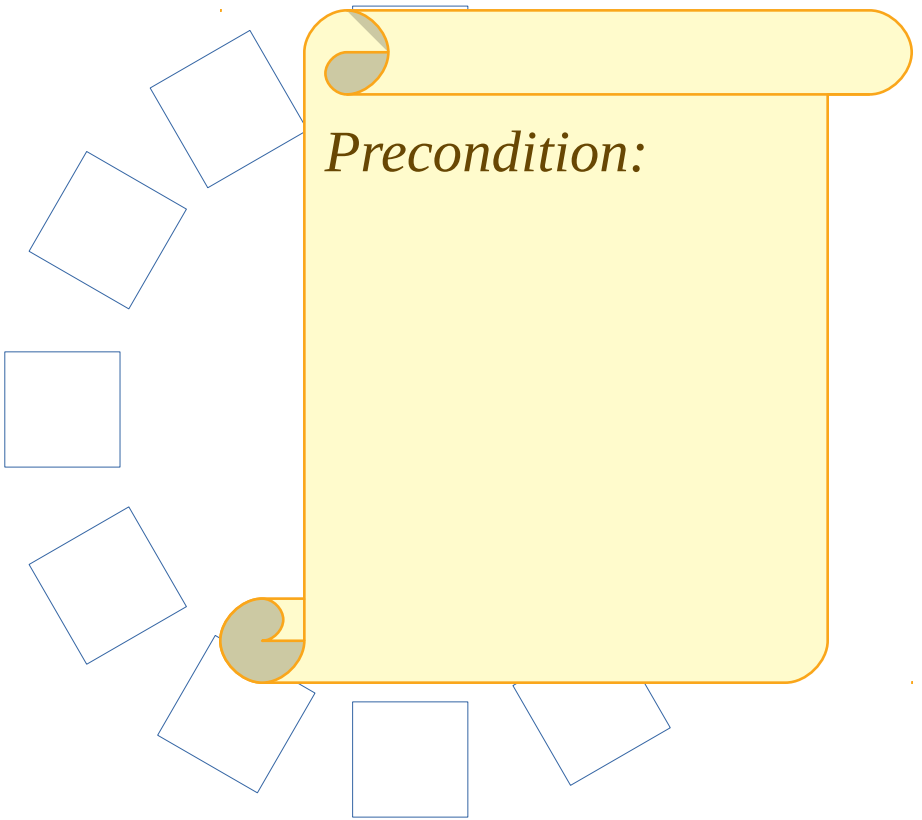

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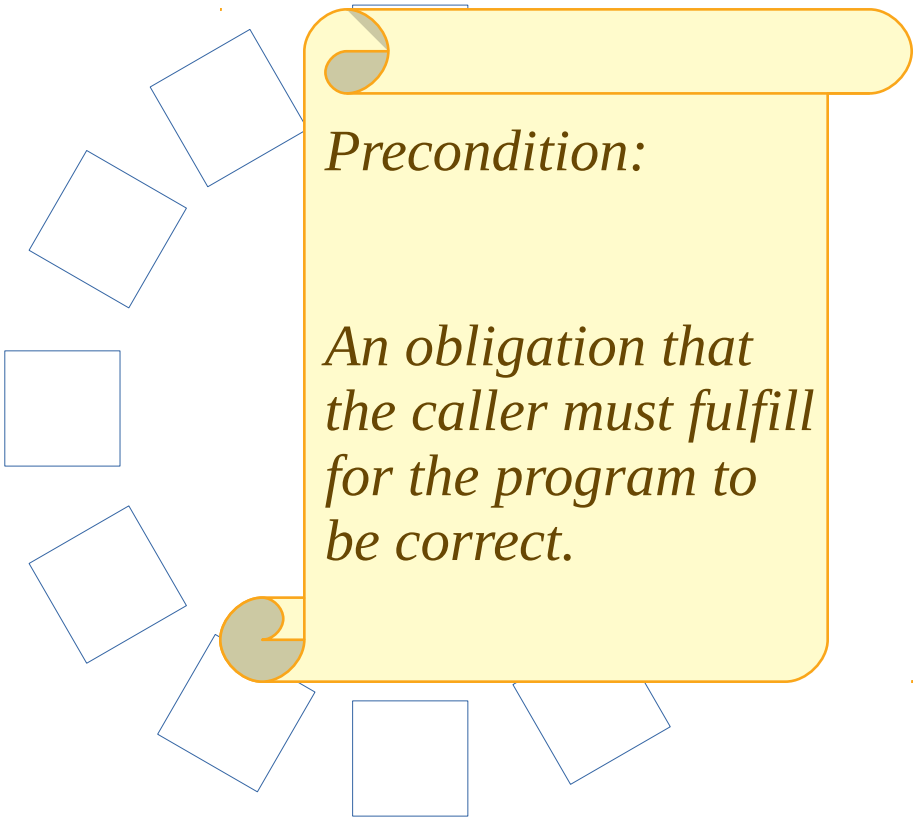

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public:

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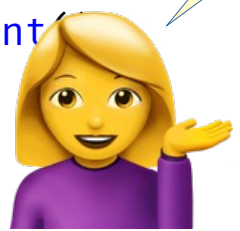
```

A precondition may refer to parameter values or the objects state, or both

Precondition:

An obligation that the caller must fulfill for the program to be correct.



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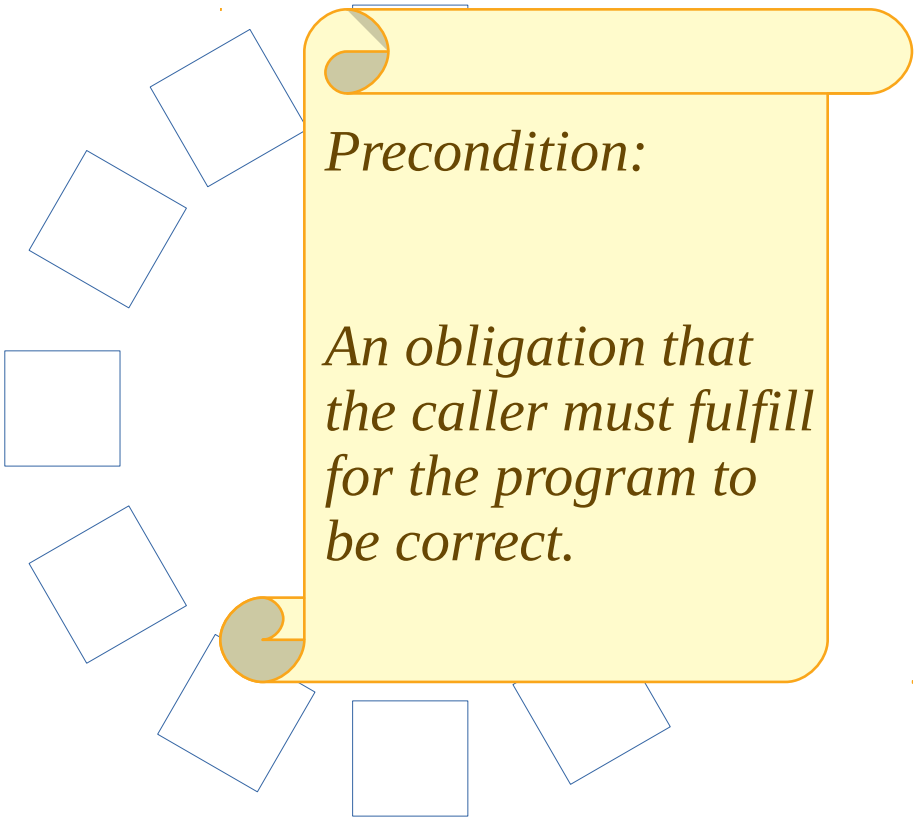

Ringbuffer example

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class ringbuffer {
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  void push_back(T);



  T pop_front();



};
```

It almost never makes sense to have a precondition on a default constructor!

Precondition:

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Ringbuffer example

```
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class ringbuffer {
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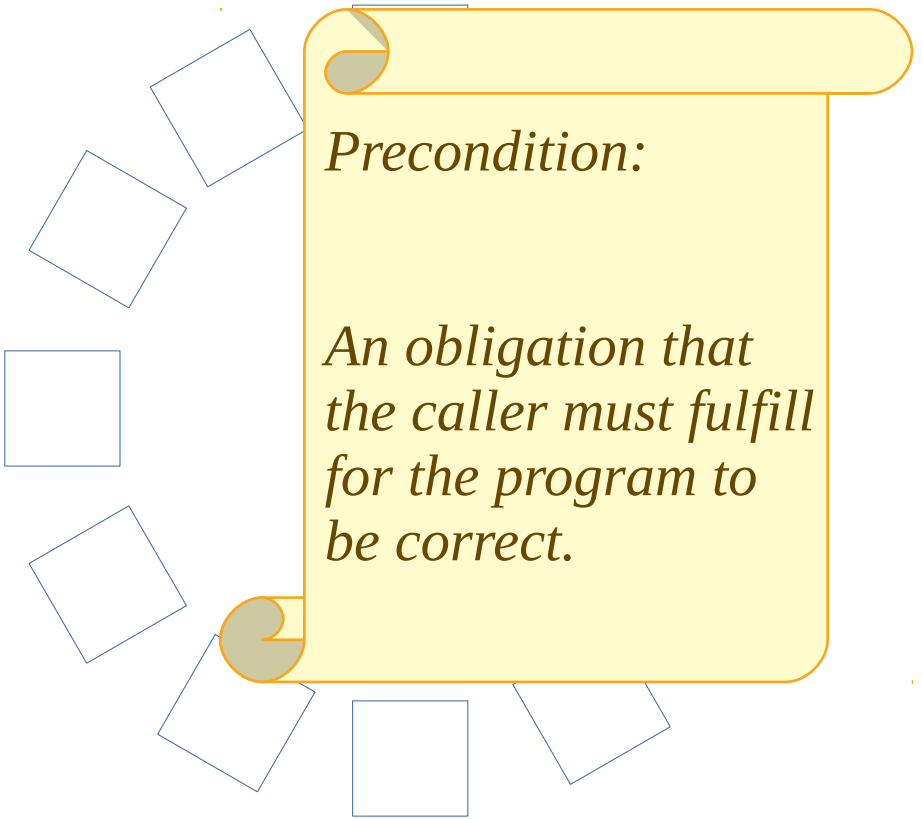

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};
```

Functions that query the state of an object rarely has any preconditions.

Precondition:

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Ringbuffer example

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class ringbuffer {
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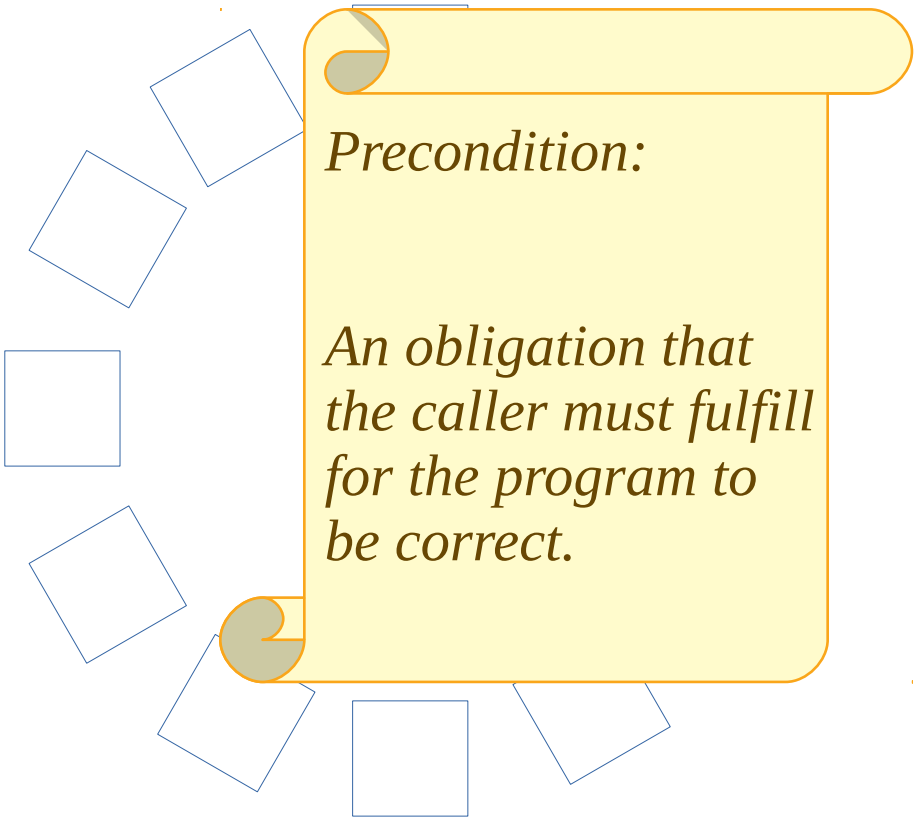

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```
template <typename T, int N>
class ringbuffer {
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  ringbuffer();

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  T pop_front();


};
```

Choose between:
Define behaviour when full, or make not-full a precondition.

Precondition:

An obligation that the caller must fulfill for the program to be correct.

Ringbuffer example

```
template <typename T, int N>
class ringbuffer {
public:

  ringbuffer();

  int size() const;

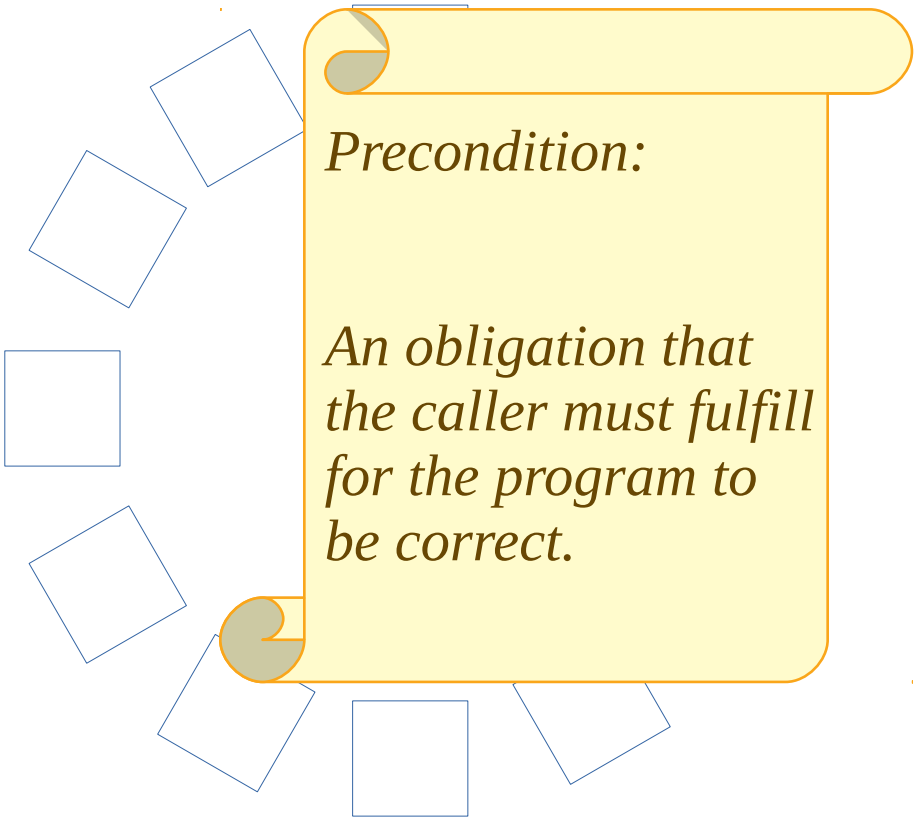


  void push_back(T);
  // requires: size() < N


  T pop_front();



};
```



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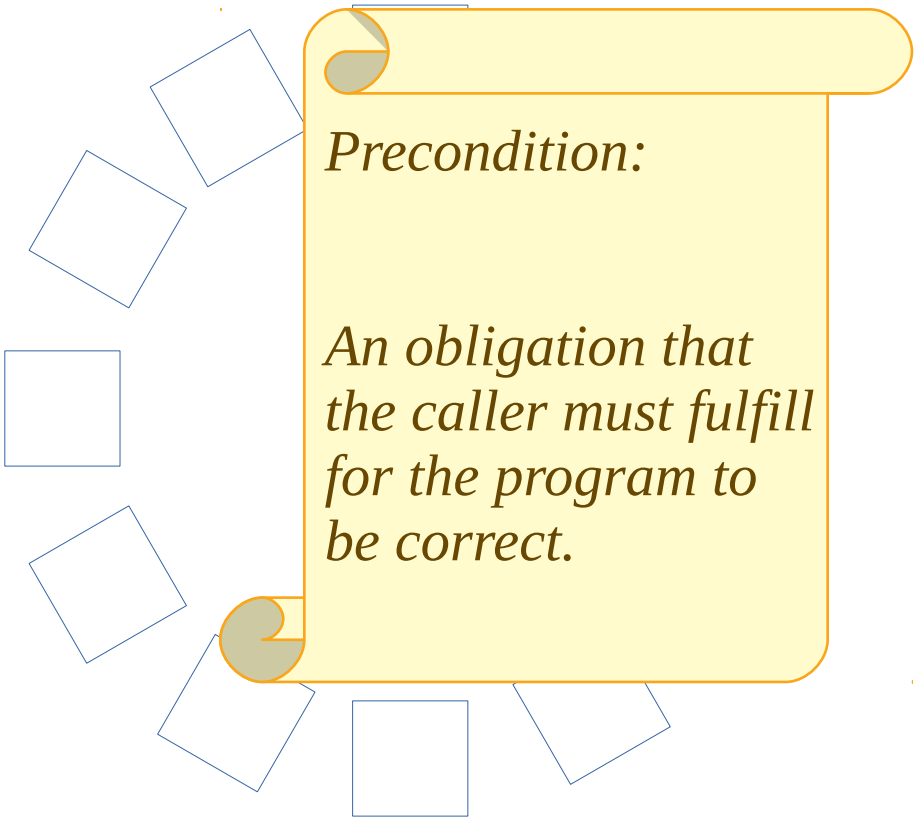

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};
```

Choose between:
Define behaviour when empty, or make not-empty a precondition.

Precondition:

An obligation that the caller must fulfill for the program to be correct.

Ringbuffer example

```
template <typename T, int N>
class ringbuffer {
public:

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  int size() const;




  void push_back(T);
  // requires: size() < N


  T pop_front();
  // requires: size() > 0

};
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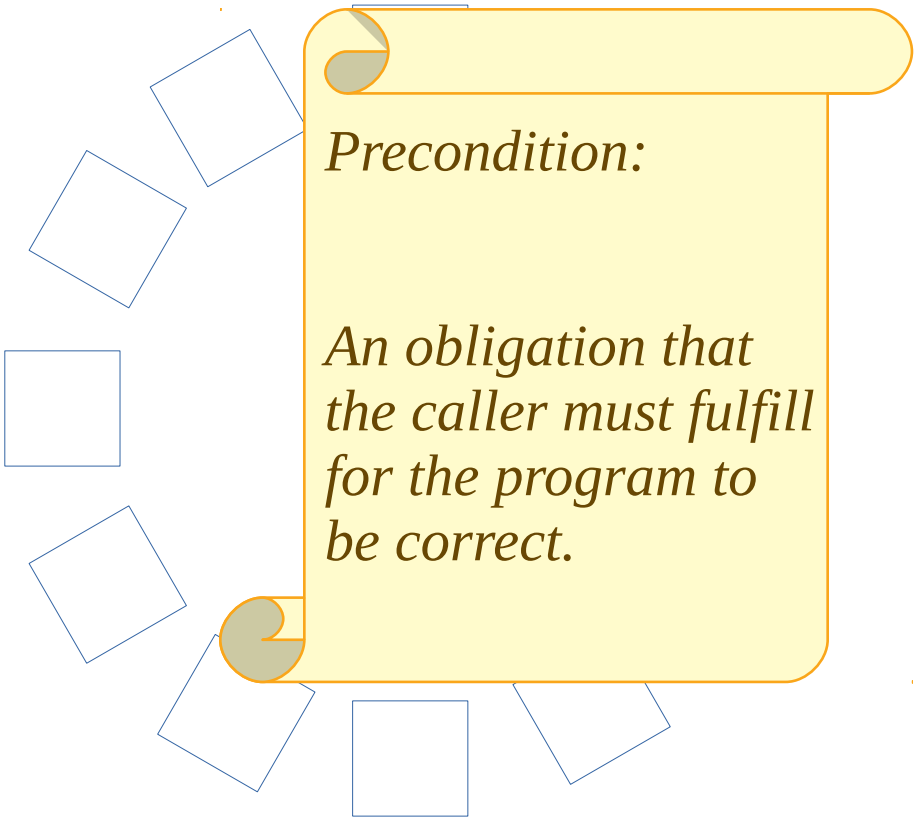

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};
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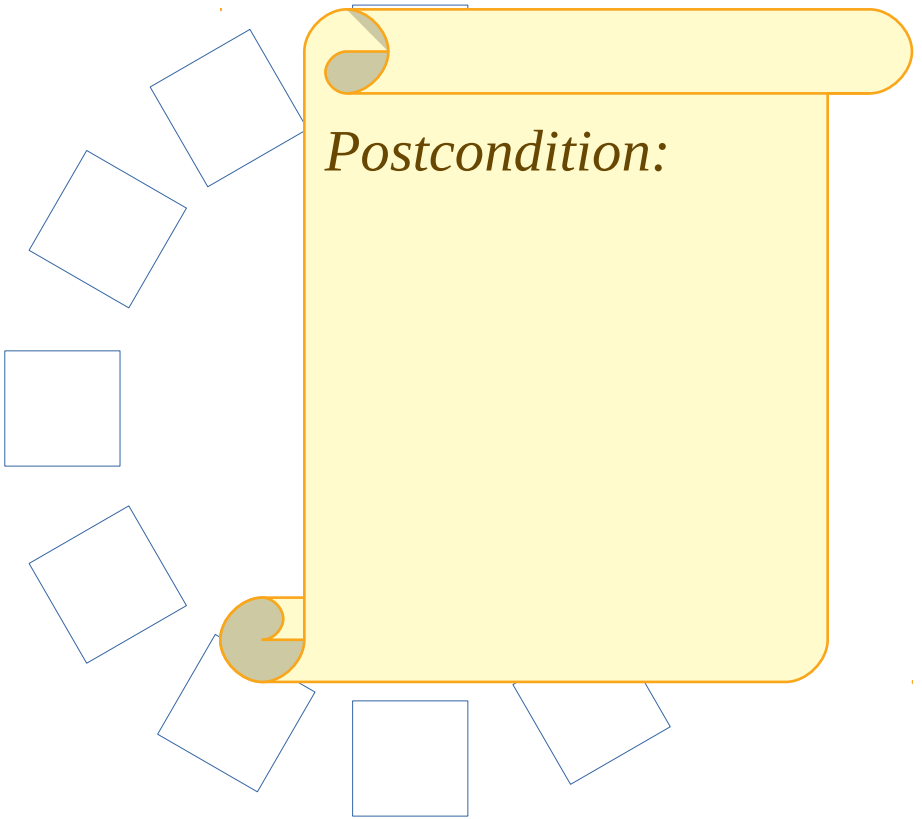

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  ringbuffer();

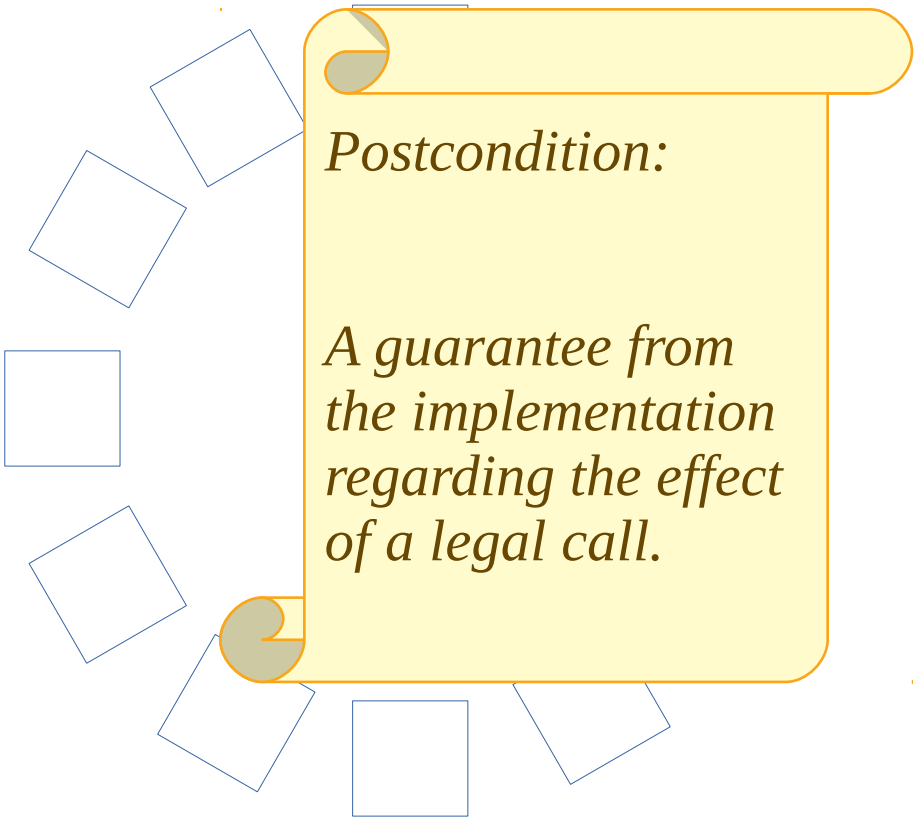
  int size() const;




  void push_back(T);
  // requires: size() < N


  T pop_front();
  // requires: size() > 0


};
```



Ringbuffer example

```
template <typename T, int N>
class ringbuffer {
public:

  ringbuffer();

  int size() const;




  void push_back(T);
  // requires: size()

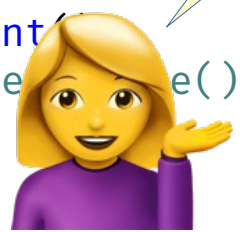

  T pop_front();
  // require      e() > 0


};
```

A postcondition may refer to return value or the objects state, or both, sometimes dependent on parameter values

Postcondition:

A guarantee from the implementation regarding the effect of a legal call.



Ringbuffer example

```
template <typename T, int N>
class ringbuffer {
public:

  ringbuffer();

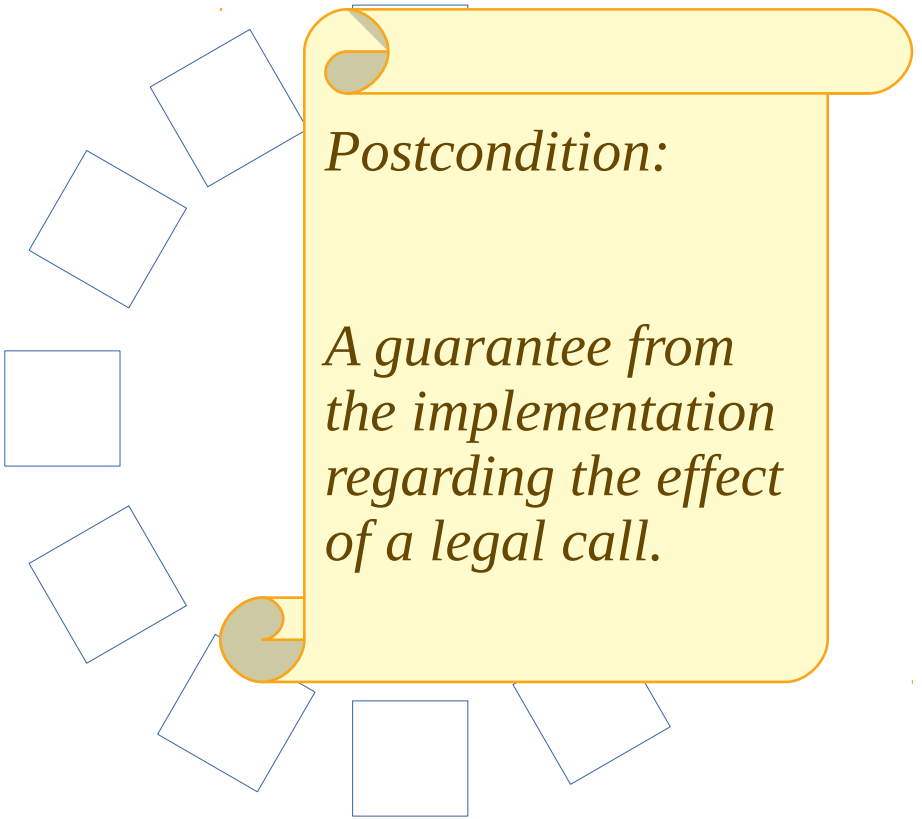
  int size() const;



  void push_back(T);
  // requires: size() < N


  T pop_front();
  // requires: size() > 0


};
```



Ringbuffer example

```
template <typename T, int N>
class ringbuffer {
public:

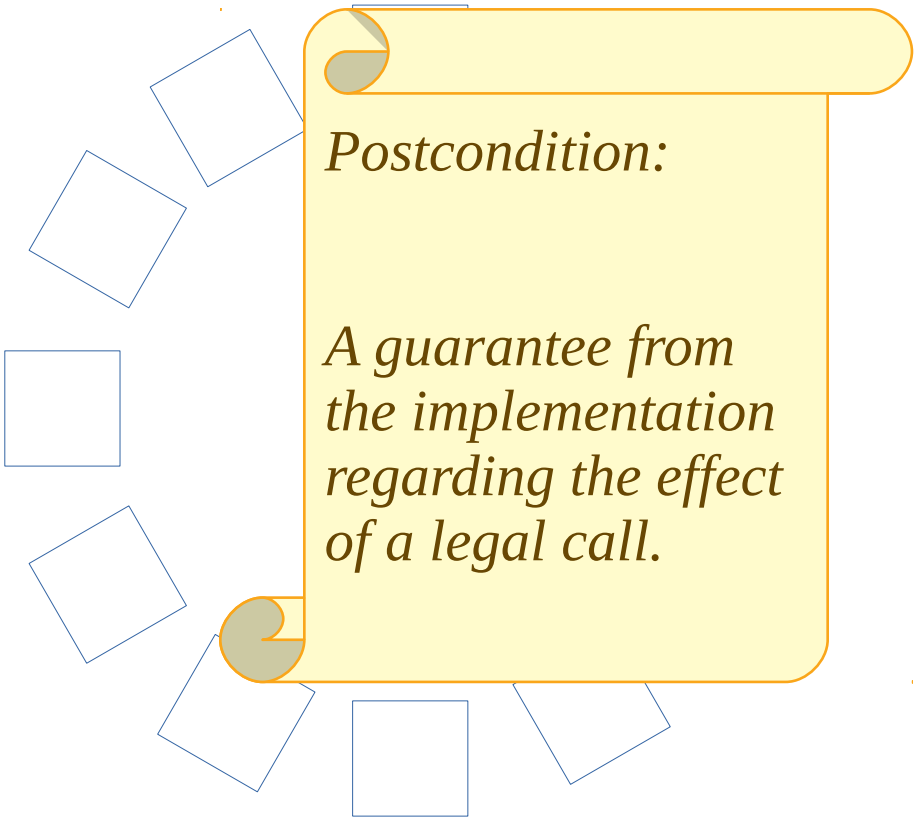
  ringbuffer();
  // ensures: size() == 0
  int size() const;



  void push_back(T);
  // requires: size() < N


  T pop_front();
  // requires: size() > 0


};
```



Ringbuffer example

```
template <typename T, int N>
class ringbuffer {
public:

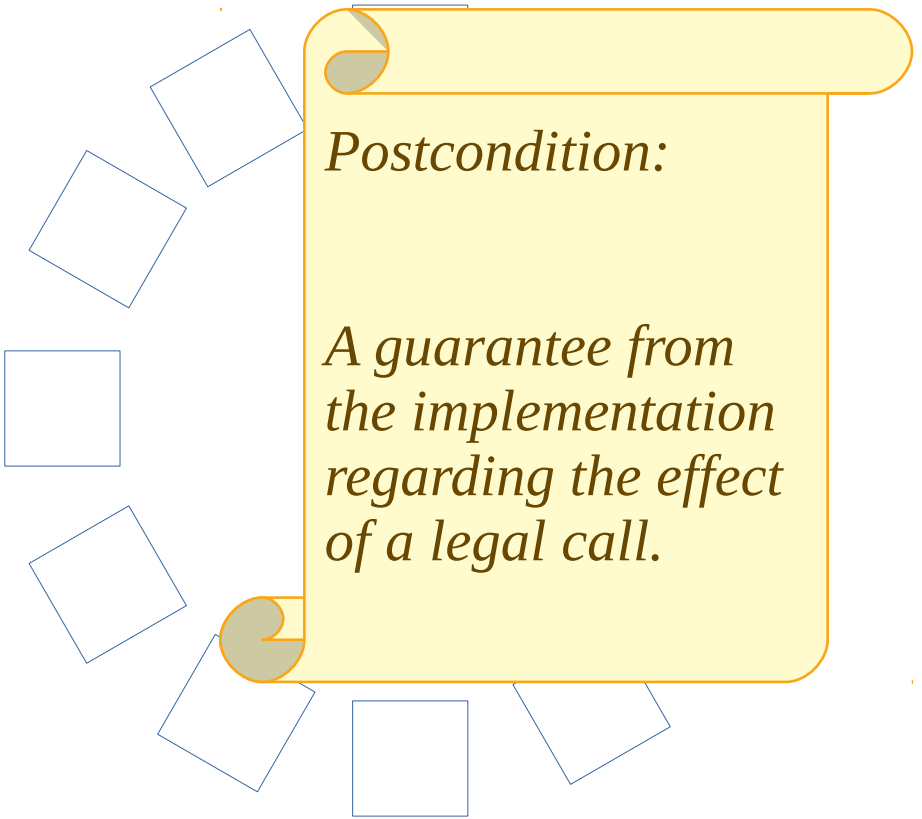
  ringbuffer();
  // ensures: size() == 0
  int size() const;




  void push_back(T);
  // requires: size() < N


  T pop_front();
  // requires: size() > 0


};
```



Ringbuffer example

```
template <typename T, int N>
class ringbuffer {
public:

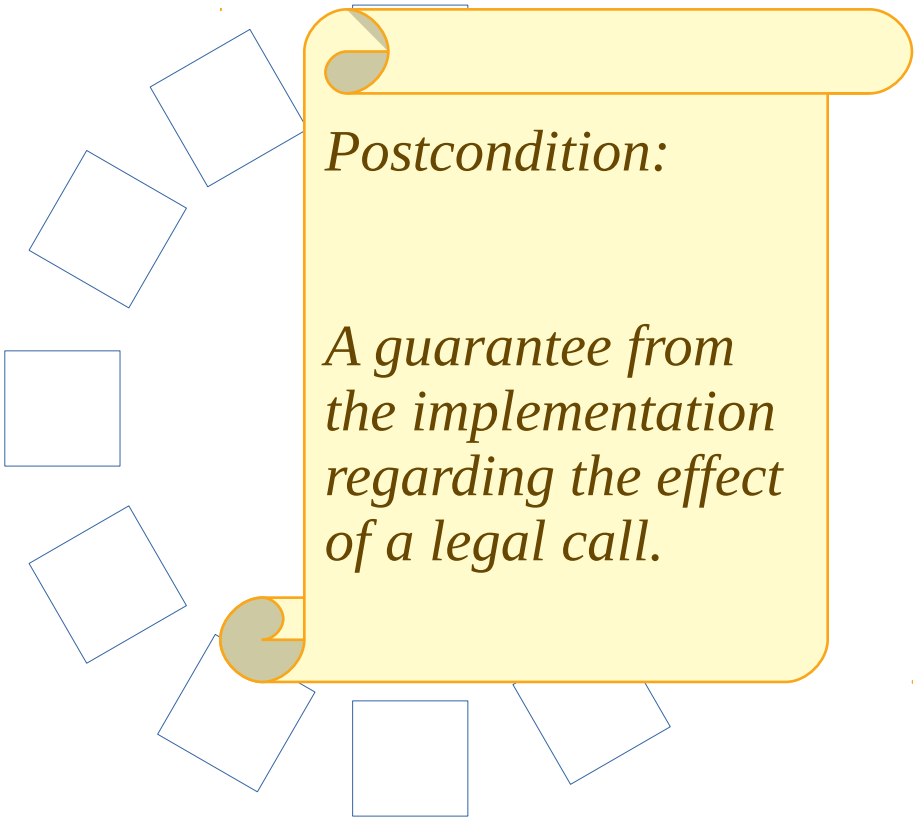
  ringbuffer();
  // ensures: size() == 0
  int size() const;



  void push_back(T);
  // requires: size() < N


  T pop_front();
  // requires: size() > 0


};
```



Ringbuffer example

```
template <typename T, int N>
class ringbuffer {
public:

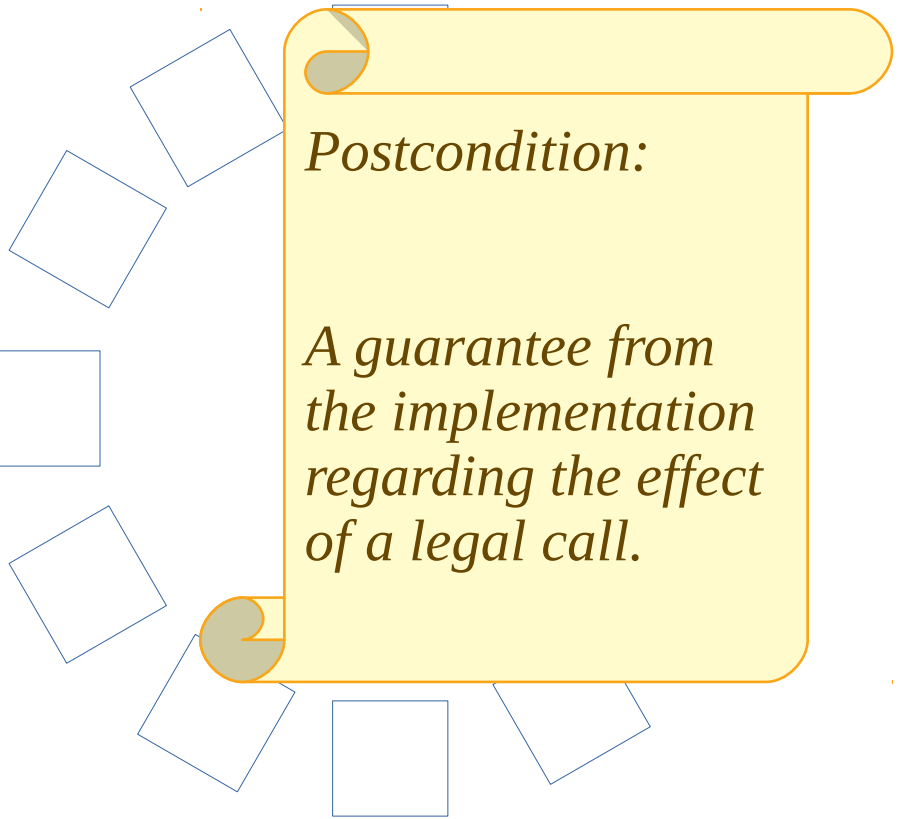
  ringbuffer();
  // ensures: size() == 0
  int size() const;



  void push_back(T);
  // requires: size() < N
  // ensures: size() == old size()+1

  T pop_front();
  // requires: size() > 0


};
```



Ringbuffer example

```
template <typename T, int N>
class ringbuffer {
public:

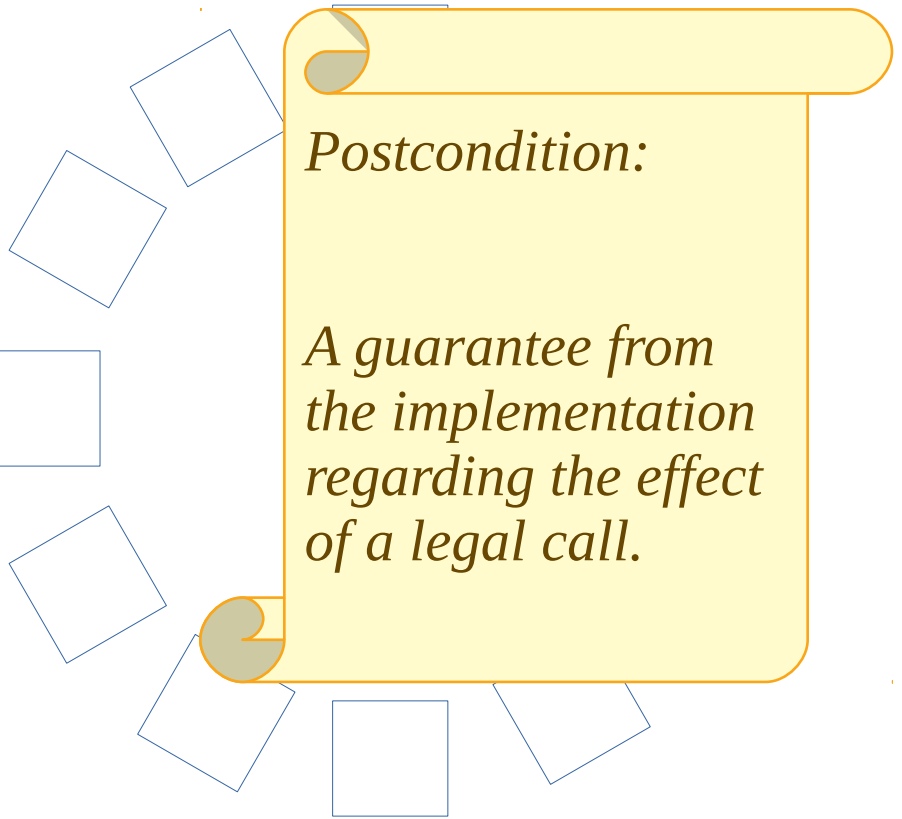
  ringbuffer();
  // ensures: size() == 0
  int size() const;



  void push_back(T t);
  // requires: size() < N
  // ensures: size() == old size()+1

  T pop_front();
  // requires: size() > 0


};
```



Ringbuffer example

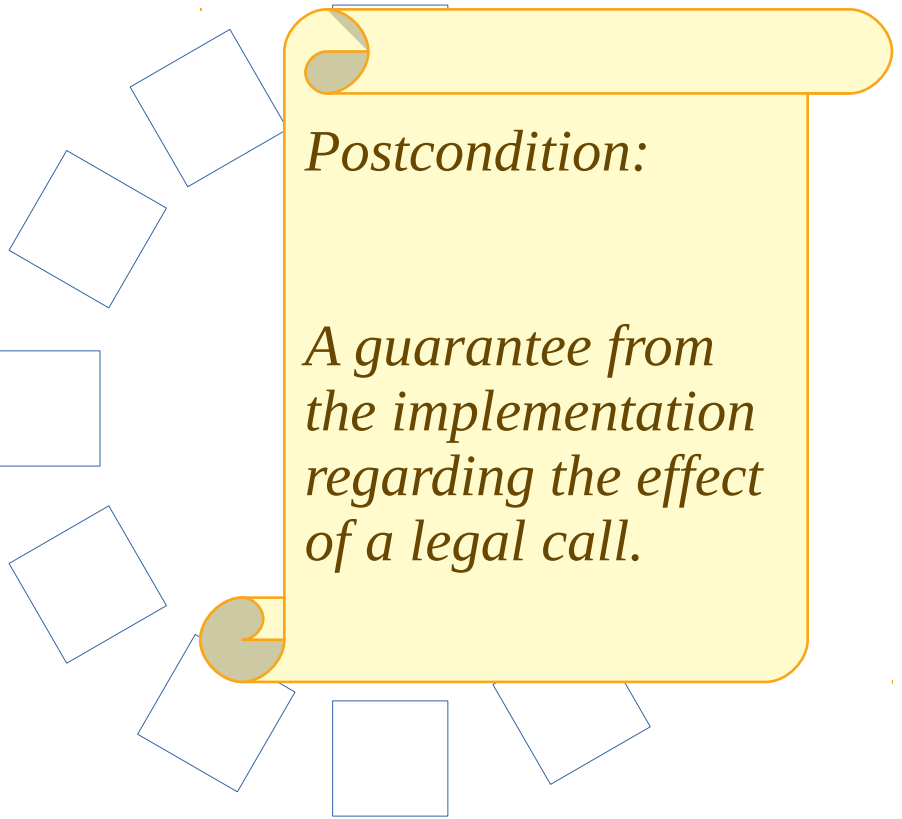
```
template <typename T, int N>
class ringbuffer {
public:

  ringbuffer();
  // ensures: size() == 0
  int size() const;
  const T& back() const;



  void push_back(T t);
  // requires: size() < N
  // ensures: size() == old size()+1
  //          back() == t
  T pop_front();
  // requires: size() > 0


};
```



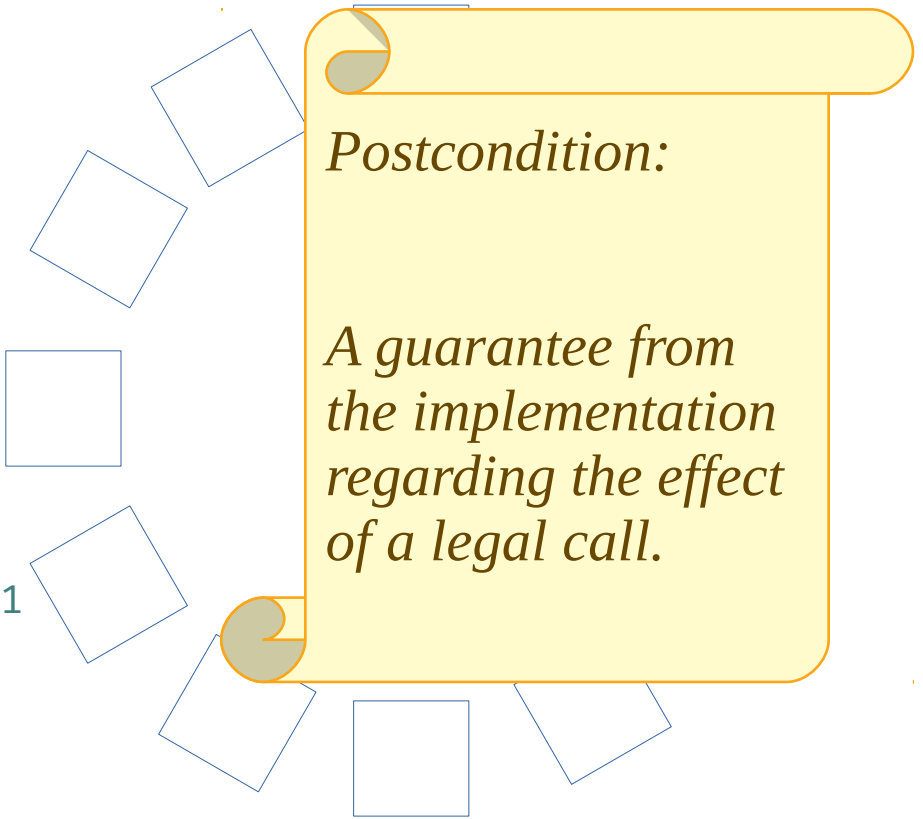
Ringbuffer example

```
template <typename T, int N>
class ringbuffer {
public:

  ringbuffer();
  // ensures: size() == 0
  int size() const;
  const T& back() const;
  // requires: size() > 0


  void push_back(T t);
  // requires: size() < N
  // ensures: size() == old size()+1
  //          back() == t
  T pop_front();
  // requires: size() > 0


};
```



Ringbuffer example

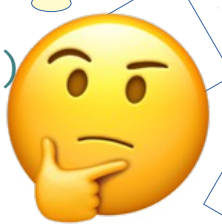
```
template <typename T, int N>
class ringbuffer {
public:

  ringbuffer();
  // ensures:
  int size() co
  const T& back(
  // requires: size() > 0


  void push_back(T t);
  // requires: size() < N
  // ensures: size() == old size()
  //          back() == t
  T pop_front();
  // requires: size() > 0


};
```

What if an exception is thrown?



Postcondition:

A guarantee from the implementation regarding the effect of a legal call.

Ringbuffer example

```
template <typename T, int N>
class ringbuffer {
public:

  ringbuffer();
  // ensures: size() == 0
  int size() const;
  const T& back() co
  // requires: size(

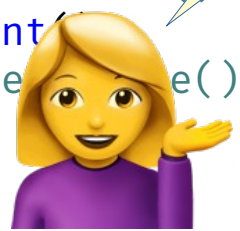
  void push_back(T t);
  // requires: size() <
  // ensures: size()    old size()+1
  //          back()    == t
  T pop_front(
  // require      e() > 0

};
```

Postconditions handles return. If an exception is thrown, there is no post condition.

Postcondition:

A guarantee from the implementation regarding the effect of a legal call.



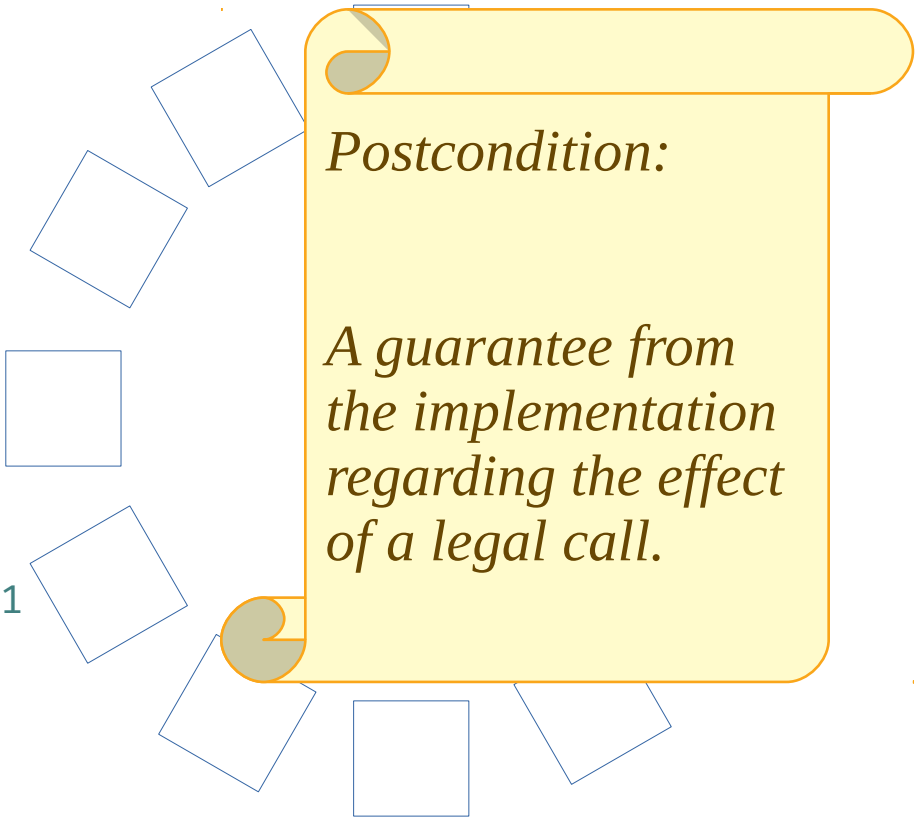
Ringbuffer example

```
template <typename T, int N>
class ringbuffer {
public:

  ringbuffer();
  // ensures: size() == 0
  int size() const;
  const T& back() const;
  // requires: size() > 0


  void push_back(T t);
  // requires: size() < N
  // ensures: size() == old size()+1
  //          back() == t
  T pop_front();
  // requires: size() > 0


};
```



Ringbuffer example

```
template <typename T, int N>
class ringbuffer {
public:

  ringbuffer();
  // ensures: size() == 0
  int size() const;
  const T& back() const;
  // requires: size() > 0


  void push_back(T t);
  // requires: size() < N
  // ensures: size() == old size()+1
  //          back() == t
  T pop_front();
  // requires: size() > 0
  // ensures: size() == old size()-1

};
```

Postcondition:

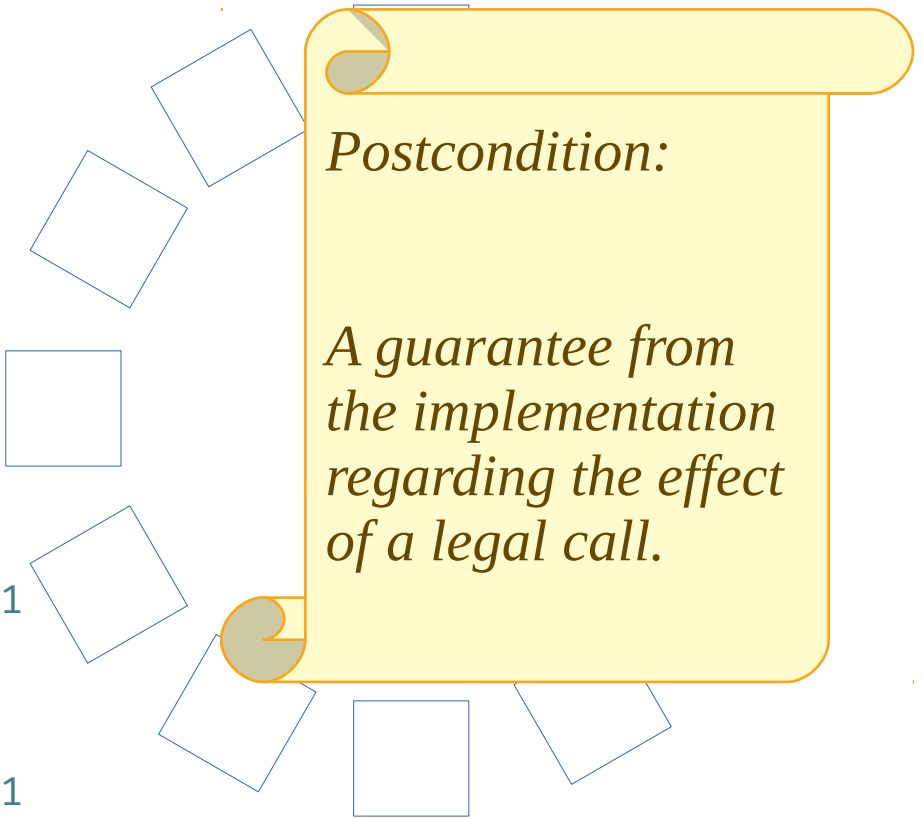
A guarantee from the implementation regarding the effect of a legal call.

Ringbuffer example

```
template <typename T, int N>
class ringbuffer {
public:

  ringbuffer();
  // ensures: size() == 0
  int size() const;
  const T& back() const;
  // requires: size() > 0
  const T& front() const;

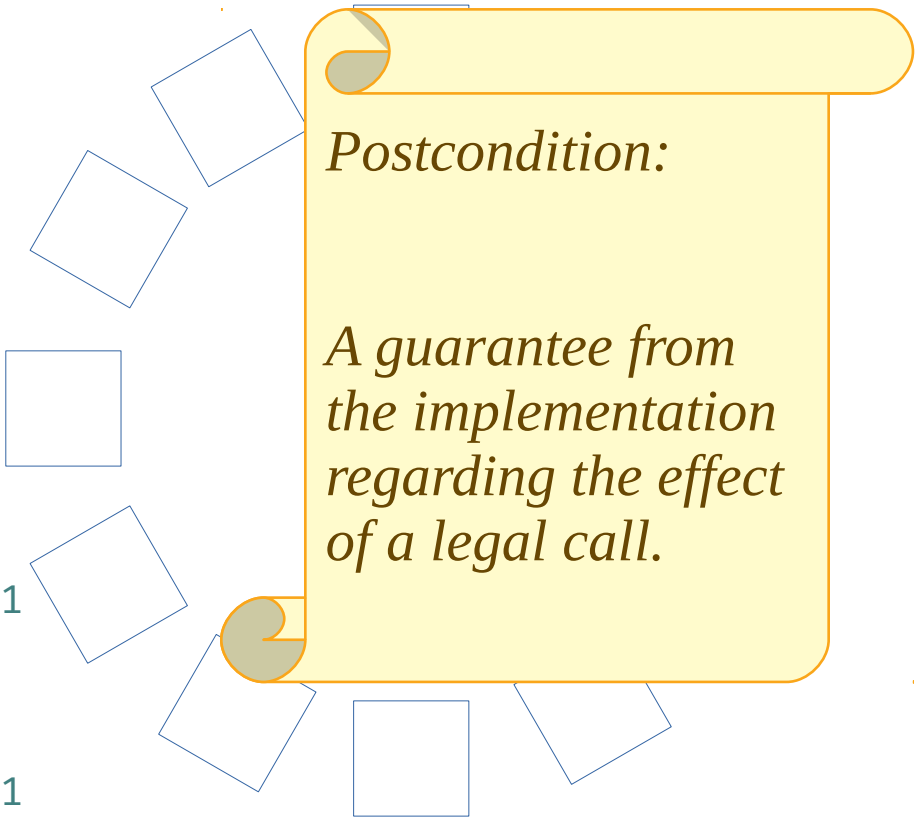
  void push_back(T t);
  // requires: size() < N
  // ensures: size() == old size()+1
  //          back() == t
  T pop_front();
  // requires: size() > 0
  // ensures: size() == old size()-1
  //          return == old front();
};
```



Ringbuffer example

```
template <typename T, int N>
class ringbuffer {
public:

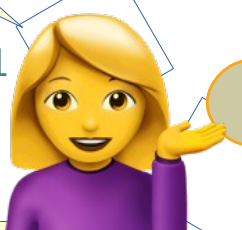
  ringbuffer();
  // ensures: size() == 0
  int size() const;
  const T& back() const;
  // requires: size() > 0
  const T& front() const;
  // requires: size() > 0
  void push_back(T t);
  // requires: size() < N
  // ensures: size() == old size()+1
  //          back() == t
  T pop_front();
  // requires: size() > 0
  // ensures: size() == old size()-1
  //          return == old front();
};
```



Ringbuffer example

```
template <typename T, int N>
class ringbuffer {
public:
  // ...
  const T& front() const;
  // requires: size() > 0
  void push_back(T t);
  // requires: size() < N
  // ensures: size() == old size()+1
  //          back() == t
  T pop_front();
  // requires: size() > 0
  // ensures: size() == old size()-1
  //          return == old front();
};
```

It does not make sense to try and express the returned value from the history of pushes and pops as a post condition.



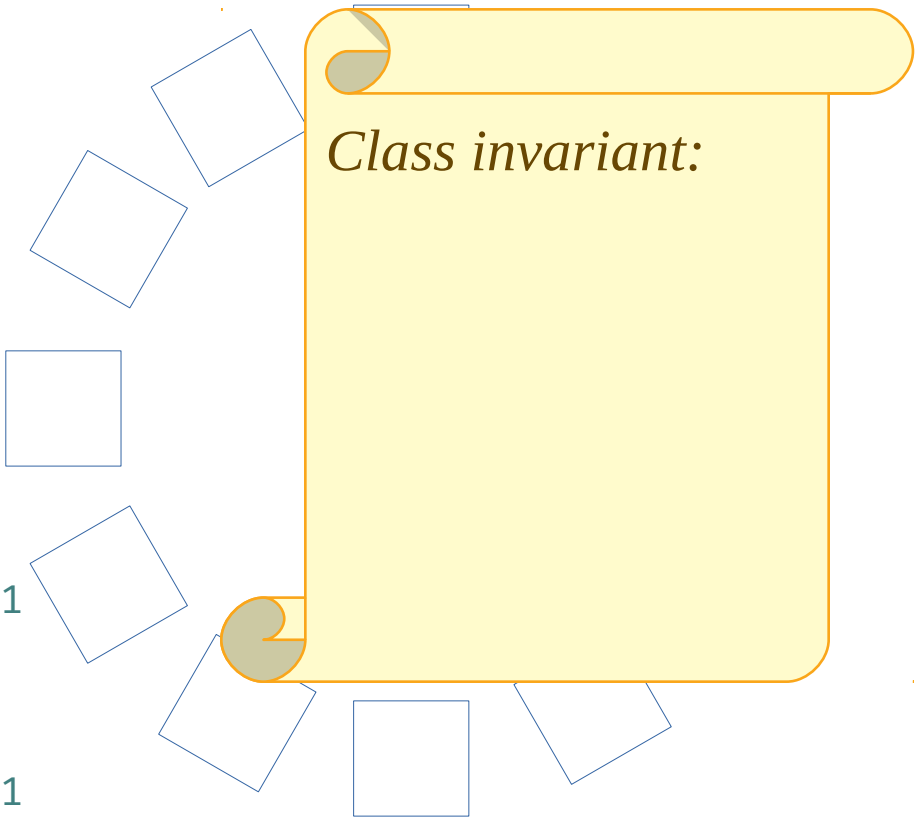
Postcondition:

A guarantee from the implementation regarding the effect of a legal call.

Ringbuffer example

```
template <typename T, int N>
class ringbuffer {
public:

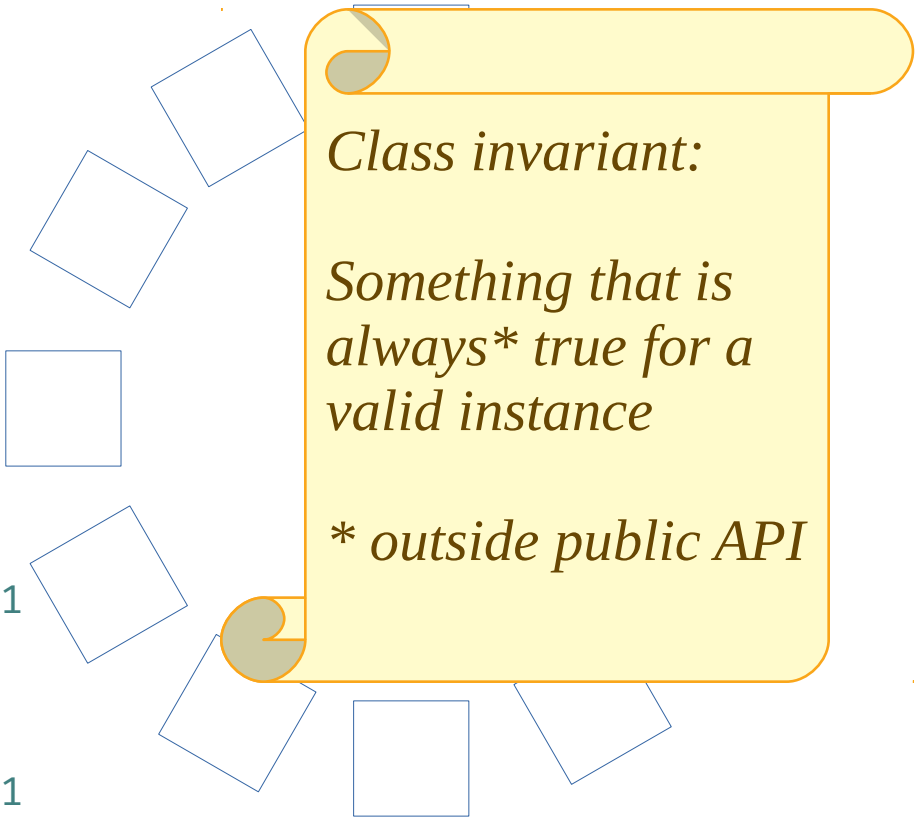
  ringbuffer();
  // ensures: size() == 0
  int size() const;
  const T& back() const;
  // ensures: size() > 0
  const T& front() const;
  // requires: size() > 0
  void push_back(T t);
  // requires: size() < N
  // ensures: size() == old size()+1
  //          back() == t
  T pop_front();
  // requires: size() > 0
  // ensures: size() == old size()-1
  //          return == old front();
};
```



Ringbuffer example

```
template <typename T, int N>
class ringbuffer {
public:

  ringbuffer();
  // ensures: size() == 0
  int size() const;
  const T& back() const;
  // ensures: size() > 0
  const T& front() const;
  // requires: size() > 0
  void push_back(T t);
  // requires: size() < N
  // ensures: size() == old size()+1
  //          back() == t
  T pop_front();
  // requires: size() > 0
  // ensures: size() == old size()-1
  //          return == old front();
};
```



Ringbuffer example

```
template <typename T, int N>
class ringbuffer {
public:

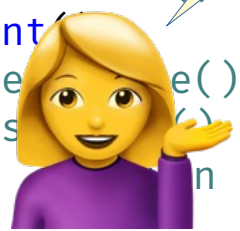
  ringbuffer();
  // ensures: size() ==
  int size() const;
  const T& back() cor
  // ensures: size() >
  const T& front() const;
  // requires: size() > 0
  void push_back(T t);
  // requires: size() <
  // ensures: size()    old size()+1
  //          back()    == t
  T pop_front();
  // require    e() > 0
  // ensures    () == old size()-1
  //            n == old front();
};
```

A class invariant always refers to state, and must be true even when exceptions are thrown.

Class invariant:

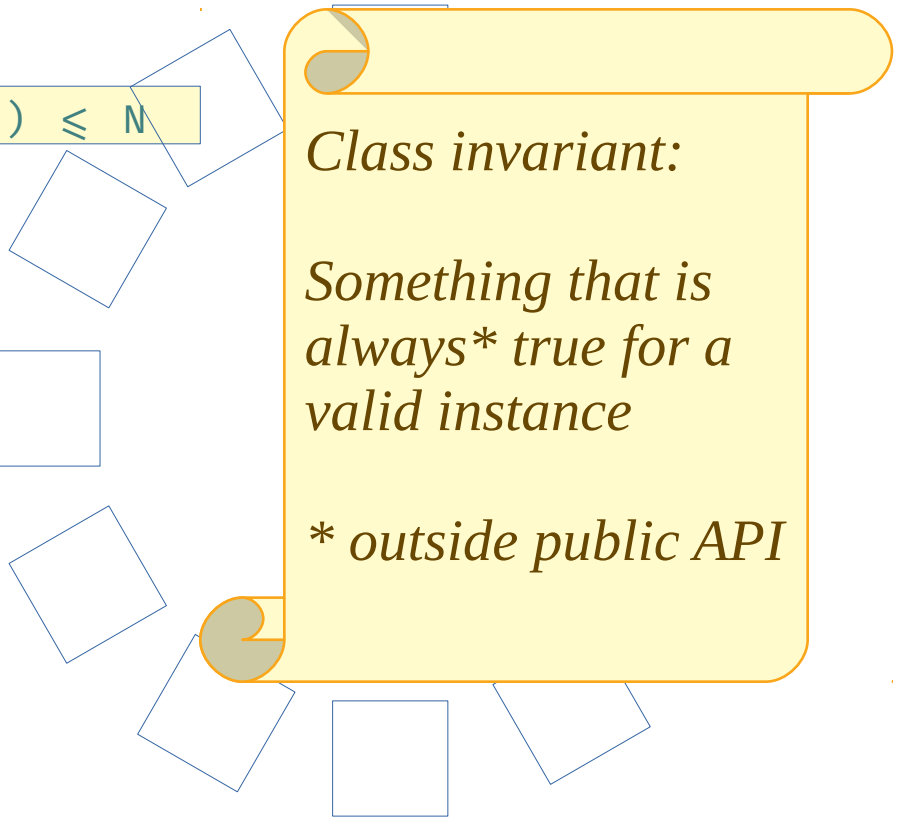
Something that is always true for a valid instance*

** outside public API*



Ringbuffer example

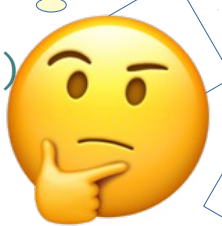
```
template <typename T, int N>
class ringbuffer {
public:
  // invariant: size() ≥ 0 && size() ≤ N
  ringbuffer();
  // ensures: size() == 0
  int size() const;
  const T& back() const;
  // ensures: size() > 0
  const T& front() const;
  // requires: size() > 0
  void push_back(T t);
  // requires: size() < N
  // ensures: size() == old size()+1
  //          back() == t
  T pop_front();
  // requires: size() > 0
  // ensures: size() == old size()-1
  //          return == old front();
};
```



Ringbuffer example

```
template <typename T, int N>
class ringbuffer {
public:
  // invariant: size() ⩾ 0 && size() ⩽ N
  ringbuffer();
  // ensures: size() =
  int size() const;
  const T& back() cor
  // ensures: size() > 0
  const T& front() const;
  // requires: size() > 0
  void push_back(T t);
  // requires: size() < N
  // ensures: size() == old size()
  //          back() == t
  T pop_front();
  // requires: size() > 0
  // ensures: size() == old size()-1
  //          return == old front();
};
```

What about a moved-from object?



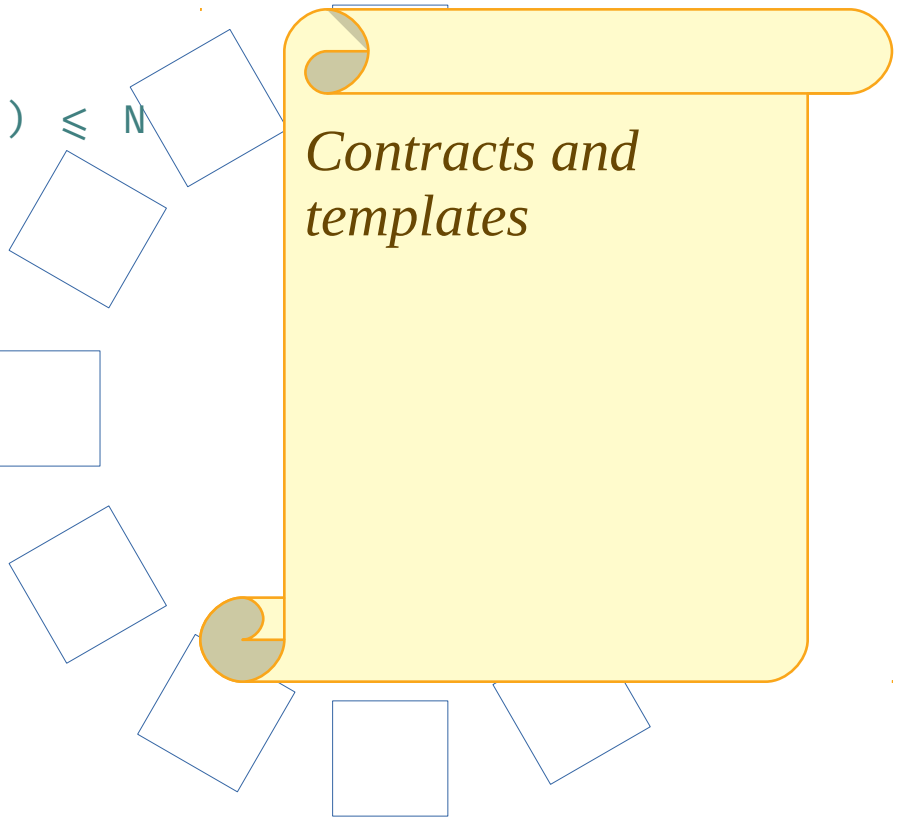
Class invariant:

Something that is always true for a valid instance*

** outside public API*

Ringbuffer example

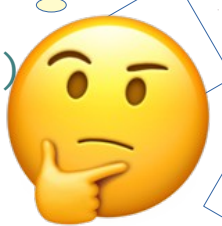
```
template <typename T, int N>
class ringbuffer {
public:
  // invariant: size() ⩾ 0 && size() ⩽ N
  ringbuffer();
  // ensures: size() == 0
  int size() const;
  const T& back() const;
  // ensures: size() > 0
  const T& front() const;
  // requires: size() > 0
  void push_back(T t);
  // requires: size() < N
  // ensures: size() == old size()+1
  //          back() == t
  T pop_front();
  // requires: size() > 0
  // ensures: size() == old size()-1
  //          return == old front();
};
```



Ringbuffer example

```
template <typename T, int N>
class ringbuffer {
public:
  // invariant: size() ⩾ 0 && size() ⩽ N
  ringbuffer();
  // ensures: size() =
  int size() const;
  const T& back() con
  // ensures: size() > 0
  const T& front() const;
  // requires: size() > 0
  void push_back(T t);
  // requires: size() < N
  // ensures: size() == old size()
  //          back() == t
  T pop_front();
  // requires: size() > 0
  // ensures: size() == old size()-1
  //          return == old front();
};
```

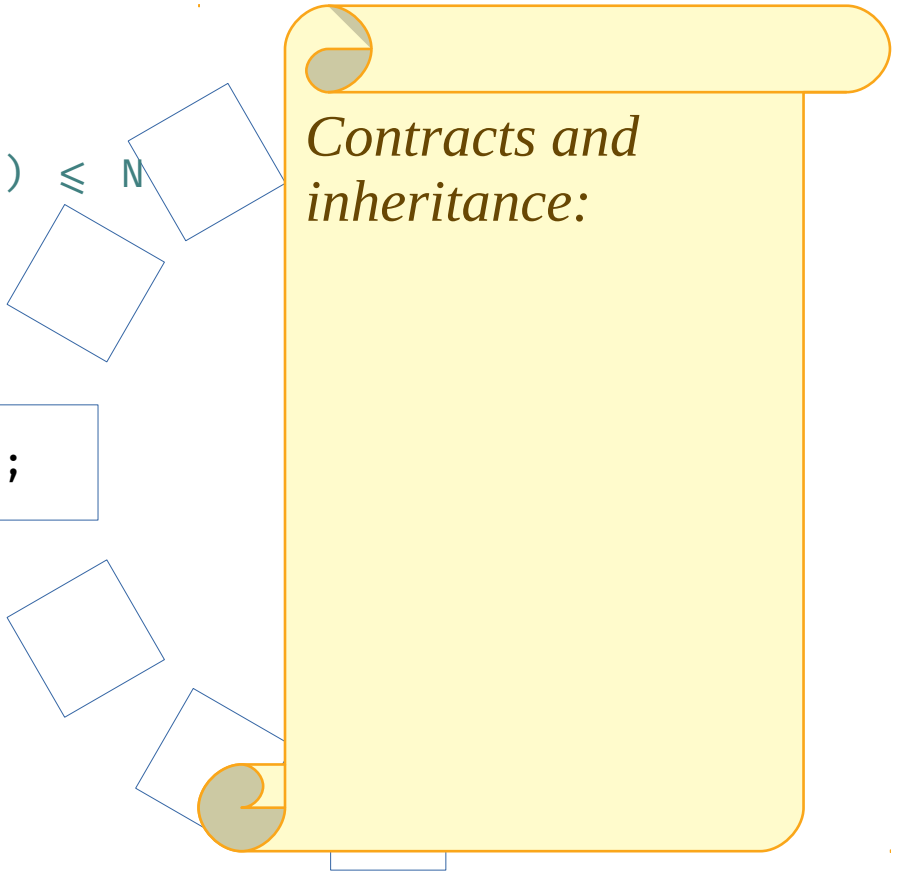
What about specializations?



Contracts and templates

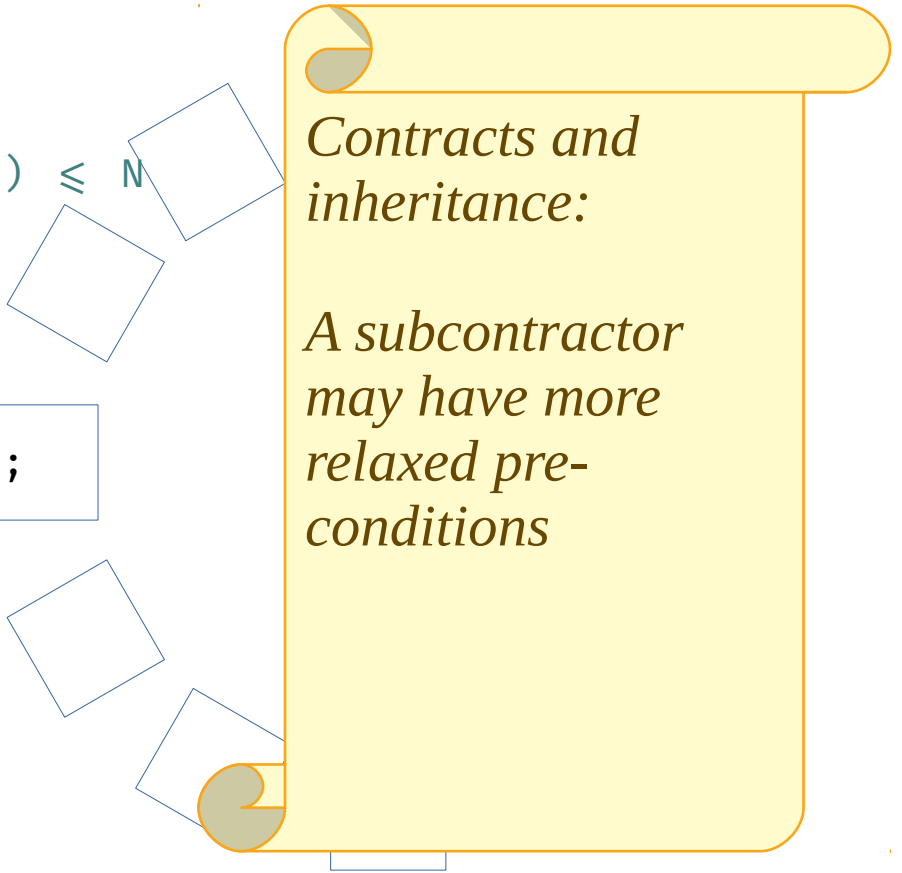
Ringbuffer example

```
template <typename T, int N>
class ringbuffer {
public:
  // invariant: size() ⩾ 0 && size() ⩽ N
  ringbuffer();
  // ensures: size() == 0
  virtual int size() const = 0;
  virtual const T& back() const = 0;
  // requires: size() > 0
  virtual const T& front() const = 0;
  // requires: size() > 0
  virtual void push_back(T t) = 0;
  // requires: size() < N
  // ensures: size() == old size()+1
  //          back() == t
  virtual T pop_front() = 0;
  // requires: size() > 0
  // ensures: size() == old size()-1
  //          return == old front();
};
```



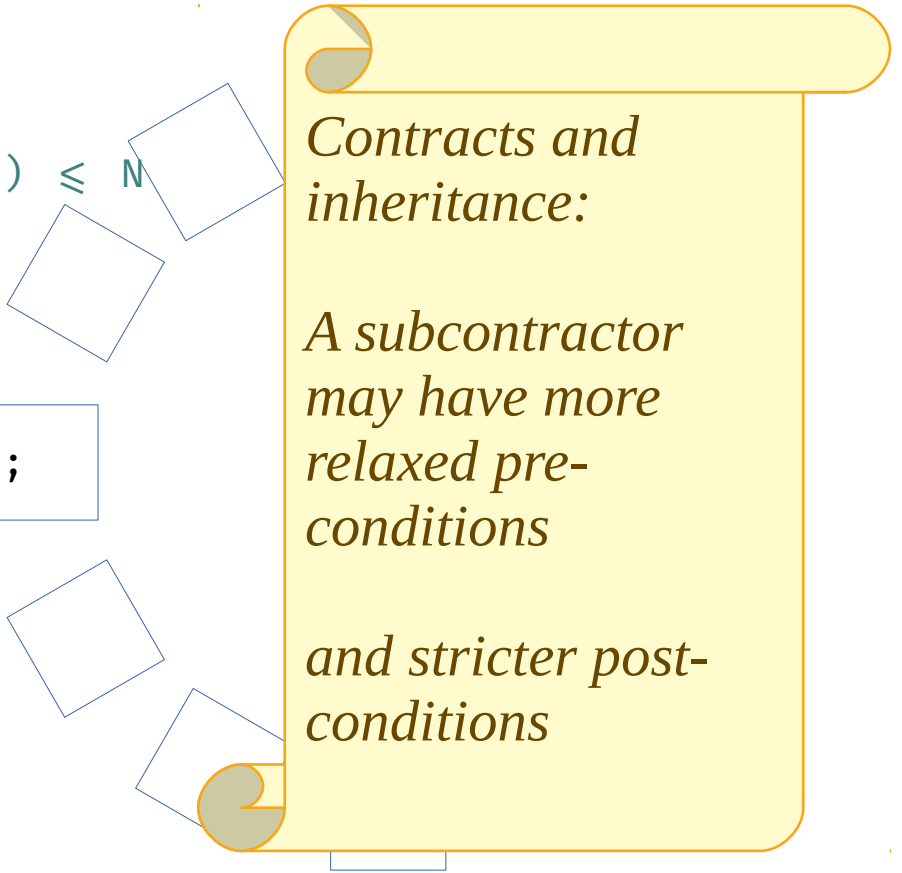
Ringbuffer example

```
template <typename T, int N>
class ringbuffer {
public:
  // invariant: size() ⩾ 0 && size() ⩽ N
  ringbuffer();
  // ensures: size() == 0
  virtual int size() const = 0;
  virtual const T& back() const = 0;
  // requires: size() > 0
  virtual const T& front() const = 0;
  // requires: size() > 0
  virtual void push_back(T t) = 0;
  // requires: size() < N
  // ensures: size() == old size()+1
  //          back() == t
  virtual T pop_front() = 0;
  // requires: size() > 0
  // ensures: size() == old size()-1
  //          return == old front();
};
```



Ringbuffer example

```
template <typename T, int N>
class ringbuffer {
public:
  // invariant: size() ⩾ 0 && size() ⩽ N
  ringbuffer();
  // ensures: size() == 0
  virtual int size() const = 0;
  virtual const T& back() const = 0;
  // requires: size() > 0
  virtual const T& front() const = 0;
  // requires: size() > 0
  virtual void push_back(T t) = 0;
  // requires: size() < N
  // ensures: size() == old size()+1
  //          back() == t
  virtual T pop_front() = 0;
  // requires: size() > 0
  // ensures: size() == old size()-1
  //          return == old front();
};
```



Why bother?

Why bother?

1)It can make interfaces much clearer

Why bother?

1)It can make interfaces much clearer

2)It can make debugging much easier

Why bother?

1)It can make interfaces much clearer

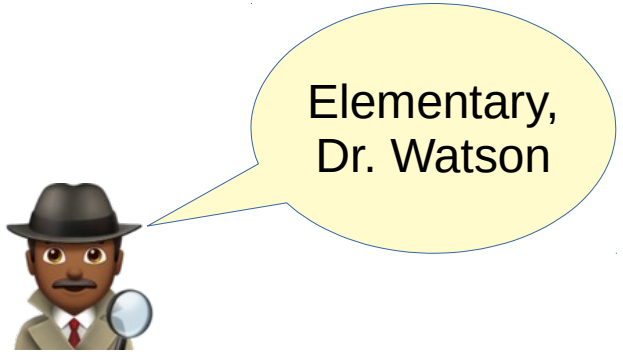
2)It can make debugging much easier

3)It removes defensive checks

Who dunnit?

		guilty	
		client	implementation
violation	precondition		
	postcondition		
	invariant		

Who dunnit?



		guilty	
		client	implementation
violation	precondition		
	postcondition		
	invariant		

Who dunnit?

		guilty	
		client	implementation
violation	precondition		
	postcondition		
	invariant		

Who dunnit?

		guilty	
		client	implementation
violation	precondition		
	postcondition		
	invariant		

Who dunnit?

		guilty	
		client	implementation
violation	precondition		
	postcondition		
	invariant		

Who dunnit?

		guilty	
		client	implementation
violation	precondition		
	postcondition		
	invariant		

Who dunnit?

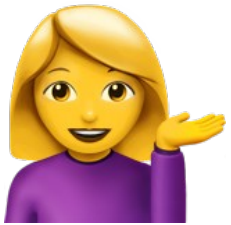
		guilty	
		client	implementation
violation	precondition		
	postcondition		
	invariant		

Who dunnit?

		guilty	
		client	implementation
violation	precondition		
	postcondition		
	invariant		

Who dunnit?

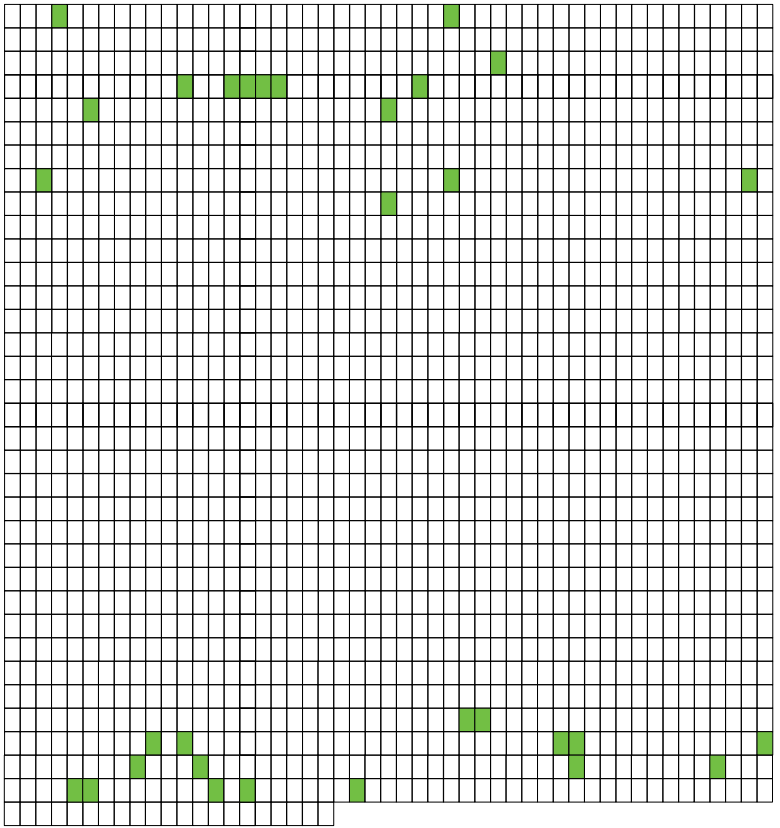
Or you have
a bad contract!



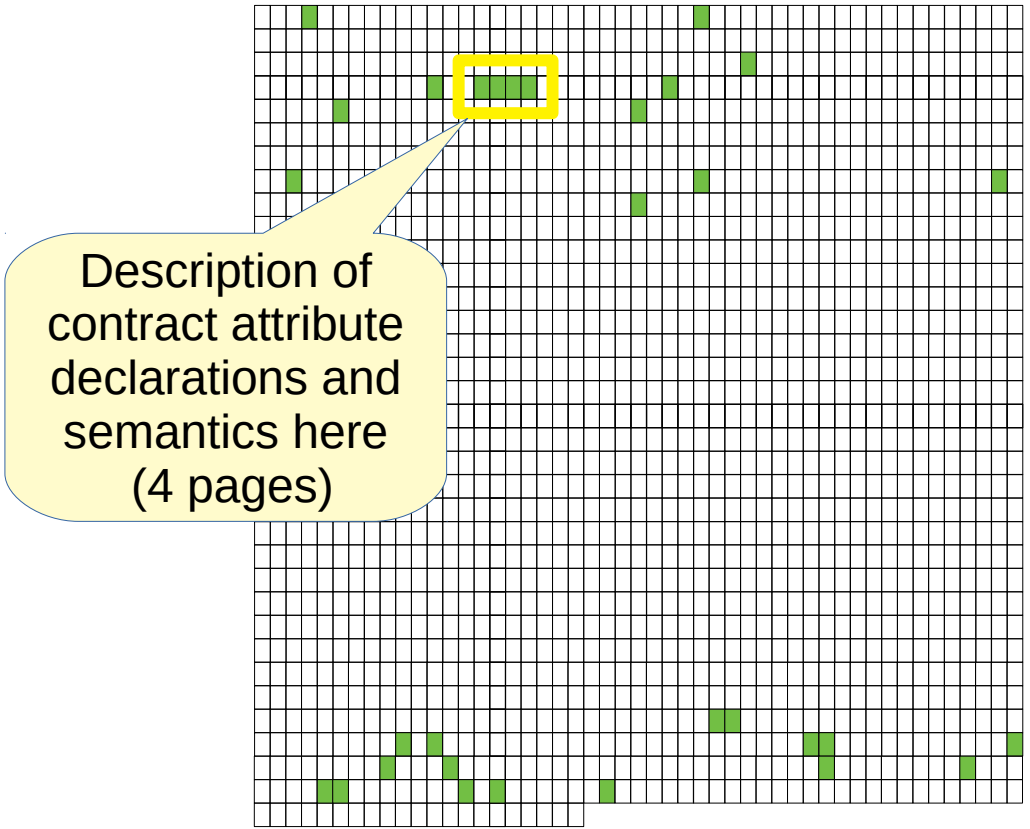
		guilty	
		client	implementation
violation	precondition		
	postcondition		
	invariant		

Contracts in C++20

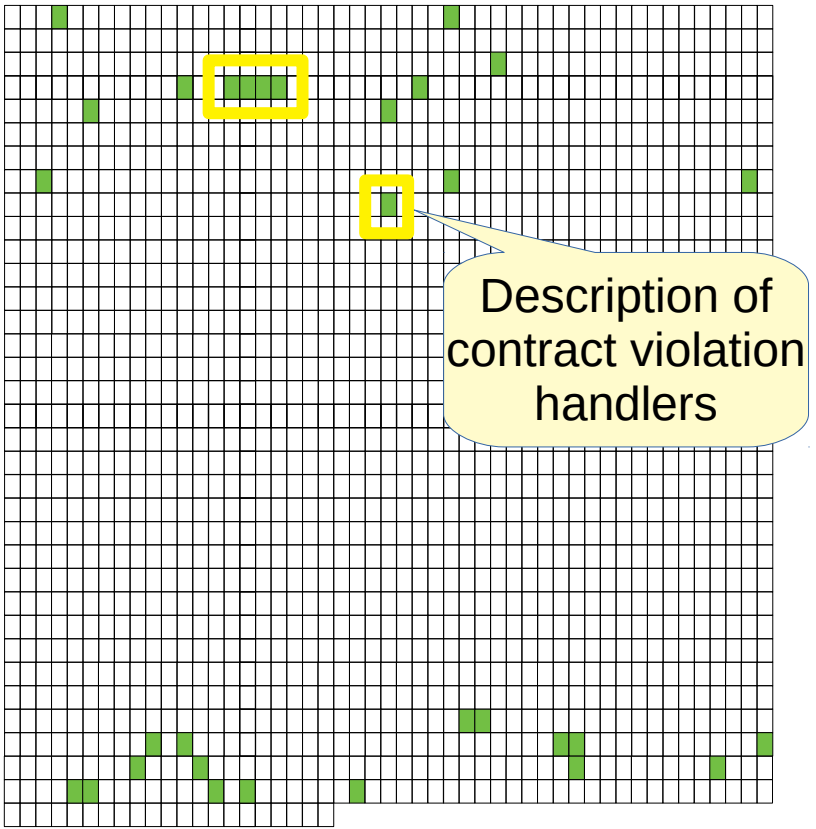
Contracts in C++20



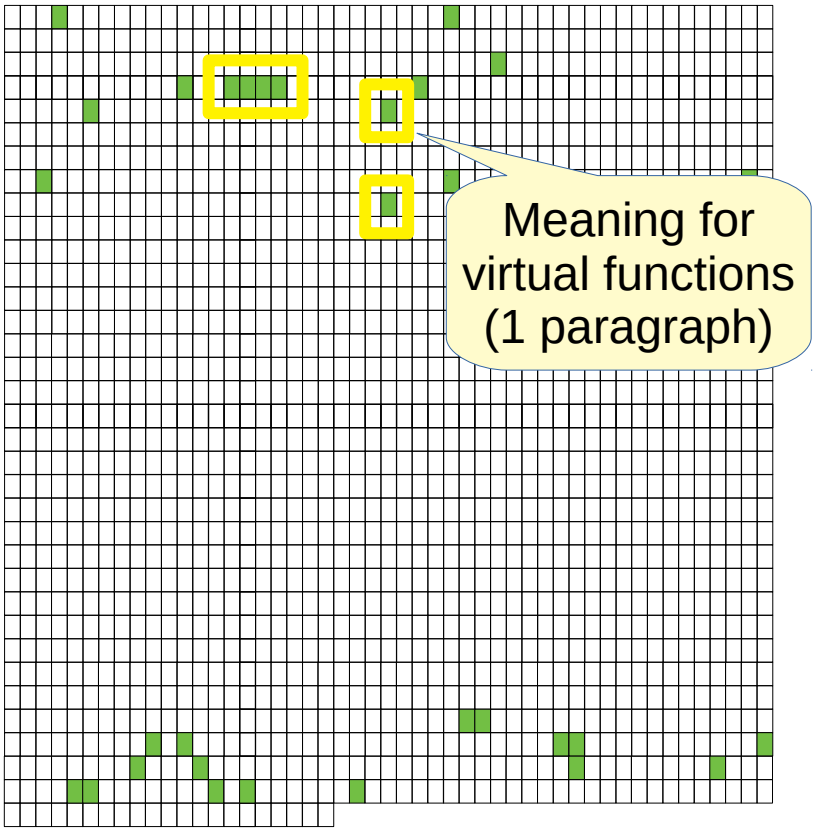
Contracts in C++20



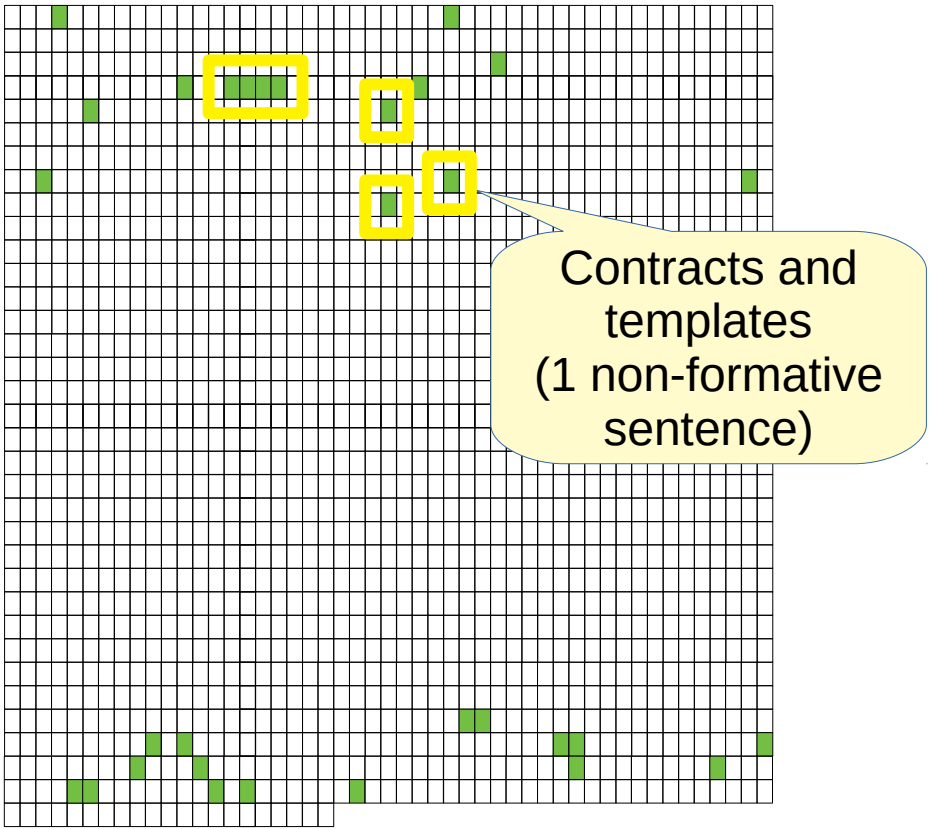
Contracts in C++20



Contracts in C++20



Contracts in C++20



Contract attributes in C++20

9.11.4.1 Syntax [dcl.attr.contract.syn]

1# Contract attributes are used to specify preconditions, postconditions, and assertions for functions.

contract-attribute-specifier:

```
[ [ expects contract-level_opt : conditional-expression ] ]
[ [ ensures contract-level_opt identifier_opt : conditional-expression ] ]
[ [ assert contract-level_opt : conditional-expression ] ]
```

contract-level:

```
default
audit
axiom
```

An ambiguity between a *contract-level* and an *identifier* is resolved in favor of *contract-level*.

http://eel.is/c++draft/dcl.attr.contract#syn-1

Contract attributes in C++20

9.11.4.1 Syntax [dcl.attr.contract.syn]

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```

contract-level:

```
default
audit
axiom
```

Pre condition

An ambiguity between a *contract-level* and an *identifier* is resolved in favor of *contract-level*.

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Contract attributes in C++20

9.11.4.1 Syntax [dcl.attr.contract.syn]

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[ [ assert contract-level_opt : conditional-expression ] ]
```

contract-level:

```
default
audit
axiom
```

Pre condition

```
template <typename T>
void func(std::unique_ptr<T> p)
[[ expects : p != nullptr ]];
```

An ambiguity between a *contract-level* and an *identifier* is resolved in favor of *contract-level*.

http://eel.is/c++draft/dcl.attr.contract#syn-1

Contract attributes in C++20

9.11.4.1 Syntax [dcl.attr.contract.syn]

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[ [ assert contract-level_opt : conditional-expression ] ]
```

contract-level:

```
default
audit
axiom
```

Optional level

```
template <typename T>
void func(std::unique_ptr<T> p)
[[ expects : p != nullptr ]];
```

An ambiguity between a *contract-level* and an *identifier* is resolved in favor of *contract-level*.

http://eel.is/c++draft/dcl.attr.contract#syn-1

Contract attributes in C++20

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[ [ assert contract-level_opt : conditional-expression ] ]
```

contract-level:

```
default
audit
axiom
```

Optional level

```
template <typename T>
void func(std::unique_ptr<T> p)
[[ expects axiom : p != nullptr ]];
```

An ambiguity between a *contract-level* and an *identifier* is resolved in favor of *contract-level*.

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Contract attributes in C++20

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[ [ assert contract-level_opt : conditional-expression ] ]
```

contract-level:

```
default
audit
axiom
```

Post condition

An ambiguity between a *contract-level* and an *identifier* is resolved in favor of *contract-level*.

http://eel.is/c++draft/dcl.attr.contract#syn-1

Contract attributes in C++20

9.11.4.1 Syntax [dcl.attr.contract.syn]

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```
[ [ expects contract-level_opt : conditional-expression ] ]
[ [ ensures contract-level_opt identifier_opt : conditional-expression ] ]
[ [ assert contract-level_opt : conditional-expression ] ]
```

contract-level:

```
default
audit
axiom
```

Post condition

```
template <typename T>
T prev(T v)
[[ expects : v > 0 ]]
[[ ensures audit r : r + 1 == v ]];
```

An ambiguity between a *contract-level* and an *identifier* is resolved in favor of *contract-level*.

http://eel.is/c++draft/dcl.attr.contract#syn-1

Contract attributes in C++20

9.11.4.1 Syntax [dcl.attr.contract.syn]

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contract-attribute-specifier:

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[ [ assert contract-level_opt : conditional-expression ] ]
```

contract-level:

```
default
audit
axiom
```

Post condition

Name for return value to use in conditional expression

```
template <typename T>
T prev(T v)
[[ expects : v > 0 ]]
[[ ensures audit r : r + 1 == v ]];
```

An ambiguity between a *contract-level* and an *identifier* is resolved in favor of *contract-level*.

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Contract attributes in C++20

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```
[ [ expects contract-level_opt : conditional-expression ] ]
[ [ ensures contract-level_opt identifier_opt : conditional-expression ] ]
[ [ assert contract-level_opt : conditional-expression ] ]
```

Generic assertion

contract-level:

```
default
audit
axiom
```

An ambiguity between a *contract-level* and an *identifier* is resolved in favor of *contract-level*.

http://eel.is/c++draft/dcl.attr.contract#syn-1

Contract attributes in C++20

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1# Contract attributes are used to specify preconditions, postconditions, and assertions for functions.

contract-attribute-specifier:

```
[ [ expects contract-level_opt : conditional-expression ] ]
[ [ ensures contract-level_opt identifier_opt : conditional-expression ] ]
[ [ assert contract-level_opt : conditional-expression ] ]
```

contract-level:

```
default
audit
axiom
```

Generic assertion

```
for (auto p : pointers) {
  [[ assert audit: p ≠ nullptr ]];
  func(p);
}
```

An ambiguity between a *contract-level* and an *identifier* is resolved in favor of *contract-level*.

http://eel.is/c++draft/dcl.attr.contract#syn-1

Contract attributes in C++20

9.11.4.1 Syntax [dcl.attr.contract.syn]

1# Contract attributes are u ons, postconditions, and assertions for functions.

There are no class invariants!

contract-attribute-specifier:

`[ [ expects` *contract expression* `] ]`

`[ [ ensures` *contract-level*$_{opt}$ *identifier*$_{opt}$ `:` *conditional-expression* `] ]`

`[ [ assert` *contract-level*$_{opt}$ `:` *conditional-expression* `] ]`

contract-level:

`default`

`audit`

`axiom`

An ambiguity between a *contract-level* and an *identifier* is resolved in favor of *contract-level*.

http://eel.is/c++draft/dcl.attr.contract#syn-1

Using C++20 contract attributes for ringbuffer

```
template <typename T, int N>
class ringbuffer {
public:
  // invariant: size() ⩾ 0 && size() ⩽ N
  ringbuffer();
  // ensures: size() == 0
  int size() const;
  const T& back() const;
  // requires: size() > 0
  const T& front() const;
  // requires: size() > 0
  void push_back(T t);
  // requires: size() < N
  // ensures: size() == old size()+1
  //          back() == t
  T pop_front();
  // requires: size() > 0
  // ensures: size() == old size()-1
  //          return == old front();
};
```

Using C++20 contract attributes for ringbuffer

```
template <typename T, int N>
class ringbuffer {
public:
  // invariant: size() ⩾ 0 && size() ⩽ N
  ringbuffer();
  // ensures: size() == 0
  int size() const;
  const T& back() const;
  // requires: size() > 0
  const T& front() const;
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  void push_back(T t);
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```

Using C++20 contract attributes for ringbuffer

```
template <typename T, int N>
class ringbuffer {
public:
  // invariant: size() ⩾ 0 && size() ⩽ N
  ringbuffer();
  // ensures: size() == 0
  int size() const;
  const T& back() const;
  // requires: size() > 0
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  //          back() == t
  T pop_front();
  // requires: size() > 0
  // ensures: size() == old size()-1
  //          return == old front();
};
```

No support for class invariants, so might as well leave as comment.

Using C++20 contract attributes for ringbuffer

```
template <typename T, int N>
class ringbuffer {
public:
  // invariant: size() ⩾ 0 && size() ⩽ N
  ringbuffer();
  // ensures: size() == 0
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  //          return == old front();
};
```

Using C++20 contract attributes for ringbuffer

```
template <typename T, int N>
class ringbuffer {
public:
  // invariant: size() ⩾ 0 && size() ⩽ N
  ringbuffer()
  [[ ensures: size() == 0 ]];
  int size() const;
  const T& back() const;
  // requires: size() > 0
  const T& front() const;
  // requires: size() > 0
  void push_back(T t);
  // requires: size() < N
  // ensures: size() == old size()+1
  //          back() == t
  T pop_front();
  // requires: size() > 0
  // ensures: size() == old size()-1
  //          return == old front();
};
```

Using C++20 contract attributes for ringbuffer

```
template <typename T, int N>
class ringbuffer {
public:
  // invariant: size() ⩾ 0 && size() < = N
  ringbuffer()
  [[ ensures: size() == 0 ]];
  int size() const;
  const T& back() const;
  // requires: size() > 0
```

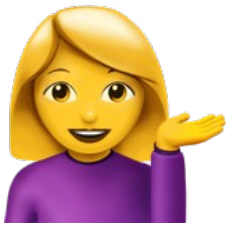
```
<source>:6:15: error: use of undeclared identifier 'size'
  [[ ensures: size() == 0 ]];
```

```
  // ensures: size() == old size()+1
  //          back() == t
  T pop_front();
  // requires: size() > 0
  // ensures: size() == old size()-1
  //          return == old front();
};
```

Using C++20 contract attributes for ringbuffer

```
template <typename T, int N>
class ringbuffer {
public:
  // invariant: size() ≥ 0 && siz
  ringbuffer()
  [[ ensures: size() == 0 ]];
  int size() const;
  const T& back() const;
  // requires: size() > 0
```

Contract attributes are declarations that can only refer to identifiers seen earlier.



```
<source>:6:15: error: use of undeclared identifier 'size'
  [[ ensures: size() == 0 ]];
```

```
  // ensures: size() == old size()+1
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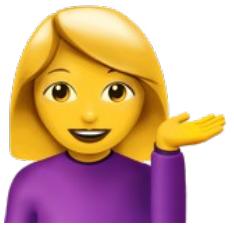

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  // requires: size() > 0
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  [[ expects: size() > 0 ]];
  const T& front() const;
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  const T& back() const
  [[ expects: size() > 0 ]];
  const T& front() const
  [[ expects: size() > 0 ]];
  void push_back(T t);
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Using C++20 contract attributes for ringbuffer

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template <typename T, int N>
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  [[ ensures: size() == 0 ]];
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```

Using C++20 contract attributes for ringbuffer

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template <typename T, int N>
class ringbuffer {
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  // invariant: size() ⩾ 0 && size() ⩽ N
  int size() const;
  ringbuffer()
  [[ ensures: size() == 0 ]];
  const T& back() const
  [[ expects: size() > 0 ]];
  const T& front() const
  [[ expects: size() > 0 ]];
  void push_back(T t)
  [[ expects: size() < N ]];
  // ensures: size() == old size()+1
  //          back() == t
  T pop_front();
  // requires: size() > 0
  // ensures: size() == old size()-1
  //          return == old front();
};
```

Using C++20 contract attributes for ringbuffer

```
template <typename T, int N>
class ringbuffer {
public:
  // invariant: size() ⩾ 0 && size() ⩽ N
  int size() const;
  ringbuffer()
  [[ ensures: size() == 0 ]];
  const T& back() const
  [[ expects: size() > 0 ]];
  const T& front() const
  [[ expects: size() > 0 ]];
  void push_back(T t)
  [[ expects: size() < N ]];
  // ensures: size() == old size()+1
  //          back() == t
  T pop_front();
  // requires: size() > 0
  // ensures: size() == old size()-1
  //          return == old front();
};
```

There is no way to refer to previous state so this cannot be expressed!

Using C++20 contract attributes for ringbuffer

```
template <typename T, int N>
class ringbuffer {
public:
  // invariant: size() ⩾ 0 && size() ⩽ N
  int size() const;
  ringbuffer()
  [[ ensures: size() == 0 ]];
  const T& back() const
  [[ expects: size() > 0 ]];
  const T& front() const
  [[ expects: size() > 0 ]];
  void push_back(T t)
  [[ expects: size() < N ]]
  [[ ensures: size() > 0 ]]; // incremented
  //          back() == t
  T pop_front();
  // requires: size() > 0
  // ensures: size() == old size()-1
  //          return == old front();
};
```

Using C++20 contract attributes for ringbuffer

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  [[ ensures: size() == 0 ]];
  const T& back() const
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  [[ expects: size() > 0 ]];
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  // requires: size() > 0
  // ensures: size() == old size()-1
  //          return == old front();
};
```

Using C++20 contract attributes for ringbuffer

```
template <typename T,
class ringbuffer {
public:
  // invariant: size(
  int size() const;
  ringbuffer()
  [[ ensures: size()
  const T& back() con
  [[ expects: size()
  const T& front() co
  [[ expects: size()
  void push_back(T t)
  [[ expects: size()
  [[ ensures: size()
  //          back()
  T pop_front();
  // requires: size() > 0
  // ensures: size() == old size()-1
  //          return == old front();
};
```

6# If a function has multiple preconditions, their evaluation (if any) will be performed in the order they appear lexically. If a function has multiple postconditions, their evaluation (if any) will be performed in the order they appear lexically. [Example:

```
void f(int * p)
  [[expects: p != nullptr]]                    // #1
  [[ensures: *p == 1]]                         // #3
  [[expects: *p == 0]]                         // #2
{
  *p = 1;
}
```

— end example]

http://eel.is/c++draft/dcl.attr.contract#cond-6

Using C++20 contract attributes for ringbuffer

```
template <typename T,
class ringbuffer {
public:
  // invariant: size(
  int size() const;
  ringbuffer()
  [[ ensures: size()
  const T& back() con
  [[ expects: size()
  const T& front() co
  [[ expects: size()
  void push_back(T t)
  [[ expects: size()
  [[ ensures: size()
  //          back()
  T pop_front();
  // requires: size() > 0
  // ensures: size() == old size()-1
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};
```

6# If a function has multiple preconditions, their evaluation (if any) will be performed in the order they appear lexically. If a function has multiple postconditions, their evaluation (if any) will be performed in the order they appear lexically. [Example:

```
void f(int * p)
  [[expects: p != nullptr]]          // #1
  [[ensures: *p == 1]]               // #3
  [[expects: *p == 0]]               // #2
{
  *p = 1;
}
```

— end example]

http://eel.is/c++draft/dcl.attr.contract#cond-6

Using C++20 contract attributes for ringbuffer

```
template <typename T,
class ringbuffer {
public:
  // invariant: size(
  int size() const;
  ringbuffer()
  [[ ensures: size()
  const T& back() con
  [[ expects: size()
  const T& front() co
  [[ expects: size()
  void push_back(T t)
  [[ expects: size() < N ]]
  [[ ensures: size() > 0 ]]; // incremented
  //          back() == t
  T pop_front();
  // requires: size() > 0
  // ensures: size() == old size()-1
  //          return == old front();
};
```

7# If a postcondition odr-uses ([basic.def.odr]) a parameter in its predicate and the function body makes direct or indirect modifications of the value of that parameter, the behavior is undefined. [Example :

```
int f(int x)
  [[ensures r: r == x]]
{
  return ++x;                    // undefined behavior
}

...
```

http://eel.is/c++draft/dcl.attr.contract#cond-7

Using C++20 contract attributes for ringbuffer

```
template <typename T,
class ringbuffer {
public:
  // invariant: size(
  int size() const;
  ringbuffer()
  [[ ensures: size()
  const T& back() con
  [[ expects: size()
  const T& front() co
  [[ expects: size()
  void push_back(T t)
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So the validity of the post condition **declaration** depends on how the function is implemented

Using C++20 contract attributes for ringbuffer

```
template <typename T, int N>
class ringbuffer {
public:
  // invariant: size() ⩾ 0 && size() ⩽ N
  int size() const;
  ringbuffer()
  [[ ensures: size() == 0 ]];
  const T& back() const
  [[ expects: size() > 0 ]];
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Cannot express condition with previous state so might as well leave as comment

Virtual functions and contracts in C++20

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If an overriding function specifies contract conditions ([dcl.attr.contract]), it shall specify the same list of contract conditions as its overridden functions; no diagnostic is required if corresponding conditions will always evaluate to the same value. Otherwise, it is considered to have the list of contract conditions from one of its overridden functions; ...

http://eel.is/c++draft/class.virtual#19

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Function pointers and contracts in C++20

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3 #[*Note*: A function pointer cannot include contract conditions. [*Example*:

```
typedef int (*fpt)(int) [[ensures r: r ≠ 0]];
     // error: contract condition not on a function declaration

int g(int x) [[expects: x ⩾ 0]] [[ensures r: r > x]]
{
  return x+1;
}

int (*pf)(int) = g;                 // OK
int x = pf(5);                      // contract conditions of g are checked
```

— *end example*] — *end note*]

http://eel.is/c++draft/dcl.attr.contract#cond-3

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{
  return x+1;
}

int (*pf)(int) = g;
int x = pf(5);
```

```
// OK
// contract conditions of g are checked
```

In other words, it is the responsibility of a function implementation to enforce its contracts, not the caller.

— *end example*] — *end note*]

http://eel.is/c++draft/dcl.attr.contract#cond-3

Let’s explore!

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Fork from clang-6

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Policing contracts in C++20

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3# A translation may be performed with one of the following build levels: *off*, *default*, or *audit*. A translation with build level set to *off* performs no checking for any contract. A translation with build level set to *default* performs checking for default contracts. A translation with build level set to *audit* performs checking for default and audit contracts. If no build level is explicitly selected, the build level is *default*. The mechanism for selecting the build level is implementation-defined. The translation of a program consisting of translation units where the build level is not the same in all translation units is conditionally-supported. There should be no programmatic way of setting, modifying, or querying the build level of a translation unit.

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3.7 [defns.cond.supp]

conditionally-supported

program construct that an implementation is not required to support

[*Note*: Each implementation documents all conditionally-supported constructs that it does not support. — *end note*]

`http://eel.is/c++draft/intro.defs#defns.cond.supp`

`http://eel.is/c++draft/dcl.attr.contract#check-3`

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```
-build-level=(off|default|audit)
```

When contracts are violated in C++20

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5# The violation handler of a program is a function of type "noexcept$_{opt}$ function of (lvalue reference to `const std::contract_violation`) returning void". The violation handler is invoked when the predicate of a checked contract evaluates to false (called a contract violation). There should be no programmatic way of setting or modifying the violation handler. It is implementation-defined how the violation handler is established for a program and how the `std::contract_violation` argument value is set, except as specified below. If a precondition is violated, the source location of the violation is implementation-defined. [*Note*: Implementations are encouraged but not required to report the caller site. — *end note*] If a postcondition is violated, the source location of the violation is the source location of the function definition. If an assertion is violated, the source location of the violation is the source location of the statement to which the assertion is applied.

http://eel.is/c++draft/dcl.attr.contract#check-5

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16.8.2 Class contract_violation [support.contract.cviol]

```
namespace std {
  class contract_violation {
  public:
    uint_least32_t line_number() const noexcept;
    string_view file_name() const noexcept;
    string_view function_name() const noexcept;
    string_view comment() const noexcept;
    string_view assertion_level() const noexcept;
  };
}
```

http://eel.is/c++draft/support.contract.cviol

http://eel.is/c++draft/dcl.attr.contract#check-5

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Let’s explore!

https://github.com/arcosuc3m/clang-contracts

Fork from clang-6

http://fragata.arcos.inf.uc3m.es/#

```
-build-level=(off|default|audit)
```

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```
-build-level=(off|default|audit)
```

```
-contract-violation-handler=function
```

When contracts are violated in C++20

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A translation may be performed with one of the following violation continuation modes: *off* or *on*. A translation with violation continuation mode set to *off* terminates execution by invoking the function `std::terminate` ([except.terminate]) after completing the execution of the violation handler. A translation with a violation continuation mode set to *on* continues execution after completing the execution of the violation handler. If no continuation mode is explicitly selected, the default continuation mode is *off*. [*Note*: A continuation mode set to *on* provides the opportunity to install a logging handler to instrument a pre-existing code base and fix errors before enforcing checks. — *end note*]

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[*Example*:

```
void f(int x) [[expects: x > 0]];

void g() {
  f(0);  // std::terminate() after handler if
         // continuation mode is off;
         // proceeds after handler if
         // continuation mode is on
  /*  ...  */
}
```

— *end example*]

http://eel.is/c++draft/dcl.attr.contract#check-7

Programming with Contracts in C++20

Björn Fahller

Summary

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@bjorn_fahller 

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