Contract assertions, the noexcept operator, and deduced exception specifications

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Audience: SG21 (Contracts)
Contracts MVP – The Final Boss
Every C++ expression is:

- either potentially-throwing
- or not potentially-throwing
An expression $E$ is *potentially-throwing* if

- $E$ is a *function call* whose *postfix-expression* has a function type, or a pointer-to-function type, with a potentially-throwing exception specification, or

- $E$ implicitly invokes a function (such as an overloaded operator, an allocation function in a *new-expression*, a constructor for a function argument, or a destructor if $E$ is a *full-expression*) that has a potentially-throwing exception specification, or

- $E$ is a *throw-expression* ([expr.throw]), or

- $E$ is a *dynamic_cast* expression that casts to a reference type and requires a runtime check ([expr.dynamic.cast]), or

- $E$ is a *typeid* expression applied to a (possibly parenthesized) built-in unary * operator applied to a pointer to a polymorphic class type ([expr.typeid]), or

- any of the *immediate subexpressions* of $E$ is potentially-throwing.
Every C++ expression is:

- either potentially-throwing
- or not potentially-throwing

It matters in two situations:

- result of `noexcept(expr)`
- whether defaulted special member functions are `noexcept` (exception specification is deduced by the compiler)
Are contract assertions potentially-throwing?
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It doesn't matter for pre and post:

```cpp
noexcept(pre(f()))  // ill-formed (pre/post are not expressions)

struct X
{
    X() pre(f()) = default;  // ill-formed (consensus in Kona)
}
```
Are contract assertions potentially-throwing?

It matters for contract_assert:

```cpp
noexcept(contract_assert(false));  // true or false?
```
Are contract assertions potentially-throwing?

It matters for `contract_assert`:

```c++
noexcept(contract_assert(false));  // true or false?

noexcept((contract_assert(x.a()), x.b()));  // true or false?
```
Are contract assertions potentially-throwing?

It matters for `contract_assert`:

```cpp
nothrow(contract_assert(false));  // true or false?

nothrow((contract_assert(x.a()), x.b()));  // true or false?
```

```cpp
class B {
    int i = (contract_assert(true), 17);  // default member initialiser
    B(int j = (contract_assert(true), 34));  // default argument
};

class D : B {};  // noexcept(D{}) true or false ?
```
Fact: `contract_assert(x)` can throw an exception.
Fact: contract_assert(x) can throw an exception.

#include <contracts>
using namespace std::contracts;

handle_contract_violation(const contract_violation&) {
    throw 666;
}

int main() {
    contract_assert(false); // this statement throws an exception
}
Design principle: "Concepts do not see Contracts" (P2932)

Adding a contract annotation to an existing program must **never** alter the compile-time semantics of the program:

- Whether a concept or constraint is satisfied
- SFINAE
- Overload resolution
- which branch is taken by if constexpr
- the result of operator noexcept
- ...


Design principle: "Concepts do not see Contracts" (P2932)

Adding a contract annotation to an existing program must never alter the compile-time semantics of the program:

- Whether a concept or constraint is satisfied
- SFINAE
- Overload resolution
- Which branch is taken by `if constexpr`
- The result of operator `noexcept`
- ...
Options

1. Make `contract_assert(x)` potentially-throwing (P2969R0, option 3.1)

    ```cpp
    noexcept(contract_assert(false));  // -> false
    noexcept((contract_assert(x.a()), x.b()));  // -> false
    ```

    ```cpp
    class B {
        int i = (contract_assert(true), 17);  // default member initialiser
        B(int j = (contract_assert(true), 34));  // default argument
    };
    ```

    ```cpp
    class D : B {};  // noexcept(D{}) -> false
    ```
Options

2. Make `contract_assert(x)` not potentially-throwing
   ~ "operator noexcept assumes no contract violations happen"
   (P2969R0, option 3.2)

```cpp
noexcept(contract_assert(false)); // -> true
noexcept((contract_assert(x.a()), x.b())); // -> true

class B {
    int i = (contract_assert(true), 17);  // default member initialiser
    B(int j = (contract_assert(true), 34));  // default argument
};
class D : B {};  // noexcept(D{}) -> true
```
Options

3. When determining if a set of expressions is potentially-throwing, CCAs are not considered. If there are no non-CCA expressions the query is ill-formed. (P2932R2, proposal 7A)

```cpp
noexcept(contract_assert(false)); // -> ill-formed, like noexcept()
noexcept((contract_assert(x.a()), x.b())); // -> true

class B {
    int i = (contract_assert(true), 17); // default member initialiser
    B(int j = (contract_assert(true), 34)); // default argument
};
class D : B {}; // noexcept(D{}) -> true
```
Options

4. Allow both options, via an extra annotation (P2969R0, option 3.3)

```cpp
int f(int i) pre (i > 0); // potentially-throwing contract check
int g(int i) pre noexcept (i > 0); // non-throwing contract check
```
Options

4. Allow both options, via an extra annotation (P2969R0, option 3.3)

```cpp
int f(int i) pre (i > 0);  // potentially-throwing contract check
int g(int i) pre noexcept (i > 0); // non-throwing contract check
```

→ not proposed; exact syntax and semantics unclear, no paper, default case still violates Concepts do not see Contracts
Options

5. Allow erroneously thrown exceptions to escape deduced non-throwing exception specifications (P2969R0, option 3.4)
Options

5. Allow erroneously thrown exceptions to escape deduced non-throwing exception specifications
   (P2969R0, option 3.4)

→ not proposed; we have SG21 consensus to not do this:

Poll, 2023-05-18
Throwing an exception from a contract violation handler shall invoke the usual exception semantics: stack unwinding occurs, and if a `noexcept` barrier is encountered during unwinding, std::terminate is called, as proposed in P2811.

SF F N A SA
10 7 2 0 0

Result: Consensus
Options

6. `contract_assert` is neither potentially-throwing nor not potentially-throwing. Any use of `contract_assert` in a situation where this must be determined is ill-formed. (P2969R0, option 3.5; P2832R2, proposal 7B)
Options

6. contract_assert is neither potentially-throwing nor not potentially-throwing. Any use of contract_assert in a situation where this must be determined is ill-formed. (P2969R0, option 3.5; P2832R2, proposal 7B)

   a. Make contract_assert a statement, not an expression
   b. Make it ill-formed if a contract_assert appears as a subexpression of the operand of noexcept or while deducing an exception specification
   c. Make it ill-formed if a contract_assert appears as a subexpression of the operand of noexcept or while deducing an exception specification, and no other subexpression is potentially-throwing
Options

6. `contract_assert` is neither potentially-throwing nor not potentially-throwing. Any use of `contract_assert` in a situation where this must be determined is ill-formed. (P2969R0, option 3.5; P2832R2, proposal 7B)

   a. Make `contract_assert` a statement, not an expression

   b. Make it ill-formed if a `contract_assert` appears as a subexpression of the operand of `noexcept` or while deducing an exception specification → not proposed

   c. Make it ill-formed if a `contract_assert` appears as a subexpression of the operand of `noexcept` or while deducing an exception specification, and no other subexpression is potentially-throwing
Options

6a. Make contract_assert a statement, not an expression

```cpp
noexcept(contract_assert(false)); // -> ill-formed
noexcept((contract_assert(x.a()), x.b())); // -> ill-formed

class B {
    int i = (contract_assert(true), 17); // -> ill-formed
    B(int j = (contract_assert(true), 34)); // -> ill-formed
};
```
Options

6c. Make it ill-formed if a `contract_assert` appears as a subexpression of the operand of `nothrow` or while deducing an exception specification, and no other subexpression is potentially-throwing

```cpp
nothrow(contract_assert(false)); // -> ill-formed
nothrow((contract_assert(false), true)); // -> ill-formed
nothrow((contract_assert(false), throw 666)); // -> OK, returns false
```
Options

7. Address the issue via coding guidelines or diagnostics
   - with `contract_assert` potentially-throwing or not potentially-throwing
   - with diagnostics being normative, recommended practice, or QoI
Options

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   • with `contract_assert` potentially-throwing or not potentially-throwing
   • with diagnostics being normative, recommended practice, or QoI

→ not proposed; not really a solution as we still need to define the normative behaviour
Options

8. Make `contract_assert(x)` not potentially-throwing and the contract-violation handler always `noexcept` (P2969R0, option 3.7: "Remove support for throwing contract-violation handlers").
Viable options – Overview

1. Make `contract_assert(x)` potentially-throwing
2. Make `contract_assert(x)` not potentially-throwing
3. When determining if a set of expressions is potentially-throwing, `contract_assert` is not considered; if there are no expressions other than `contract_assert`, the query is ill-formed

6a. Make `contract_assert` a statement rather than an expression

6c. `contract_assert` is neither potentially-throwing nor not potentially-throwing; if a `contract_assert` appears as a subexpression of the operand of `nothrow` or while deducing an exception specification, and no other subexpression is potentially-throwing, the program is ill-formed.

8. Make `contract_assert(x)` not potentially-throwing and the contract-violation handler always `nothrow` (= remove throwing violation handlers)
Instead of talking about solutions, let's talk about the underlying design goals and principles!

*The Swan, The Pike, and The Crab – Fable by Ivan Krylov, 1814*
Desiderata for this problem:

- Maximises teachability
- Minimises chance of standardising something suboptimal
- Concepts do not see Contracts (~ adding a contract assertion cannot silently switch behaviour of surrounding code)
- Maximises consistency with existing language
- Minimises cognitive dissonance with current understanding that noexcept(x) means "x will not throw"
- Minimises making code ill-formed when adding Contracts to it
- Minimises interaction between Contracts and exception handling (makes them orthogonal)
- Minimises ability to write useless code
- Maximises backward-compatible evolution of the language
- Does not inject new code paths into existing code
- Maximises compatibility with code bases that compile with exceptions turned off or have coding guidelines against using exceptions
- Does not disenfranchise important use cases
- Allows effective negative testing
- Allows recovery (non-terminating non-continuing violation handling)
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These are the four properties which were referred to with words like "this is imperative", "people won't use Contracts", "I will vote against Contracts", "over my dead body", etc.
<table>
<thead>
<tr>
<th>Concepts do not see Contracts</th>
<th>1. contract assert is potentially-throwing</th>
<th>2. contract assert is not potentially-throwing</th>
<th>3. contract assert is not considered when determining exception spec</th>
<th>6a. Make contract assert a statement, not an expression</th>
<th>6c. Determining exception spec of contract assert is ill-formed</th>
<th>8. Remove support for throwing contract-violation handlers</th>
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</thead>
<tbody>
<tr>
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<td>Unlike options 2 and 3, this does not subvert the meaning of noexcept(x), but it creates a new category of expressions for which noexcept(x) is ill-formed</td>
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Treating `contract_assert` as not potentially-throwing lands you in the `noexcept(true)` branch of algorithms such as `push_back`; throwing an exception in such a place is likely to lead to UB, reducing the usefulness of a throwing contract-violation handler.
Desiderata for this problem:

- Maximises teachability
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- Concepts do not see Contracts (~ adding a contract assertion cannot silently switch behaviour of surrounding code)
- Maximises consistency with existing language
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- **Maximises backward-compatible evolution of the language**
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- Maximises compatibility with code bases that compile with exceptions turned off or have coding guidelines against using exceptions
- Does not disenfranchise important use cases
- Allows effective negative testing
- Allows recovery (non-terminating non-continuing violation handling)
Possible language evolution paths

1. contract_assert is potentially-throwing
2. contract_assert is not potentially-throwing
3. contract_assert is not considered when determining exception spec
4. determining exception spec of contract Assert is ill-formed
5a. Make contract_assert a statement, not an expression
5b. Remove support for throwing contract-violation handlers
6a. Make contract Assert a statement, not an expression
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7. Make contract Assert a statement, not an expression
8. Remove support for throwing contract-violation handlers