

Contract Use: Past, Present, and Future

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Who am I?

- Software developer all century



- I have a purple house.
- First time presenting at CppCon
- First time presenting at a Conference

Who am I?

- Software developer all century



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Who am I?

- Bloomberg LP since 2017
- Joined BDE team in 2018
- Contract checking and deployment with BSLS_REVIEW
- WG21 participation to make contracts better
- SG21 participation with same goal

- 1 Introduction
- 2 Basic Contracts
 - English Contracts
 - In Code Contracts
- 3 Doing Stuff With Contracts
- 4 SG21
- 5 Conclusion

English Contracts

Contracts are an agreement between two parties

English Contracts

Software contracts are an agreement between a library writer and client

English Contracts

Function contracts can be rendered in english

```
T* binsearch(T*begin, T*end, const T& val);  
    // Return a pointer to an element between the  
    // specified 'begin' and 'end' that is greater  
    // than or equal to the specified 'val', or 'end'  
    // if no such value exists. This function will  
    // perform no more than log(distance(begin,end))  
    // comparisons. The behavior is undefined  
    // unless '[begin,end)' is a contiguous sorted  
    // range.
```

English Contracts

Describe what a function will do

```
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  // specified 'begin' and 'end' that is greater  
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English Contracts

Describe what behavior is not supported

```
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    // specified 'begin' and 'end' that is greater  
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```

Undefined Behavior

undefined behavior

behavior for which this document imposes no requirements

N4830 - Working Draft, Standard for Programming Language C++

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library undefined behavior

behavior for which a library contract provides no guarantees

John Lakos - CppCon 2014

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```

English Contracts

Preconditions

```
T* binsearch(T*begin, T*end, const T& val);  
    // Return a pointer to an element between the  
    // specified 'begin' and 'end' that is greater  
    // than or equal to the specified 'val', or 'end'  
    // if no such value exists. This function will  
    // perform no more than  $\log(\text{distance}(\text{begin}, \text{end}))$   
    // comparisons. The behavior is undefined  
    // unless '[begin, end)' is a contiguous sorted  
    // range.
```


English Contracts

Postconditions

```
T* binsearch(T*begin, T*end, const T& val);  
  // Return a pointer to an element between the  
  // specified 'begin' and 'end' that is greater  
  // than or equal to the specified 'val', or 'end'  
  // if no such value exists. This function will  
  // perform no more than  $\log(\text{distance}(\text{begin}, \text{end}))$   
  // comparisons. The behavior is undefined  
  // unless '[begin, end)' is a contiguous sorted  
  // range.
```

English Contracts

Essential Behavior

```
T* binsearch(T*begin, T*end, const T& val);  
    // Return a pointer to an element between the  
    // specified 'begin' and 'end' that is greater  
    // than or equal to the specified 'val', or 'end'  
    // if no such value exists. This function will  
    // perform no more than log(distance(begin,end))  
    // comparisons. The behavior is undefined  
    // unless '[begin,end)' is a contiguous sorted  
    // range.
```

Violating a contract is a bug

Violating a contract is a bug

Bugs are contract violations

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Bugs are contract violations

Possibly a contract no one wrote down

What can be checked?

- Parts of the english contract might be checkable with standard C++ expressions.

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- Parts might have readable representations that cannot be implemented

What can be checked?

- Parts of the english contract might be checkable with standard C++ expressions.
- Parts might have readable representations that cannot be implemented
- Parts might be statements beyond the scope of a single function execution

In code contracts

Some parts can be rendered with code

```
T* binsearch(T*begin, T*end, const T& val);  
    // Return a pointer to an element between the  
    // specified 'begin' and 'end' that is greater  
    // than or equal to the specified 'val', or 'end'  
    // if no such value exists. This function will  
    // perform no more than log(distance(begin,end))  
    // comparisons. The behavior is undefined  
    // unless '[begin,end)' is a contiguous sorted  
    // range.
```

In code contracts

Simple boolean predicates

```
begin != nullptr  
end != nullptr  
begin <= end
```

```
T* binsearch(T*begin, T*end, const T& val);  
    // Return a pointer to an element between the  
    // specified 'begin' and 'end' that is greater  
    // than or equal to the specified 'val', or 'end'  
    // if no such value exists. This function will  
    // perform no more than log(distance(begin,end))  
    // comparisons. The behavior is undefined  
    // unless '[begin,end)' is a contiguous sorted  
    // range.
```

In code contracts

Predicates about returned value

```
return_val >= begin  
return_val <= end  
return_val == end *return_val >= val
```

```
T* binsearch(T*begin, T*end, const T& val);  
// Return a pointer to an element between the  
// specified 'begin' and 'end' that is greater  
// than or equal to the specified 'val', or 'end'  
// if no such value exists. This function will  
// perform no more than log(distance(begin,end))  
// comparisons. The behavior is undefined  
// unless '[begin,end)' is a contiguous sorted  
// range.
```

In code contracts

Hard to check things

```
is_sorted(begin, end)
```

```
T* binsearch(T*begin, T*end, const T& val);  
    // Return a pointer to an element between the  
    // specified 'begin' and 'end' that is greater  
    // than or equal to the specified 'val', or 'end'  
    // if no such value exists. This function will  
    // perform no more than log(distance(begin, end))  
    // comparisons. The behavior is undefined  
    // unless '[begin, end)' is a contiguous sorted  
    // range.
```

In code contracts

Uncheckable things?

```
is_reachable_from(begin,end)
```

```
T* binsearch(T*begin, T*end, const T& val);  
    // Return a pointer to an element between the  
    // specified 'begin' and 'end' that is greater  
    // than or equal to the specified 'val', or 'end'  
    // if no such value exists. This function will  
    // perform no more than log(distance(begin,end))  
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    // unless '[begin,end)' is a contiguous sorted  
    // range.
```

In code contracts

Properties of repeated execution

????????????????

```
T* binsearch(T*begin, T*end, const T& val);  
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    // specified 'begin' and 'end' that is greater  
    // than or equal to the specified 'val', or 'end'  
    // if no such value exists. This function will  
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 - A Dream
 - Less Bugs
 - Deploying it
 - Faster Code
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Proven contracts

- Prove software correctness

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- Encode contracts completely

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 - All preconditions

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 - For each function, prove postconditions and essential behavior

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 - For each function, prove postconditions and essential behavior
 - Use called functions contract in proofs of larger functions

Proven contracts

- Prove software correctness
- Encode contracts completely
 - All preconditions
 - All postconditions
 - All essential behavior
- Statically prove everything
 - For each function, prove postconditions and essential behavior
 - Use called functions contract in proofs of larger functions
- PROFIT

Dream Benefit #1 - Less Bugs

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- Compiler identifies all violated contracts

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- Compiler identifies all violated contracts
- Edge cases must be thought through
- All assumptions are captured in compiled code
- Mostly, if it compiles, it doesn't have bugs (contract violations)
- If there is a bug, contracts just need to be elaborated

Dream Benefit #2 - Less Heat Generation

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- No need for any checks

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- More knowledge for the compiler

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 - Vectorization/SIMD instructions

Dream Benefit #2 - Less Heat Generation

- No need for any checks
- More knowledge for the compiler
 - `__builtin_assume`
 - Removing excess branches
 - Vectorization/SIMD instructions
- Smaller code size

Realizing parts of the dream

- WARNING:

Realizing parts of the dream

- WARNING: MACROS INCOMING

Realizing parts of the dream

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- How to leverage contracts without a language feature

Realizing parts of the dream

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- How to leverage contracts without a language feature
- Bloomberg has been doing this for 15 years

Realizing parts of the dream

- WARNING: MACROS INCOMING
- How to leverage contracts without a language feature
- Bloomberg has been doing this for 15 years
- See the BDE open source repository for the real implementation
 - https://github.com/bloomberg/bde/blob/master/groups/bsl/bsls/bsls_assert.h
 - https://github.com/bloomberg/bde/blob/master/groups/bsl/bsls/bsls_review.h

What do you do if you can't prove a contract is being followed?

What do you do if you can't prove a contract is being followed?

Experiment

- 1 Introduction
- 2 Basic Contracts
- 3 **Doing Stuff With Contracts**
 - A Dream
 - **Less Bugs**
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Documenting expectations

- Initial benefit of contracts in code

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```
#define ASSERT(X)
```

Documenting expectations

- Initial benefit of contracts in code
- Bloomberg specific naming

```
#define BSLS_ASSERT(X)
```


Documenting expectations

- Initial benefit of contracts in code
- Bloomberg specific naming
- Avoid code rot

```
#define BSLS_ASSERT(X) sizeof( (X)?true:false )
```

Documenting expectations

- Initial benefit of contracts in code
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- Avoid code rot
- ... wish we had done that originally

```
#ifdef BSLS_ASSERT_VALIDATE_DISABLED_MACROS  
#define BSLS_ASSERT(X) sizeof( (X)?true:false )  
#else  
#define BSLS_ASSERT(X)  
#endif
```

Documenting expectations

- Initial benefit of contracts in code
- Bloomberg specific naming
- Avoid code rot
- ... wish we had done that originally
- ... or at least this to require a ;

```
#define BSLS_ASSERT(X) ((void)0)
```

Documenting expectations

- Initial benefit of contracts in code
- Bloomberg specific naming
- Avoid code rot
- ... wish we had done that originally
- ... or at least this to require a ;
- For simplicity

```
#define ASSERT(X)
```

Aborting on bugs

- Identifying violations would be nice

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- The safest thing to do is stop immediately

```
#define ASSERT(X) if (!(X)) { std::abort(); }
```

Aborting on bugs

- Identifying violations would be nice
- The safest thing to do is stop immediately
- Nice if ASSERT(X) needs a semicolon

```
#define ASSERT(X) do { if (!(X)) { std::abort(); } } while (false)
```

Aborting on bugs

- Identifying violations would be nice
- The safest thing to do is stop immediately
- Nice if ASSERT(X) needs a semicolon
- For simplicity

```
#define ASSERT(X) if (!(X)) { std::abort(); }
```


... only in some builds

- Checks of contracts are redundant if they're not broken

... only in some builds

- Checks of contracts are redundant if they're not broken
- NDEBUG might be a way to control enablement

```
#ifdef NDEBUG  
#define ASSERT(X)  
else  
#define ASSERT(X) if (!(X)) { std::abort(); }  
#endif
```

... only in some builds

- Checks of contracts are redundant if they're not broken
- NDEBUG might be a way to control enablement
- This reminds me of something

```
#include <cassert>  
#define ASSERT(X) assert(X)
```

... only in some builds

- Checks of contracts are redundant if they're not broken
- NDEBUG might be a way to control enablement
- This reminds me of something
- Separating out controls from behavior helps

```
#define ASSERT_IMP(X)          if (!(X)) { std::abort(); }
```

... only in some builds

- Checks of contracts are redundant if they're not broken
- NDEBUG might be a way to control enablement
- This reminds me of something
- Separating out controls from behavior helps

```
#define ASSERT_IMP(X)          if (!(X)) { std::abort(); }  
#define ASSERT_DISABLED_IMP(X)
```

... only in some builds

- Checks of contracts are redundant if they're not broken
- NDEBUG might be a way to control enablement
- This reminds me of something
- Separating out controls from behavior helps

```
#define ASSERT_IMP(X)          if (!(X)) { std::abort(); }  
#define ASSERT_DISABLED_IMP(X)  
  
#ifdef ASSERT_LEVEL_ASSERT  
#define ASSERT(X) ASSERT_IMP(X)  
#else  
#define ASSERT(X) ASSERT_DISABLED_IMP(X)  
#endif
```

... but what happened?

- Aborting with no information sucks

```
#define ASSERT_IMP(X) if (!(X)) {  
    /*POOF*/;  
    std::abort();  
}
```

... but what happened?

- Aborting with no information sucks
- Logging something helps

```
#define ASSERT_IMP(X) if (!(X)) {                                \
    printf("ASSERTION FAILED!\n");                               \
                                                                    \
    std::abort();                                                 \
}
```


... but what happened?

- Aborting with no information sucks
- Logging something helps
- The preprocessor can give us more help

```
#define ASSERT_IMP(X) if (!(X)) { \
    printf("ASSERTION FAILED (" __FILE__ ":%d): %s\n", \
        __LINE__, #X); \
    std::abort(); \
}
```

What about this guy?

⚠ ERROR

IF YOU'RE SEEING THIS, THE CODE IS IN WHAT I THOUGHT WAS AN UNREACHABLE STATE.

I COULD GIVE YOU ADVICE FOR WHAT TO DO. BUT HONESTLY, WHY SHOULD YOU TRUST ME? I CLEARLY SCREWED THIS UP. I'M WRITING A MESSAGE THAT SHOULD NEVER APPEAR, YET I KNOW IT WILL PROBABLY APPEAR SOMEDAY.

ON A DEEP LEVEL, I KNOW I'M NOT UP TO THIS TASK. I'M SO SORRY.



NEVER WRITE ERROR MESSAGES TIRED.

... but what happened?

- Aborting with no information sucks
- Logging something helps
- The preprocessor can give us more help
- Delegating to a pluggable function helps that

```
#define ASSERT_IMP(X) if (!(X)) { \
    bb::Assert::invoke_violation_handler(__FILE__, __LINE__, #X); \
    \
    std::abort(); \
}
```

... but what happened?

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- Logging something helps
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```
#define ASSERT_IMP(X) if (!(X)) { \
    bb::assert_violation violation(__FILE__, __LINE__, #X); \
    bb::Assert::invoke_violation_handler(violation); \
    std::abort(); \
}
```

... but what happened?

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- Delegating to a pluggable function helps that
- Leave all behavior up to the violation handler

```
#define ASSERT_IMP(X) if (!(X)) { \
    bb::assert_violation violation(__FILE__, __LINE__, #X); \
    bb::Assert::invoke_violation_handler(violation); \
}
```

... but what happened?

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```
void bb::Assert::invoke_violation_handler(  
    const bb::assert_violation &violation) {  
    getViolationHandler()(violation);  
}
```

... but what happened?

- Aborting with no information sucks
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```
void xkcd::violationHandler(const bb::assert_violation &violation) {  
    printf("Error\n");  
    printf("If you're seeing this, the code is in what\n");  
    printf("I thought was an unreachable state.");  
    //...  
}
```

... but what happened?

- Aborting with no information sucks
- Logging something helps
- The preprocessor can give us more help
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- Leave all behavior up to the violation handler

```
int main() {  
    bb::Assert::setViolationHandler(&xkcd::violationHandler);  
    //..  
}
```


... that doesn't work everywhere!

- The violation handler can notify in different ways

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- ... do different things
 - `std::abort()`
 - `while (true) {std::this_thread::sleep_for(std::chrono::years(1));}`

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- The violation handler can notify in different ways
 - Custom logging frameworks
 - GUI messages (abort, retry, fail?)
 - Hardware notifications
- ... do different things
 - `std::abort()`
 - `while (true) {std::this_thread::sleep_for(std::chrono::years(1));}`
 - `throw std::exception("Oops?");`

... that doesn't work everywhere!

- The violation handler can notify in different ways
 - Custom logging frameworks
 - GUI messages (abort, retry, fail?)
 - Hardware notifications
- ... do different things
 - `std::abort()`
 - `while (true) {std::this_thread::sleep_for(std::chrono::years(1));}`
 - `throw std::exception("Oops?");`
- ... or try to recover?

... that doesn't work everywhere!

- The violation handler can notify in different ways
 - Custom logging frameworks
 - GUI messages (abort, retry, fail?)
 - Hardware notifications
- ... do different things
 - `std::abort()`
 - `while (true) {std::this_thread::sleep_for(std::chrono::years(1));}`
 - `throw std::exception("Oops?");`
- ... or try to recover?
- main gets to decide

Checking is slow!

- Checks use state already in cache, are often very fast

```
T* binsearch(T*begin, T*end, const T& val) {  
    ASSERT(begin);  
    ASSERT(end);  
    ASSERT(begin < end)  
    //..  
}
```

Checking is slow!

- Checks use state already in cache, are often very fast
- Algorithmic complexity can still ruin that

```
T* binsearch(T*begin, T*end, const T& val) {  
    ASSERT(is_sorted_range(begin,end));  
    //..  
}
```

Checking is slow!

- Checks use state already in cache, are often very fast
- Algorithmic complexity can still ruin that
- 3 levels of complexity

```
#define ASSERT_OPT(X) ...  
#define ASSERT(X) ...  
#define ASSERT_SAFE(X) ...
```

Checking is slow!

- Checks use state already in cache, are often very fast
- Algorithmic complexity can still ruin that
- 3 levels of complexity
- ... 2 levels probably sufficient

```
[[ assert default : X ]];  
[[ assert audit : X ]];
```

Checking is slow!

- Checks use state already in cache, are often very fast
- Algorithmic complexity can still ruin that
- 3 levels of complexity
- ... 2 levels probably sufficient
- Linear scale of enablement

```
#if defined(ASSERT_LEVEL_NONE)    ? 1 : 0 \  
  + defined(ASSERT_LEVEL_OPT)    ? 1 : 0 \  
  + defined(ASSERT_LEVEL_ASSERT) ? 1 : 0 \  
  + defined(ASSERT_LEVEL_SAFE)   ? 1 : 0 \  
  > 1  
#error Multiple ASSERT_LEVEL macros defined  
#endif
```

Checking is slow!

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- 3 levels of complexity
- ... 2 levels probably sufficient
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```
#if !defined(ASSERT_LEVEL_NONE) \
    && !defined(ASSERT_LEVEL_OPT) \
    && !defined(ASSERT_LEVEL_ASSERT) \
    && !defined(ASSERT_LEVEL_SAFE)
#define ASSERT_LEVEL_ASSERT
#endif
```


Checking is slow!

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```
#if defined(ASSERT_LEVEL_NONE)  
#define ASSERT_OPT(X)  ASSERT_DISABLED_IMP(X)  
#define ASSERT(X)      ASSERT_DISABLED_IMP(X)  
#define ASSERT_SAFE(X) ASSERT_DISABLED_IMP(X)  
//..
```

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- 3 levels of complexity
- ... 2 levels probably sufficient
- Linear scale of enablement

```
//..  
#elif defined(ASSERT_LEVEL_OPT)  
#define ASSERT_OPT(X)  ASSERT_IMP(X)  
#define ASSERT(X)      ASSERT_DISABLED_IMP(X)  
#define ASSERT_SAFE(X) ASSERT_DISABLED_IMP(X)  
//..
```

Checking is slow!

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- Algorithmic complexity can still ruin that
- 3 levels of complexity
- ... 2 levels probably sufficient
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```
//..  
#elif defined(ASSERT_LEVEL_ASSERT)  
#define ASSERT_OPT(X)  ASSERT_IMP(X)  
#define ASSERT(X)      ASSERT_IMP(X)  
#define ASSERT_SAFE(X) ASSERT_DISABLED_IMP(X)  
//..
```

Checking is slow!

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- ... 2 levels probably sufficient
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```
//..  
#elif defined(ASSERT_LEVEL_SAFE)  
#define ASSERT_OPT(X)  ASSERT_IMP(X)  
#define ASSERT(X)      ASSERT_IMP(X)  
#define ASSERT_SAFE(X) ASSERT_IMP(X)  
#endif
```

Checking is slow!

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- 3 levels of complexity
- ... 2 levels probably sufficient
- Linear scale of enablement

```
#if defined(ASSERT_LEVEL_OPT)    \  
    defined(ASSERT_LEVEL_ASSERT) \  
    defined(ASSERT_LEVEL_SAFE)  
#define ASSERT_OPT(X) ASSERT_IMP(X)  
#else  
    // defined(ASSERT_LEVEL_NONE)  
#define ASSERT_OPT(X) ASSERT_DISABLED_IMP(X)  
#endif
```

Checking is slow!

- Checks use state already in cache, are often very fast
- Algorithmic complexity can still ruin that
- 3 levels of complexity
- ... 2 levels probably sufficient
- Linear scale of enablement

```
#if defined(ASSERT_LEVEL_ASSERT) \  
    defined(ASSERT_LEVEL_SAFE)  
#define ASSERT(X) ASSERT_IMP(X)  
#else  
    // defined(ASSERT_LEVEL_OPT)  
    // defined(ASSERT_LEVEL_NONE)  
#define ASSERT(X) ASSERT_DISABLED_IMP(X)  
#endif
```

Checking is slow!

- Checks use state already in cache, are often very fast
- Algorithmic complexity can still ruin that
- 3 levels of complexity
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- Linear scale of enablement
- Bloomberg 2005-2018

```
#if defined(ASSERT_LEVEL_SAFE)
#define ASSERT_SAFE(X) ASSERT_IMP(X)
#else
    // defined(ASSERT_LEVEL_OPT)
    // defined(ASSERT_LEVEL_ASSERT)
    // defined(ASSERT_LEVEL_NONE)
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#endif
```

- 1 Introduction
- 2 Basic Contracts
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 - A Dream
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- 5 Conclusion

Choosing Levels in code

- Original Suggestion:

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 - OPT: 5% most critical tests

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- Changing is hard

Choosing Levels in builds

- What we did

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- What we did
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- What we did
 - Developement - `ASSERT_LEVEL_ASSERT`
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 - Production - `ASSERT_LEVEL_ASSERT_OPT`
- What we wanted
 - Developement - `ASSERT_LEVEL_ASSERT` or `ASSERT_LEVEL_SAFE`

Choosing Levels in builds

- What we did
 - Developement - `ASSERT_LEVEL_ASSERT`
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 - Developement - `ASSERT_LEVEL_ASSERT` or `ASSERT_LEVEL_SAFE`
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Choosing Levels in builds

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 - Developement - `ASSERT_LEVEL_ASSERT`
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 - Production - `ASSERT_LEVEL_ASSERT_OPT`
- What we wanted
 - Developement - `ASSERT_LEVEL_ASSERT` or `ASSERT_LEVEL_SAFE`
 - Unit tests - `ASSERT_LEVEL_ASSERT` or `ASSERT_LEVEL_SAFE`
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 - Production - `ASSERT_LEVEL_ASSERT`

Choosing Levels in builds

- What we did
 - Development - `ASSERT_LEVEL_ASSERT`
 - Unit tests - `ASSERT_LEVEL_ASSERT` hopefully
 - Beta testing - `ASSERT_LEVEL_ASSERT_OPT`
 - Production - `ASSERT_LEVEL_ASSERT_OPT`
- What we wanted
 - Development - `ASSERT_LEVEL_ASSERT` or `ASSERT_LEVEL_SAFE`
 - Unit tests - `ASSERT_LEVEL_ASSERT` or `ASSERT_LEVEL_SAFE`
 - Beta testing - `ASSERT_LEVEL_ASSERT` or `ASSERT_LEVEL_SAFE`
 - Production - `ASSERT_LEVEL_ASSERT`
- ... which is where we are

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- Adding more assertions

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- Everyone will need to do this in 202x!

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- Adding more assertions
 - `~bsl::string() { ASSERT(m_data[m_size] == 0); }`
 - Time ABI change
- Changing levels of assertions
 - SAFE to ASSERT
 - ASSERT to OPT
- Changing deployed assertion levels
- Everyone will need to do this in 202x!
 - Using language contracts when they come will be a case of adding new assertions to existing code.

Mis-Step #1

- Continuing violation handler (2008-2015)

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 - At least 1 major Bloomberg (WP) bug was because of this
 - Blanket continuation unsafe

Mis-Step #2

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Mis-Step #2

- Extra Smart violation handler (2016)
 - Configuration to allow continuation
 - Tracking failure counts
 - Alternate logging
- Still unsuccessful
 - Requires even more cooperation from main
 - No way to indicate in code that a check is “new”
 - Rarely used, minimal progress

Step?

- BSLS_REVIEW (2018)

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BSLS_REVIEW overview

- Parallel structure to BSLS_ASSERT

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BSLS_REVIEW overview

- Parallel structure to BSLS_ASSERT
- Separate violation handler, defaults to logging
- Lifecycle BSLS_ASSERT_SAFE to BSLS_REVIEW to BSLS_ASSERT
- Alternately, <nothing> to BSLS_REVIEW_? to BSLS_ASSERT_?

BSLS_REVIEW

- Initially a copy of ASSERT

```
#define REVIEW_IMP(X) if (!(X)) {                                     \  
    bb::assert_violation violation(__FILE__, __LINE__, #X);        \  
    bb::Review::invoke_violation_handler(violation);               \  
}
```

BSLS_REVIEW

- Initially a copy of ASSERT
- Number of failures is important

```
#define REVIEW_IMP(X) if (!(X)) {                                \
    static std::atomic<int> count;                                \
    bb::review_violation violation(__FILE__, __LINE__, ++count, #X);\
    bb::Review::invoke_violation_handler(violation);              \
}
```

BSLS_REVIEW

- Initially a copy of ASSERT
- Number of failures is important
- Default violation handler logs only

```
void Review::default_violation_handler(  
    const bb::review_violation &violation)  
{  
    // Log a message, with contents of violation  
    // Log a stack trace  
    // Return  
}
```

BSLS_REVIEW

- Initially a copy of ASSERT
- Number of failures is important
- Default violation handler logs only
- With exponential backoff

```
void Review::default_violation_handler(  
    const bb::review_violation &violation)  
{  
    int count = violation.count();  
    if (0 == (count & (count-1))) {  
        // Log a message, with contents of violation  
        // Log a stack trace  
    }  
    // Return  
}
```

BSLS_REVIEW Build time control

- Mutually exclusive

```
#if defined(REVIEW_LEVEL_NONE)    ? 1 : 0 \  
  + defined(REVIEW_LEVEL_OPT)    ? 1 : 0 \  
  + defined(REVIEW_LEVEL_REVIEW) ? 1 : 0 \  
  + defined(REVIEW_LEVEL_SAFE)   ? 1 : 0 \  
  > 1  
#error Multiple REVIEW_LEVEL macros defined  
#endif
```


BSLS_REVIEW Build time control

- Mutually exclusive
- Default to assert level

```
#if defined(ASSERT_LEVEL_NONE)  
#define REVIEW_LEVEL_NONE  
#elif defined(ASSERT_LEVEL_OPT)  
#define REVIEW_LEVEL_OPT  
#elif defined(ASSERT_LEVEL_ASSERT)  
#define REVIEW_LEVEL_REVIEW  
#elif defined(ASSERT_LEVEL_SAFE)  
#define REVIEW_LEVEL_SAFE  
#else  
#define REVIEW_LEVEL_REVIEW  
#endif
```

BSLS_REVIEW Build time control

- Mutually exclusive
- Default to assert level (In reality copies assert logic)

```
#if defined(ASSERT_LEVEL_NONE)  
#define REVIEW_LEVEL_NONE  
#elif defined(ASSERT_LEVEL_OPT)  
#define REVIEW_LEVEL_OPT  
#elif defined(ASSERT_LEVEL_ASSERT)  
#define REVIEW_LEVEL_REVIEW  
#elif defined(ASSERT_LEVEL_SAFE)  
#define REVIEW_LEVEL_SAFE  
#else  
#define REVIEW_LEVEL_REVIEW  
#endif
```

BSLS_REVIEW Build time control

- Mutually exclusive
- Default to assert level
- Controls just like ASSERT

```
#if defined(REVIEW_LEVEL_NONE)  
#define REVIEW_OPT(X)    REVIEW_DISABLED_IMP(X)  
#define REVIEW(X)        REVIEW_DISABLED_IMP(X)  
#define REVIEW_SAFE(X)   REVIEW_DISABLED_IMP(X)  
//..
```

BSLS_REVIEW Build time control

- Mutually exclusive
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```
//..  
#elif defined(REVIEW_LEVEL_OPT)  
#define REVIEW_OPT(X)    REVIEW_IMP(X)  
#define REVIEW(X)        REVIEW_DISABLED_IMP(X)  
#define REVIEW_SAFE(X)   REVIEW_DISABLED_IMP(X)  
//..
```

BSLS_REVIEW Build time control

- Mutually exclusive
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- Controls just like ASSERT

```
//..  
#elif defined(REVIEW_LEVEL_REVIEW)  
#define REVIEW_OPT(X)    REVIEW_IMP(X)  
#define REVIEW(X)        REVIEW_IMP(X)  
#define REVIEW_SAFE(X)   REVIEW_DISABLED_IMP(X)  
//..
```

BSLS_REVIEW Build time control

- Mutually exclusive
- Default to assert level
- Controls just like ASSERT

```
//..  
#elif defined(REVIEW_LEVEL_SAFE)  
#define REVIEW_OPT(X) REVIEW_IMP(X)  
#define REVIEW(X) REVIEW_IMP(X)  
#define REVIEW_SAFE(X) REVIEW_IMP(X)  
#endif
```

BSLS_REVIEW Build time control

- Mutually exclusive
- Default to assert level
- Controls just like ASSERT

```
#if defined(REVIEW_LEVEL_OPT) \
    defined(REVIEW_LEVEL_REVIEW) \
    defined(REVIEW_LEVEL_SAFE)
#define REVIEW_OPT(X) REVIEW_IMP(X)
#else
    // defined(REVIEW_LEVEL_NONE)
#define REVIEW_OPT(X) REVIEW_DISABLED_IMP(X)
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```

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- Mutually exclusive
- Default to assert level
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```
#if defined(REVIEW_LEVEL_REVIEW) \  
    defined(REVIEW_LEVEL_SAFE)  
#define REVIEW(X) REVIEW_IMP(X)  
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    // defined(REVIEW_LEVEL_OPT)  
    // defined(REVIEW_LEVEL_NONE)  
#define REVIEW(X) REVIEW_DISABLED_IMP(X)  
#endif
```


BSLS_REVIEW Build time control

- Mutually exclusive
- Default to assert level
- Controls just like ASSERT

```
#if defined(REVIEW_LEVEL_SAFE)
#define REVIEW_SAFE(X) REVIEW_IMP(X)
#else
    // defined(REVIEW_LEVEL_OPT)
    // defined(REVIEW_LEVEL_REVIEW)
    // defined(REVIEW_LEVEL_NONE)
#define REVIEW_SAFE(X) REVIEW_DISABLED_IMP(X)
#endif
```

ASSERT and REVIEW interaction

- Changing build levels requires reviewing all asserts at the target level

ASSERT and REVIEW interaction

- Changing build levels requires reviewing all asserts at the target level
- BSLS_ASSERT again

```
#if defined(BSLS_ASSERT_LEVEL_ASSERT) \  
    defined(BSLS_ASSERT_LEVEL_SAFE)  
#define BSLS_ASSERT(X) ASSERT_IMP(X)  
else  
#define BSLS_ASSERT(X)  
#endif
```

ASSERT and REVIEW interaction

- Changing build levels requires reviewing all asserts at the target level
- BSLS_ASSERT again

```
#if defined(BSLS_ASSERT_LEVEL_ASSERT) \
    defined(BSLS_ASSERT_LEVEL_SAFE)
#define BSLS_ASSERT(X) ASSERT_IMP(X)
#elif defined(BSLS_REVIEW_LEVEL_REVIEW) \
    defined(BSLS_REVIEW_LEVEL_SAFE)
#define BSLS_ASSERT(X) REVIEW_IMP(X)
#else
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#endif
```

ASSERT and REVIEW interaction

- Changing build levels requires reviewing all asserts at the target level
- BSLS_ASSERT again
- Same for BSLS_ASSERT_OPT and BSLS_ASSERT_SAFE

```
#if defined(BSLS_ASSERT_LEVEL_OPT) \
    defined(BSLS_ASSERT_LEVEL_ASSERT) \
    defined(BSLS_ASSERT_LEVEL_SAFE)
#define BSLS_ASSERT_OPT(X) ASSERT_IMP(X)
#elif defined(BSLS_REVIEW_LEVEL_OPT) \
    defined(BSLS_REVIEW_LEVEL_REVIEW) \
    defined(BSLS_REVIEW_LEVEL_SAFE)
#define BSLS_ASSERT_OPT(X) REVIEW_IMP(X)
#else
#define BSLS_ASSERT_OPT(X) ASSERT_DISABLED_IMP(X)
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ASSERT and REVIEW interaction

- Changing build levels requires reviewing all asserts at the target level
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```
#if defined(BSLS_ASSERT_LEVEL_SAFE)
#define BSLS_ASSERT_SAFE(X) ASSERT_IMP(X)
#elif defined(BSLS_REVIEW_LEVEL_SAFE)
#define BSLS_ASSERT_SAFE(X) REVIEW_IMP(X)
#else
#define BSLS_ASSERT_SAFE(X) ASSERT_DISABLED_IMP(X)
#endif
```

BSLS_REVIEW Takeaways

- So far a success

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- Why?
 - Ability to make a check a review alongside existing asserts.
 - Can control from code
 - Can control at build time

What do you do if you can't prove a contract is being followed?

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Believe

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We were promised performance

- Performance improvements come from the compiler *knowing* something will be true
- `[[noreturn]]` on `invoke_violation_handler` lets you safely trade the cost of checking for the benefit of assumption
- If you believe the contract is being followed, `__builtin_assume` can give you the benefit without the cost
- The risk is the strength of your belief

BSLS_ASSERT_LEVEL_ASSUME

- Let's add another choice for mapping the BSLS_ASSERT macros

```
#define BSLS_ASSERT_ASSUME(X) if (!(X)) { std::unreachable(); }
```

BSLS_ASSERT_LEVEL_ASSUME

- Let's add another choice for mapping the BSLS_ASSERT macros
- Lots of ways to implement, different tradeoffs and portability

```
#define BSLS_ASSERT_ASSUME(X) if (!(X)) { std::unreachable(); }  
#define BSLS_ASSERT_ASSUME(X) __builtin_assume(X)  
#define BSLS_ASSERT_ASSUME(X) if (!(X)) { int *p = nullptr; *p = 17; }
```


BSLS_ASSERT_LEVEL_ASSUME

- Let's add another choice for mapping the BSLS_ASSERT macros
- Lots of ways to implement, different tradeoffs and portability
- This almost made it to the standard

```
#define BSLS_ASSERT_ASSUME(X) [[ assert assume : X ]]
```

BSLS_ASSERT_LEVEL_ASSUME

- Let's add another choice for mapping the BSLS_ASSERT macros
- Lots of ways to implement, different tradeoffs and portability
- This almost made it to the standard
- Coming to BDE with an extended BSLS_ASSERT_LEVEL scale

```
//..  
#elif defined(ASSERT_LEVEL_ASSUME_OPT)  
#define ASSERT_OPT(X)    ASSERT_ASSUME(X)  
#define ASSERT(X)        ASSERT_DISABLED_IMP(X)  
#define ASSERT_SAFE(X)   ASSERT_DISABLED_IMP(X)  
//..
```

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//..
```

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 - Assumption of any unchecked contracts
 - Axiom was isomorphic to `__builtin_assume`
 - `default/audit/axiom` were both too simplistic and too complicated for many
 - Numerous edge case decisions had been made without publicizing clearly their reasoning

What happened?

- Numerous papers in Kona and Cologne attempted to fix these problems

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- Numerous papers in Kona and Cologne attempted to fix these problems
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- P1607's two options were the only consensus reached that day by EWG

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- On Saturday, July 20th, P1823 was ratified and SG21 was announced to pursue contracts again

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 - As a C++ API Developer In Order to Enforce contracts in async code I want to Express contracts on callbacks such as `std::function`, function pointers, or references to functions, lambdas, or function objects

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- Expect these results to be ready to analyze and discuss by Belfast.

- 1 Introduction
- 2 Basic Contracts
- 3 Doing Stuff With Contracts
- 4 SG21
- 5 Conclusion**

Conclusion

- Bloomberg's `BSLS_ASSERT` and `BSLS_REVIEW` provide a rich set of contract enforcement utility. Grab the open source BDE to play with it today
- The needs of that facility will hopefully be met by language level contracts in the future, SG21 is working hard to see that happen