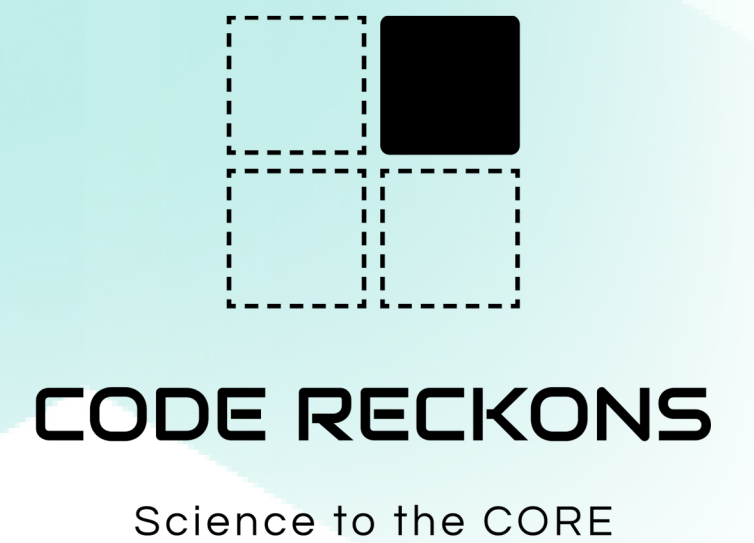




Exceptional C++

Victor Ciura



Exceptional C++

CPPP 2021

December 1st



@ciura_victor

Victor Ciura
Principal Engineer



When writing code we usually focus our attention on the happy paths - that's where the interesting stuff happens. But there are also plenty of exciting things happening on the error handling flow, too. Although not universally loved/used, exceptions are a powerful mechanism of maneuvering execution on the unhappy path.

Even if `std::exception` and related machinery are not your cup of tea, you might care about hardware faults or OS signals like access violations, page errors, ALU overflows.

Let's take a deep dive and explore what happens when an exception occurs, both at the application level and the OS level. We'll explore the unwind process, the compiler generated code, the CRT hooks available and other exception internals. As we're taking the scenic Windows route, we're also going to encounter async exceptions (structured exceptions) on our quest for a better crash. We'll poke into these mechanisms and see how we can leverage them in our application error handling. Did I mention threads? Routing exceptions between threads... oh my!



Advanced Installer



Clang Power Tools

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Q & A

Discord

When writing code we usually focus our attention on the **happy paths** - that's where the interesting stuff happens

But there are also plenty of exciting things happening on the **error handling flow**, too

Although not universally loved, exceptions are a powerful mechanism of **maneuvering execution** on the unhappy path



Some people are **afraid** of exceptions because they don't understand very well what's going on **behind the scenes**

This talk is **not** about:

Exceptions vs Error codes vs `Expected<T>`

Exception safe code

Error handling best practices



P0881

A Proposal to add stacktrace library

- *Alexey Gorgurov, Antony Polukhin*

First draft: **2018-01-23** [R0]

based on `Boost.Stacktrace`

....

Didn't make into **C++20** 😞

...

[R7] wg21.link/P0881

```
#include <stacktrace>
```



twitter.com/alisdairmered/status/1325854252338716672?s=21

Key features (desired):

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Key features (desired):

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- **dynamic size** for trace - all the available invokers must be stored in a stacktrace
- implementations: allow to **disable/enable** gathering stacktraces by a linker switch
- stacktracing shouldn't prevent any of **optimizations**
- stacktrace should be **usable** in contract violation handler, coroutines, handler functions, parallel algorithms

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Key features (desired):

- `stacktrace_entry::description()` should return a **demangled** function signature
- `to_string(stacktrace)` should query information from **debug symbols**, symbol export tables and any other sources, returning *demangled* signatures
- information about **inlined functions** that have no separate stacktrace entries is welcomed -> `to_string(stacktrace)`
- avoid doing **heavy** operations in `basic_stacktrace` constructors or `stacktrace_entry::current()`

```
class stacktrace_entry
{
public:
    using native_handle_type = implementation-defined;
    ...
    constexpr native_handle_type native_handle() const noexcept;
    constexpr explicit operator bool() const noexcept;
    ...
    string    description() const;
    string    source_file() const;
    uint32_t  source_line() const;
};
```

`stacktrace_entry` models concepts:

regular and `three_way_comparable<strong_ordering>`

C++ 23 <stacktrace>

```
template<class Allocator>
class basic_stacktrace
{
public:
    using value_type = stacktrace_entry;
    using allocator_type = Allocator;
    ...
    const_iterator begin() const noexcept;
    const_iterator end() const noexcept;
    const_reverse_iterator rbegin() const noexcept;
    const_reverse_iterator rend() const noexcept;
    ...

private:
    vector<value_type, allocator_type> m_frames;
};
```

```
static basic_stacktrace current(const allocator_type& alloc = allocator_type()) noexcept;  
static basic_stacktrace current(size_type skip,  
                                const allocator_type& alloc = allocator_type()) noexcept;  
static basic_stacktrace current(size_type skip, size_type max_depth,  
                                const allocator_type& alloc = allocator_type()) noexcept;
```

=> `basic_stacktrace` object with `m_frames` storing the stack trace of the current evaluation in the *current thread* of execution

`alloc` is passed to the constructor of the `m_frames` object.

C++ 23 <stacktrace>

```
namespace std {  
  
    using stacktrace = basic_stacktrace<allocator<stacktrace_entry>>;  
  
    string to_string(const stacktrace_entry& f);  
  
    template<class Alloc>  
    string to_string(const basic_stacktrace<Alloc>& st);  
  
    template<class charT, class traits>  
    basic_ostream<charT, traits>&  
    operator<<(basic_ostream<charT, traits>& os, const stacktrace_entry& f);  
  
    template<class charT, class traits, class Alloc>  
    basic_ostream<charT, traits>&  
    operator<<(basic_ostream<charT, traits>& os, const basic_stacktrace<Alloc>& st);  
}
```

description()
source_file()
source_line()

C++ 23 Example

```
auto trace = basic_stacktrace::current();

for (stacktrace_entry frame : trace)
{
    std::cerr << frame.description() << " at "
               << frame.source_file() << ":" << frame.source_line() << "\n";
}
```

C++ 23 Example

```
auto trace = basic_stacktrace::current();  
  
for (stacktrace_entry frame : trace)  
{  
    std::cerr << std::to_string(frame) << "\n";  
}
```


C++ 23 Example

```
auto trace = basic_stacktrace::current();  
  
for (stacktrace_entry frame : trace)  
{  
    std::cerr << frame << "\n";  
}
```

C++ 23 Example

```
auto trace = basic_stacktrace::current();  
std::cerr << std::to_string(trace);
```

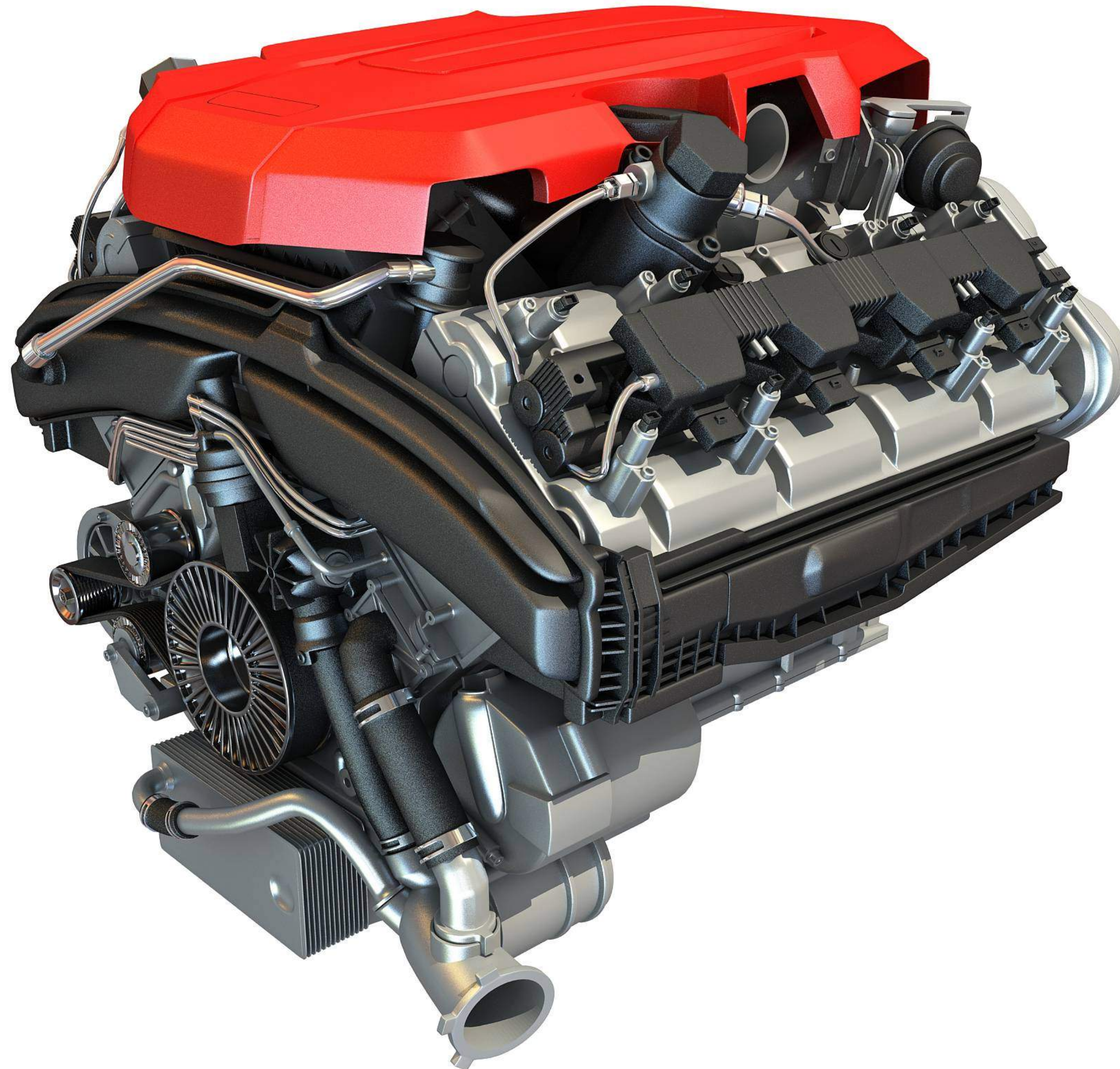
C++ 23 Example

```
auto trace = basic_stacktrace::current();  
std::cerr << trace;
```

It can't get any simpler than that.

I can't wait to see **early** implementations from our standard library providers!

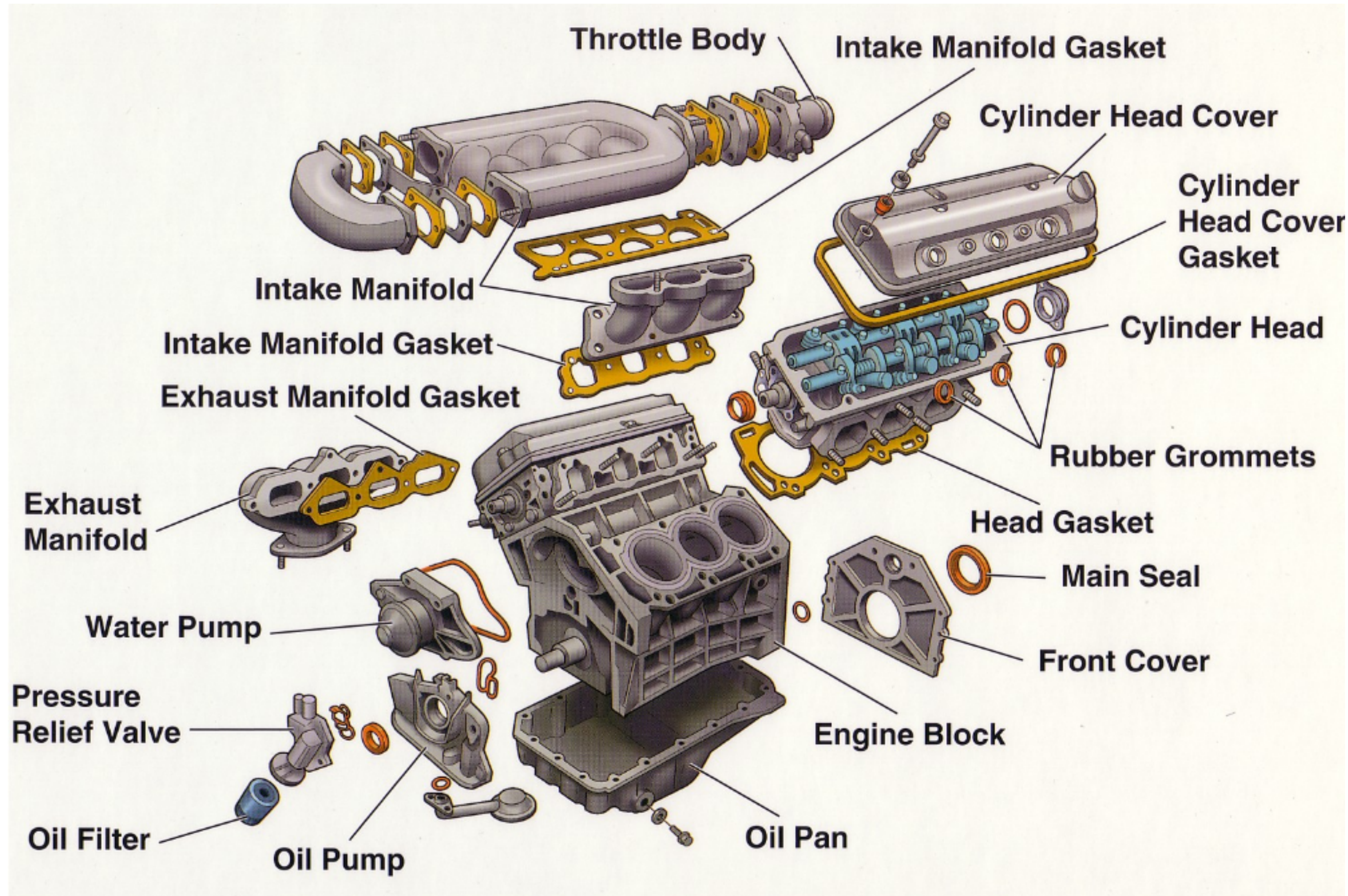
This talk is about



To be honest...



What we actually care about



This talk is about

Exception Internals

Windows

x86 / x64 / ARM*

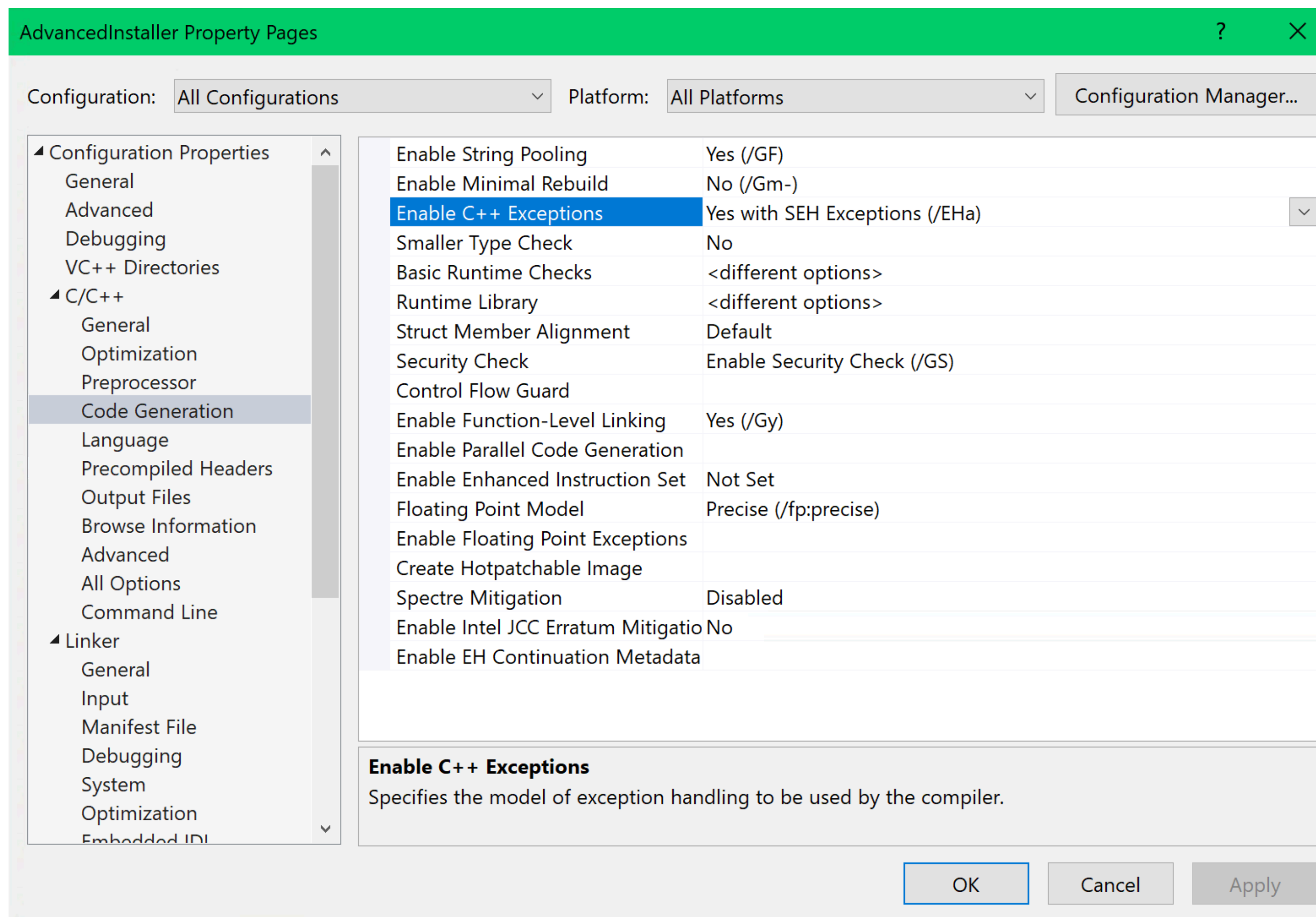
Structured Exception Handling (SEH)

To understand C++ exceptions (on Windows),
we need to understand **structured exceptions**

docs.microsoft.com/en-us/windows/win32/debug/structured-exception-handling

docs.microsoft.com/en-us/cpp/cpp/structured-exception-handling-c-cpp?view=msvc-160

Structured Exception Handling (SEH)



Structured Exception Handling (SEH)

```
<ItemDefinitionGroup>
  <ClCompile>
    <DebugInformationFormat>ProgramDatabase</DebugInformationFormat>
    <ExceptionHandling>Async</ExceptionHandling>
  </ClCompile>
  <Link>
    <GenerateDebugInformation>DebugFull</GenerateDebugInformation>
    <SubSystem>Windows</SubSystem>
  </Link>
</ItemDefinitionGroup>
```

/EHa **/DEBUG:FULL** **/Zi**

Structured Exceptions

```
__try
{
    // stuff we hope works
}
__except( ExceptionFilter(GetExceptionInformation()) )
{
    // pretend it never happened
}
```

Life happens...

[SEH_AV_WRITE_NULLPTR] ACCESS_VIOLATION (0xc0000005) at address [0x000000014002772f]

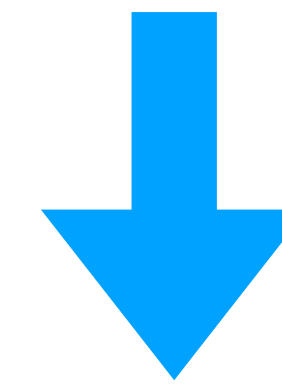
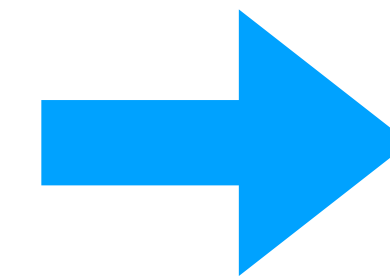
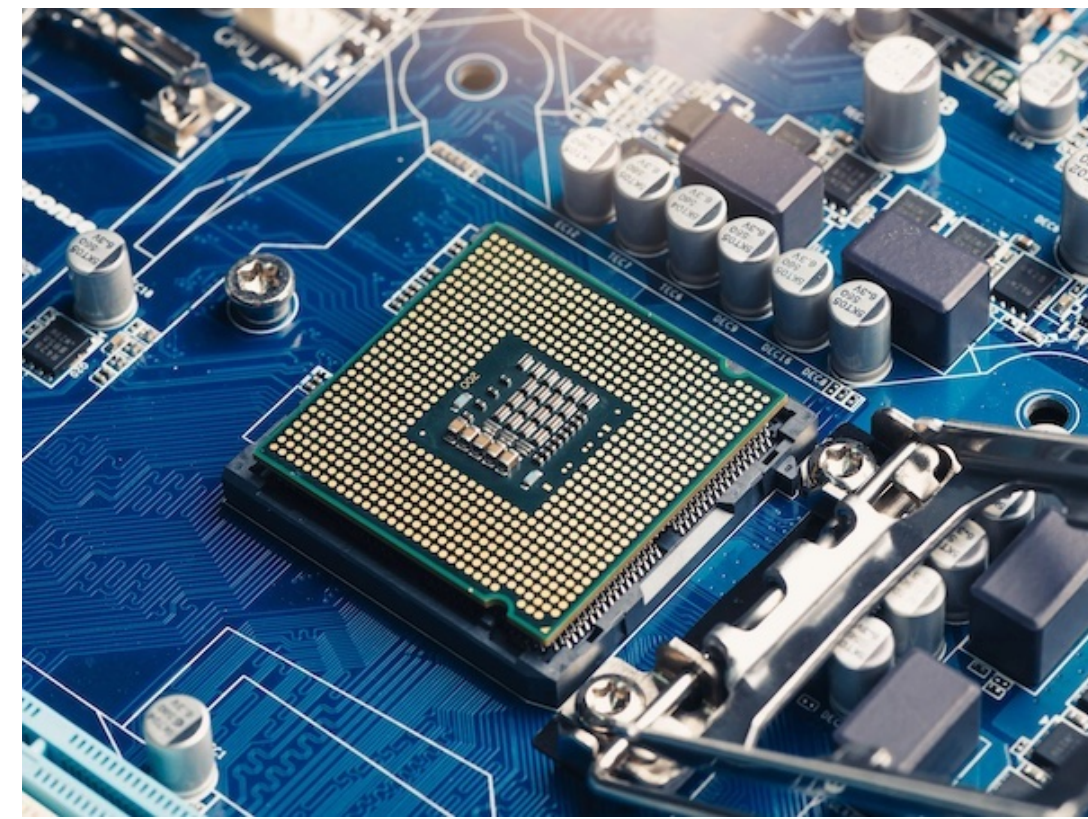
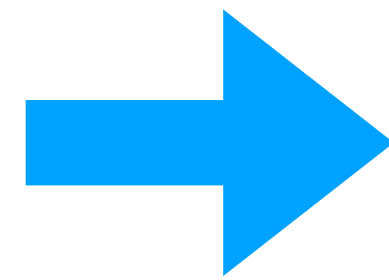
Advanced Repackager (x64) 17.6 build c087f2e6

*** Stack Trace (x64) ***

```
[0x000000014002772f] ProductDetailsPage::OnWizardNext() -> productdetailspage.cpp:97
[0x000000014002911c] WTL::CPropertyPageImpl<ProductDetailsPage>::OnNotify() -> atldlgs.h:4527
[0x0000000140026f86] ProductDetailsPage::_ProcessWindowMessage() -> productdetailspage.h:36
[0x0000000140026e68] ProductDetailsPage::ProcessWindowMessage() -> productdetailspage.h:31
[0x0000000140020be8] ATL::CDialogImplBaseT<WTL::CPropertyPageWindow>::DialogProc() -> atlwin.h:3862

...

[0x000000014003268e] WTL::CPropertySheetImpl<RepackagerWizard>::OnCommand() -> atldlgs.h:4257
[0x00000001400312d4] RepackagerWizard::ProcessWindowMessage() -> repackagerwizard.h:48
[0x00000001400338a3] ATL::CWindowImplBaseT<WTL::CWizard97SheetWindow>::WindowProc() -> atlwin.h:3508
[0x000000014004176e] Repackager::RunNormal() -> repackager.cpp:192
[0x00000001400429bb] wWinMain() -> repackager.cpp:250
[0x0000000140089d02] __tmainCRTStartup() -> crtexe.c:547
[0x0000000076a6652d] BaseThreadInitThunk()
[0x000000007715c521] RtlUserThreadStart()
[0x00000000000a0000] MODULE_BASE_ADDRESS
```



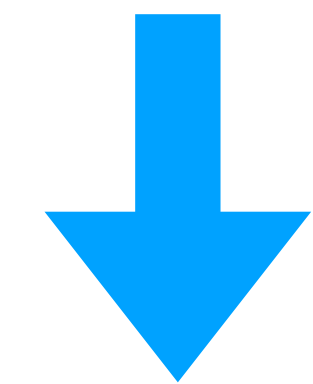
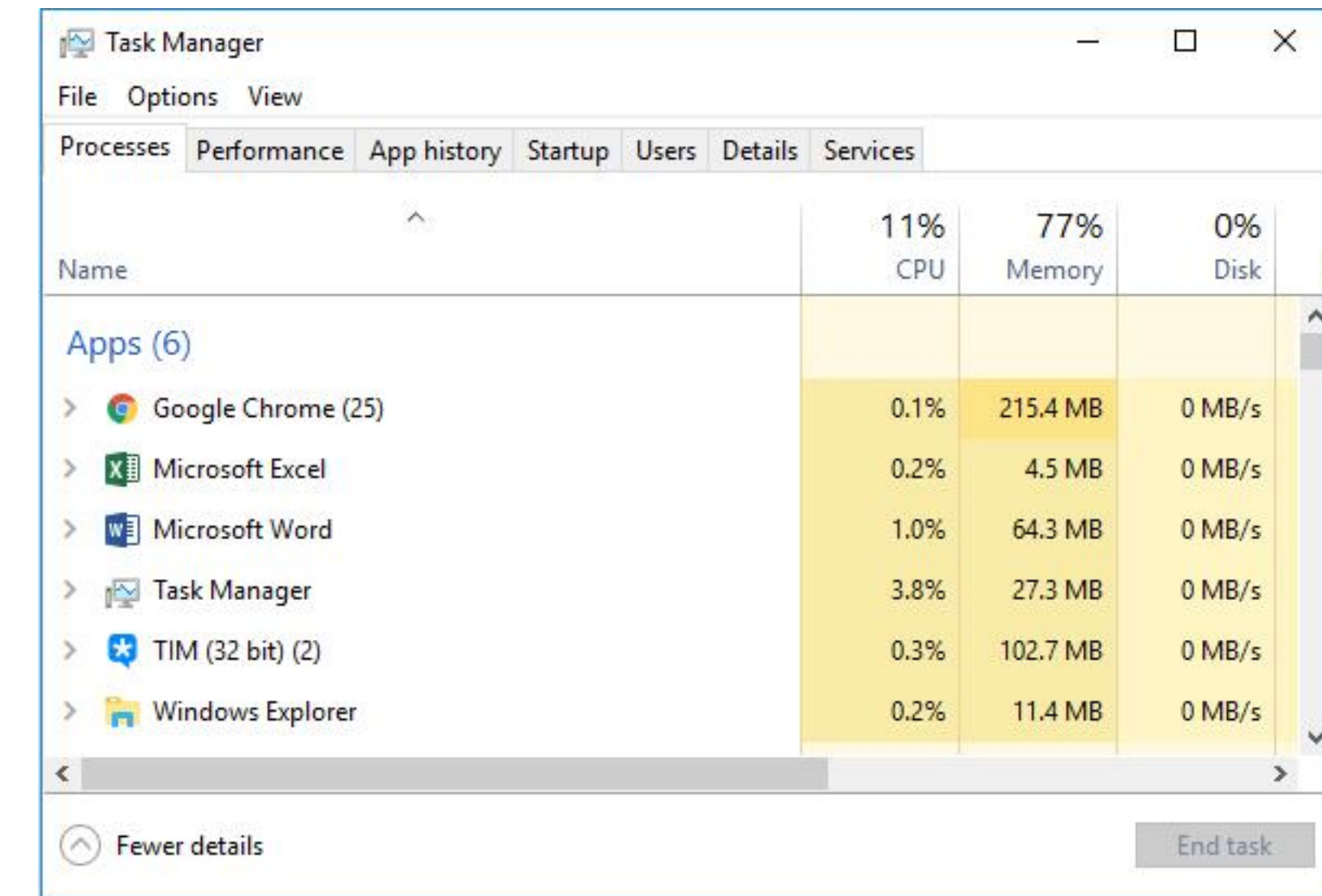
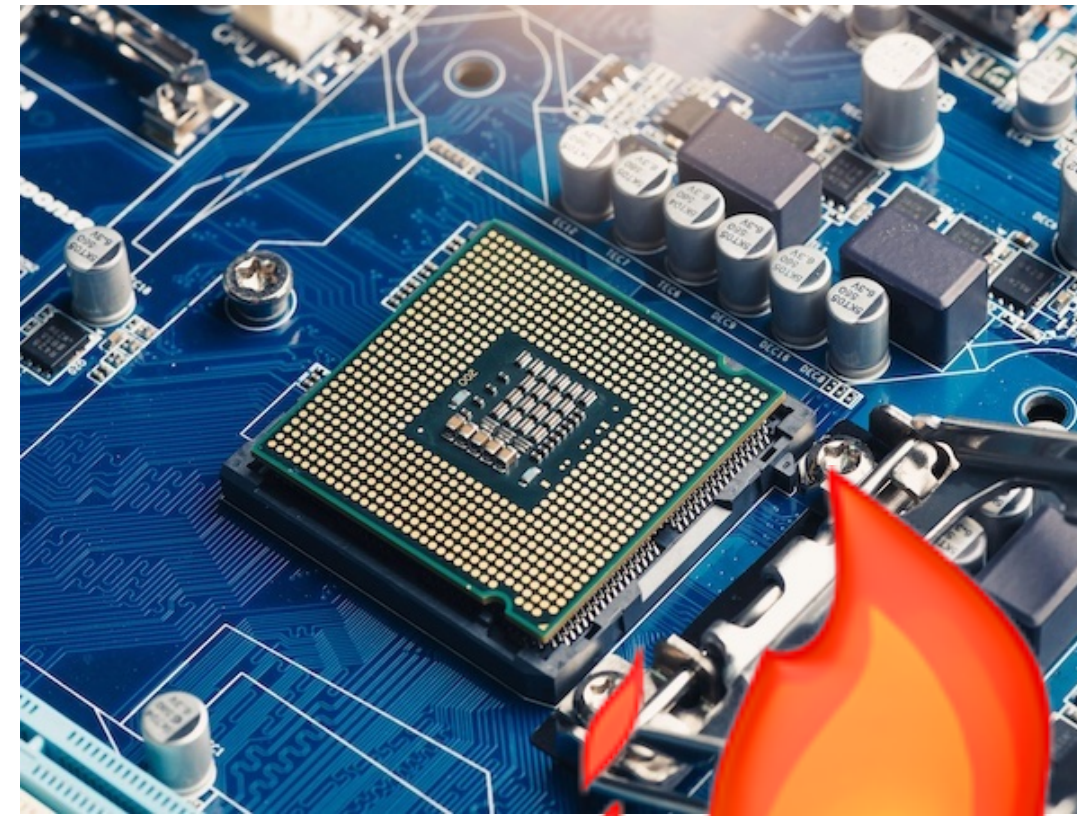
```
int * p = nullptr;  
*p = 5;
```

interrupt handler

SEH

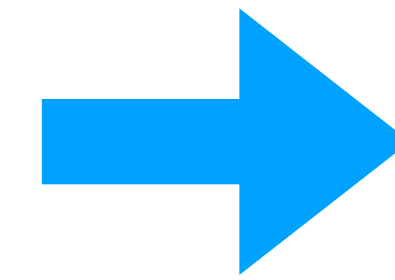
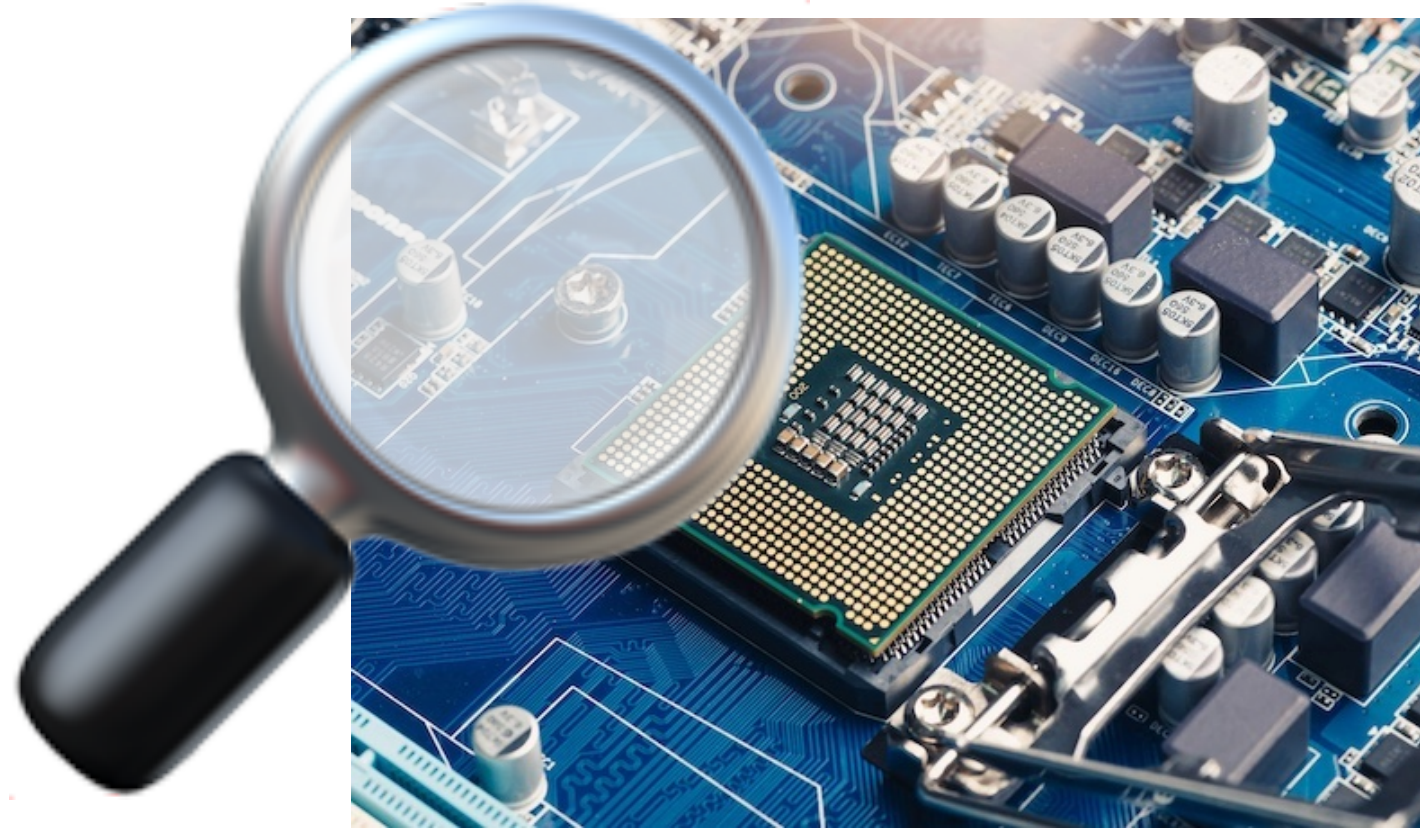
What's next?

SEH



React / Recover / Control

Snapshot - context



SEH

CONTEXT

```
struct CONTEXT {
    DWORD ContextFlags;

    // This section is specified/returned if CONTEXT_DEBUG_REGISTERS is
    // set in ContextFlags. Note that CONTEXT_DEBUG_REGISTERS is NOT
    // included in CONTEXT_FULL.
    DWORD   Dr0;
    DWORD   Dr1;
    DWORD   Dr2;
    DWORD   Dr3;
    DWORD   Dr6;
    DWORD   Dr7;

    // This section is specified/returned if the
    // ContextFlags word contains the flag CONTEXT_FLOATING_POINT.
    FLOATING_SAVE_AREA FloatSave;

    // This section is specified/returned if the
    // ContextFlags word contains the flag CONTEXT_SEGMENTS.
    DWORD   SegGs;
    DWORD   SegFs;
    DWORD   SegEs;
    DWORD   SegDs;

    // This section is specified/returned if the
    // ContextFlags word contains the flag CONTEXT_INTEGER.
    DWORD   Edi;
    DWORD   Esi;
    DWORD   Ebx;
    DWORD   Edx;
    DWORD   Ecx;
    DWORD   Eax;

    // This section is specified/returned if the
    // ContextFlags word contains the flag CONTEXT_CONTROL.
    DWORD   Ebp;
    DWORD   Eip;
    DWORD   SegCs;
    DWORD   EFlags;
    DWORD   Esp;
    DWORD   SegSs;


    // This section is specified/returned if the ContextFlags word
    // contains the flag CONTEXT_EXTENDED_REGISTERS.
    // The format and contexts are processor specific
    BYTE   ExtendedRegisters[MAXIMUM_SUPPORTED_EXTENSION];
};
```

Contains processor-specific **register** data.

The system uses **CONTEXT** structures to perform various internal operations.

docs.microsoft.com/en-us/windows/win32/api/winnt/ns-winnt-context

CONTEXT



```
struct CONTEXT {  
    ...  
    DWORD    ContextFlags;  
  
    DWORD    SegGs;  
    DWORD    SegFs;  
    DWORD    SegEs;  
    DWORD    SegDs;  
  
    DWORD    Edi;  
    DWORD    Esi;  
    DWORD    Ebx;  
    DWORD    Edx;  
    DWORD    Ecx;  
    DWORD    Eax;  
  
    DWORD    Ebp;  
    DWORD    Eip;  
    DWORD    SegCs;  
    DWORD    EFlags;  
    DWORD    Esp;  
    DWORD    SegSs;  
  
    BYTE     ExtendedRegisters [MAXIMUM_SUPPORTED_EXTENSION];  
    ...  
};
```

Contains processor-specific **register** data.

The system uses **CONTEXT** structures to perform various internal operations.

docs.microsoft.com/en-us/windows/win32/api/winnt/ns-winnt-context

EXCEPTION_RECORD

```
struct EXCEPTION_RECORD
{
    DWORD ExceptionCode;
    DWORD ExceptionFlags;
    EXCEPTION_RECORD * ExceptionRecord;
    PVOID ExceptionAddress;
    DWORD NumberParameters;
    ULONG_PTR ExceptionInformation[EXCEPTION_MAXIMUM_PARAMETERS];
};
```

docs.microsoft.com/en-us/windows/win32/api/winnt/ns-winnt-exception_record

EXCEPTION_RECORD x86/x64

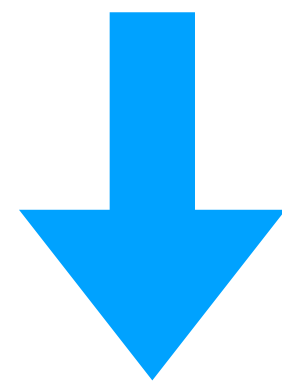
```
struct EXCEPTION_RECORD32 {  
    DWORD    ExceptionCode;  
    DWORD    ExceptionFlags;  
    DWORD    ExceptionRecord;  
    DWORD    ExceptionAddress;  
    DWORD    NumberParameters;  
    DWORD    ExceptionInformation[EXCEPTION_MAXIMUM_PARAMETERS];  
};
```

```
struct EXCEPTION_RECORD64 {  
    DWORD    ExceptionCode;  
    DWORD    ExceptionFlags;  
    DWORD64  ExceptionRecord;  
    DWORD64  ExceptionAddress;  
    DWORD    NumberParameters;  
    DWORD    __unusedAlignment;  
    DWORD64  ExceptionInformation[EXCEPTION_MAXIMUM_PARAMETERS];  
};
```

docs.microsoft.com/en-us/windows/win32/api/winnt/ns-winnt-exception_record

EXCEPTION_RECORD

```
EXCEPTION_RECORD ex;  
  
ex.ExceptionCode           = STATUS_ACCESS_VIOLATION; // 0xc0000005  
ex.ExceptionFlags          = 0;  
ex.ExceptionRecord         = nullptr; // next exception rec in the chain  
ex.ExceptionAddress        = 0x05ED24C0; // WHERE: instruction address (PC)  
ex.NumberParameters        = 2;  
ex.ExceptionInformation[0] = EXCEPTION_WRITE_FAULT; // 0 = read; 1 = write; 8 = DEP  
ex.ExceptionInformation[1] = 0x01ED6F42; // WHAT: the virtual address of the inaccessible data
```



?

Win32 Thread Information Block (TIB)

a data structure that stores information about the currently running thread

It is accessed from:

- the **FS** segment register on 32-bit Windows => **FS: [18h]**
- the **GS** register on 64-bit Windows => **GS: [30h]**

```
NT_TIB * tib = (NT_TIB*)::NtCurrentTeb();
```

```
void * getTIB()  
{  
#ifdef _M_IX86  
    return (void *)__readfsdword(0x18);  
#elif _M_AMD64  
    return (void *)__readgsqword(0x30);  
#endif  
}
```

Win32 Thread Information Block (TIB)

The TIB contains the thread-specific **exception handling chain** and pointer to the TLS (thread local storage)

FS: [0x00]

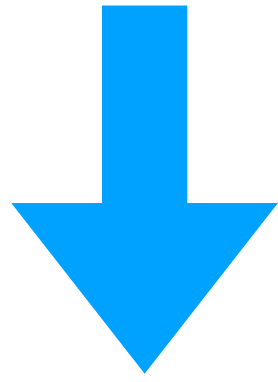
GS: [0x00]

Current Structured Exception Handling (SEH) frame

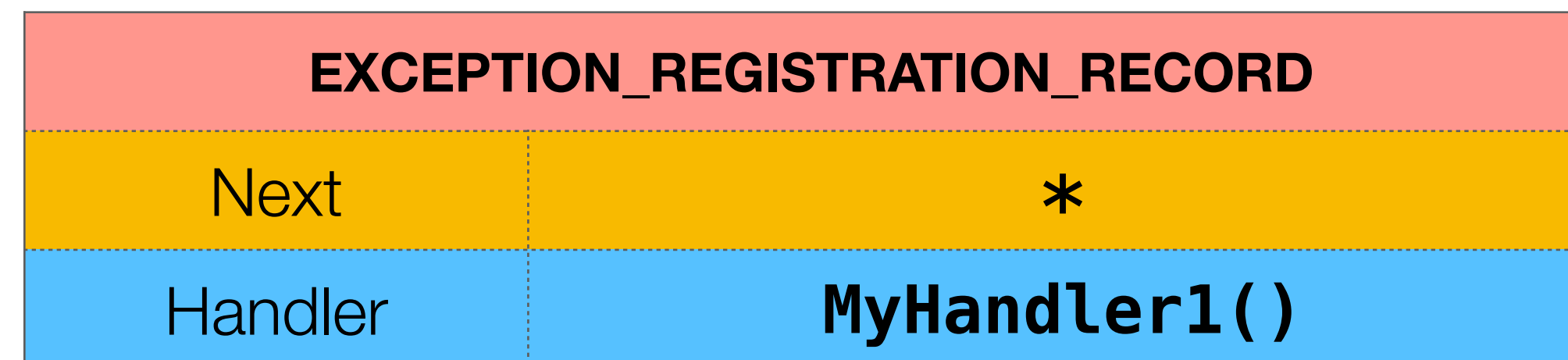
* 64-bit Windows uses stack unwinding done in kernel mode instead

EXCEPTION_REGISTRATION_RECORD

TIB => FS:[0] => exception handling chain

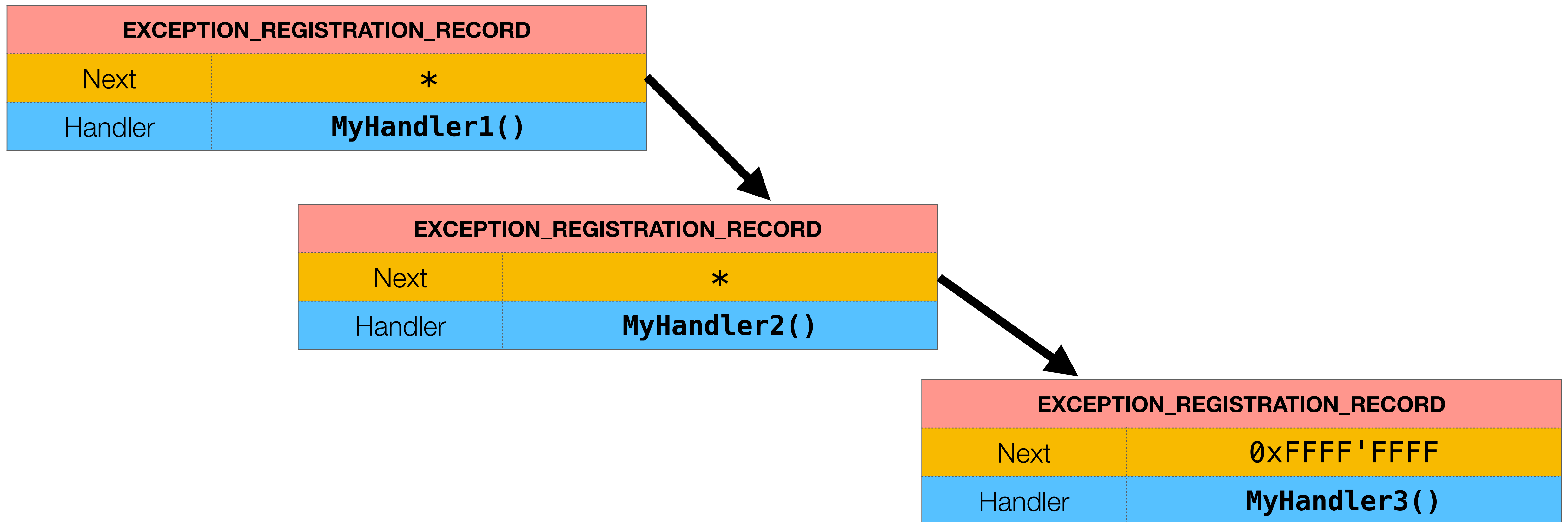
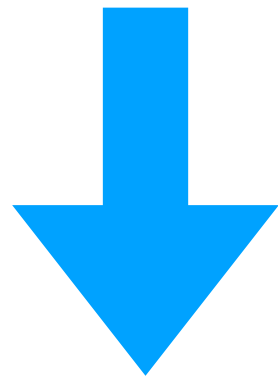


```
struct EXCEPTION_REGISTRATION_RECORD
{
    PEXCEPTION_REGISTRATION_RECORD Next;
    PEXCEPTION_DISPOSITION Handler;
}
```



EXCEPTION_REGISTRATION_RECORD

TIB => FS:[0] => exception handling chain



EXCEPTION_REGISTRATION_RECORD

If you don't register any handler and
a [structured exception](#) occurs => process crash



Simple Handler

```
void Func()
{
    NT_TIB * tib = (NT_TIB*)::NtCurrentTeb();

    EXCEPTION_REGISTRATION_RECORD reg;
    reg.Handler = &MyExceptionHandler;
    reg.Next = tib->ExceptionList;

    tib->ExceptionList = &reg;

    int * p = nullptr;
    *p = 5;

    // restore original handler
    tib->ExceptionList = tib->ExceptionList->Next;
}
```

Simple Handler

```
EXCEPTION_DISPOSITION MyExceptionHandler(EXCEPTION_RECORD * aExRecord,
                                         void * aEstablisherFrame,
                                         CONTEXT * aContextRecord,
                                         void * aDispatcherContext)
{
    printf("Exception at address: [0x%p] - ExceptionCode = 0x%08x\n",
          aExRecord->ExceptionAddress,
          aExRecord->ExceptionCode);

    // we don't handle the exception
    return ExceptionContinueSearch;
}
```

Simple Handler

```
EXCEPTION_DISPOSITION MyExceptionHandler(EXCEPTION_RECORD * aExRecord,  
                                          void * aEstablisherFrame,  
                                          CONTEXT * aContextRecord,  
                                          void * aDispatcherContext)  
{  
    printf("Exception at address: [0x%p] - ExceptionCode = 0x%08x\n",  
          aExRecord->ExceptionAddress,  
          aExRecord->ExceptionCode);  
  
    { magic fix }  
  
    // if we attempt to handle the exception,  
    // stop searching for another handler func  
    // and continue execution  
    return ExceptionContinueExecution;  
}
```

Simple Handler

```
EXCEPTION_DISPOSITION MyExceptionHandler(EXCEPTION_RECORD * aExRecord,
                                         void * aEstablisherFrame,
                                         CONTEXT * aContextRecord,
                                         void * aDispatcherContext)
{
    if (aExRecord->ExceptionCode == EXCEPTION_ACCESS_VIOLATION)
    {
        // the first element of the array contains a read-write flag
        // that indicates the type of operation that caused the access violation
        ULONG_PTR operationType = aExRecord->ExceptionInformation[0];

        // the second array element specifies the virtual address of the inaccessible data
        ULONG_PTR virtualAddress = aExRecord->ExceptionInformation[1];

        if (operationType == EXCEPTION_READ_FAULT)
            seType = virtualAddress ? SehException::SEH_AV_READ_BADPTR : SehException::SEH_AV_READ_NULLPTR;
        else if (operationType == EXCEPTION_WRITE_FAULT)
            seType = virtualAddress ? SehException::SEH_AV_WRITE_BADPTR : SehException::SEH_AV_WRITE_NULLPTR;

        { handle/fix the issue }
    }

    // if we attempt to handle the exception, stop searching for another handler and continue execution
    return ExceptionContinueExecution;
}
```

Simple Handler

So much boilerplate for such a simple handler...



Simple Handler

```
void Func()
```

```
{
```

```
  __try
```

```
{
```

```
  int * p = nullptr;
```

```
  *p = 5;
```

```
}
```

```
  __except( ExceptionFilter( GetExceptionInformation() ) )
```

```
{
```

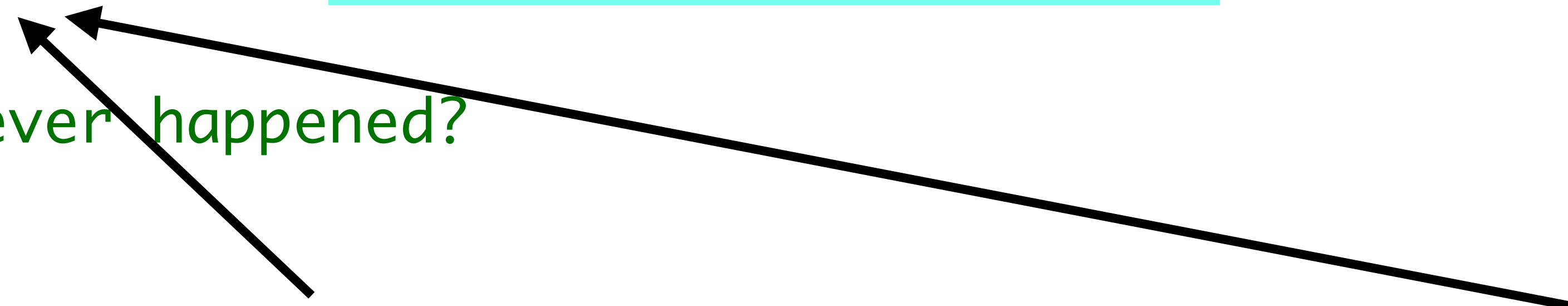
```
  // pretend it never happened?
```

```
}
```

```
}
```

EXCEPTION_CONTINUE_SEARCH

EXCEPTION_CONTINUE_EXECUTION



GetExceptionInformation()

Retrieves a computer-independent *description* of an exception, and information about the *computer state* that exists for the thread when the exception occurs.

This function can be called only from within the *filter expression* of an exception handler.

```
EXCEPTION_POINTERS * GetExceptionInformation();
```

```
DWORD GetExceptionCode();
```

docs.microsoft.com/en-us/windows/win32/debug/getexceptioninformation

docs.microsoft.com/en-us/windows/win32/debug/getexceptioncode

EXCEPTION_POINTERS

We've already seen this (`CONTEXT`)

```
struct EXCEPTION_POINTERS
{
    EXCEPTION_RECORD * ExceptionRecord;
    CONTEXT * ContextRecord;
};
```

docs.microsoft.com/en-us/windows/win32/api/winnt/ns-winnt-exception_pointers

Simple Handler

```
void Func()
```

```
{
```

```
  __try
```

```
{
```

```
  int * p = nullptr;
```

```
  *p = 5;
```

```
}
```

```
  __except( ExceptionHandler( GetExceptionInformation() ) ) )
```

```
{
```

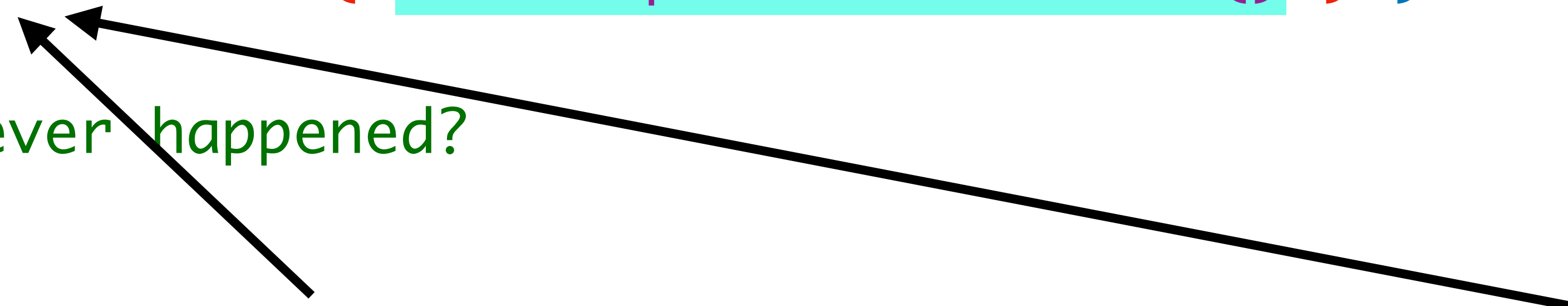
```
  // pretend it never happened?
```

```
}
```

```
}
```

EXCEPTION_CONTINUE_SEARCH

EXCEPTION_CONTINUE_EXECUTION



Exception Filter

```
int ExceptionFilter( EXCEPTION_POINTERS * aPtrs )
{
    if (aPtrs->ExceptionRecord->ExceptionCode != STATUS_ACCESS_VIOLATION ||
        aPtrs->ExceptionRecord->ExceptionInformation[0] != EXCEPTION_WRITE_FAULT)
    {
        return EXCEPTION_CONTINUE_SEARCH;
    }

    void * writeAddress = aPtrs->ExceptionRecord->ExceptionInformation[1];

    // attempt a fix
    ::VirtualProtect(writeAddress, sizeof(int), PAGE_READWRITE);

    // resume execution from the faulting instruction
    return EXCEPTION_CONTINUE_EXECUTION;
}
```

Why are we bothering to understand all this ?

Why are we bothering to understand all this ?

Because **C++ exceptions** are built on top of the SEH machinery.

The **compiler** does all the bookkeeping work.

C++ Exceptions

What does the compiler map to:

C++	SEH
<code>throw</code>	<code>RaiseException()</code>
<code>try catch</code>	<code>__try __except</code>
Local variable destruction	<code>__try __finally</code>
<code>_CxxFrameHandler()</code>	<code>_except_handler3()</code>

C++ Exceptions

```
throw MyException{};           =>   MyException exObject{};
```

```
[[noreturn]]  
void _CxxThrowException(void * aExObject, _ThrowInfo * aThrowInfo);
```

```
_CxxThrowException(&exObject, &_ThrowInfoFor<MyException>);
```

C++ Exceptions

```
struct _ThrowInfo
{
    unsigned int      attributes;
    Destructor        * pmfnUnwind;
    CatchableTypeArray * pCatchableTypeArray;
};
```

```
struct CatchableTypeArray
{
    int                nCatchableTypes;
    CatchableType * arrayOfCatchableTypes [nCatchableTypes];
};
```

```
struct CatchableType
{
    unsigned int      properties;
    std::type_info * pType;
    PMD              thisDisplacement;
    int               sizeOrOffset;
    CopyConstructor * copyFunction;
};
```

_CxxThrowException()

```
[[noreturn]]
void _CxxThrowException(void * aExObject, _ThrowInfo * aThrowInfo)
{
    EXCEPTION_RECORD exception;

    exception.ExceptionCode = EH_EXCEPTION_NUMBER; // 0xE06D7363 ('msc'|0xE0000000)
    exception.ExceptionFlags = EXCEPTION_NONCONTINUABLE;

    exception.NumberParameters = 3;
    exception.ExceptionInformation[0] = EH_MAGIC_NUMBER1;
    exception.ExceptionInformation[1] = (ULONG_PTR)aExObject;
    exception.ExceptionInformation[2] = (ULONG_PTR)aThrowInfo;

    ::RaiseException(exception.ExceptionCode,
                    exception.ExceptionFlags,
                    exception.NumberParameters,
                    exception.ExceptionInformation);
}
```

a C++ exception is born 🎉

Let's flip this around...

SEH \Rightarrow **C++ exceptions**

Structured Exception Handling (SEH)

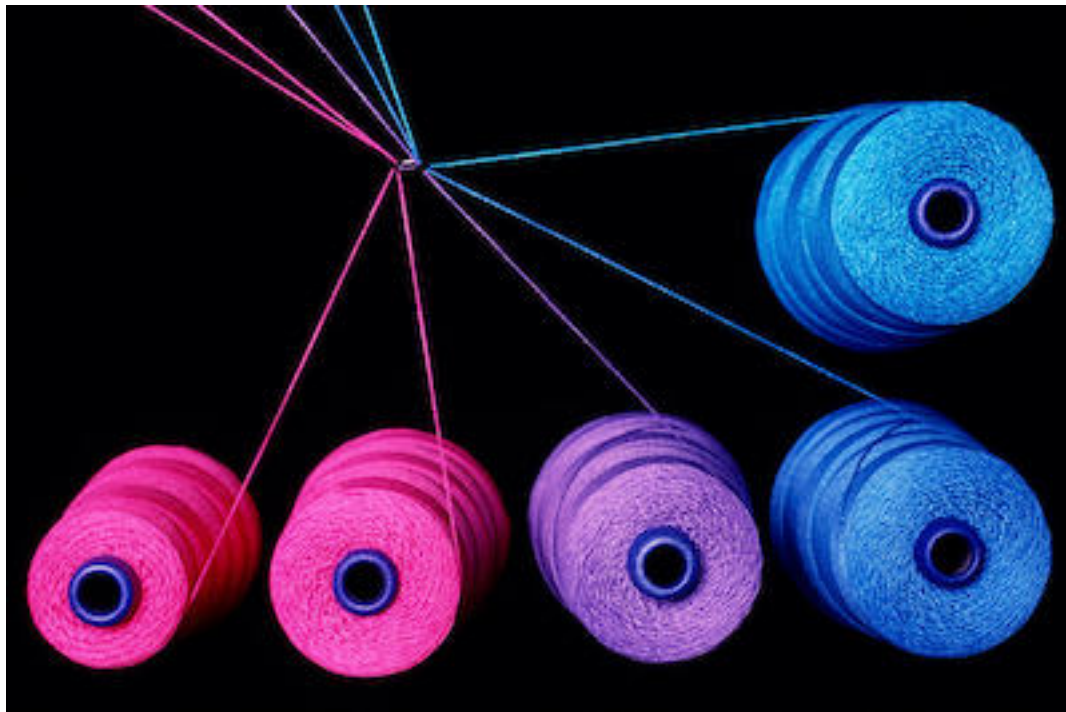
Handle C structured exceptions (Win32) as C++ typed exceptions:

```
_set_se_translator(ExceptionHandling::TransFunc);
```

docs.microsoft.com/en-us/cpp/c-runtime-library/reference/set-se-translator

Structured Exception Handling (SEH)

```
_set_se_translator(ExceptionHandling::TransFunc);
```

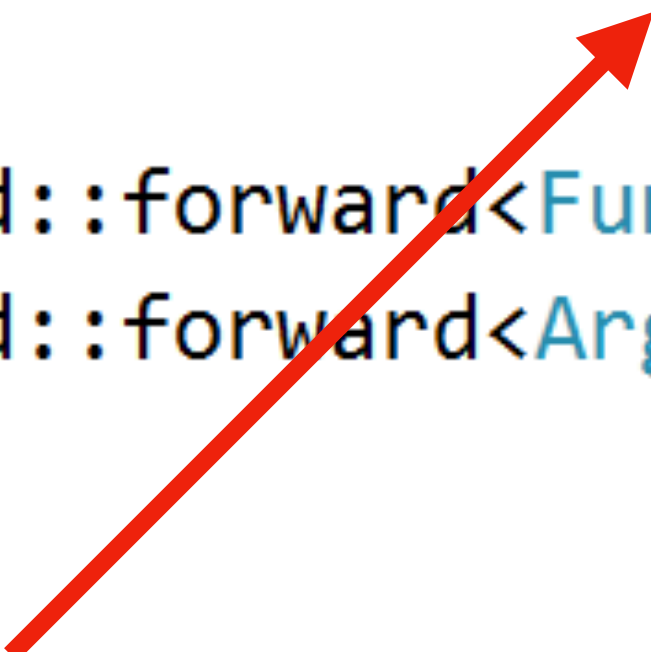


Each new **thread** needs to install its own translator function
=> each thread is in charge of its own translation handling

docs.microsoft.com/en-us/cpp/c-runtime-library/reference/set-se-translator

Structured Exception Handling (SEH)

```
|class thread
|{
|public:
|    using id = std::thread::id;
|
|    thread() noexcept {}
|
|    template <
|        class FunType,
|        class... ArgTypes,
|        class = typename enable_if<!is_same<typename decay<FunType>::type, thread>::value>::type>
|explicit thread(FunType && aFun, ArgTypes &&... aArgs)
|    : mTh(&ai::thread::shim_proc<typename std::decay<FunType>::type,
|        typename std::decay<ArgTypes>::type...>,
|        std::forward<FunType>(aFun),
|        std::forward<ArgTypes>(aArgs)...)
|    {}
|}
```



Structured Exception Handling (SEH)

```
private:
    template <class FunType, class... ArgTypes>
    static decltype(auto) shim_proc(FunType && aFun, ArgTypes &&... aArgs)
    {
        // handle Win32 exceptions (C structured exceptions) as C++ typed exceptions
        ExceptionHandling::HandleSEH();

        return std::invoke(std::forward<FunType>(aFun), std::forward<ArgTypes>(aArgs)...);
    }

    std::thread mTh;
};
```



`_set_se_translator(ExceptionHandling::TransFunc);`

SEH Translator

```
void ExceptionHandling::TransFunc(unsigned int aSECode, EXCEPTION_POINTERS * aExInfo)
{
    // write the exception prolog (type, code, address, etc.)

    switch (aSECode) // decode SEH exception type
    {
        case EXCEPTION_ACCESS_VIOLATION:
            swprintf_s(buf, MSG_BUFFER_LEN, L"%hs (0x%.8x) at address " ADDRESS_FORMAT SW_EOL,
                "ACCESS_VIOLATION", EXCEPTION_ACCESS_VIOLATION,
                aExInfo->ExceptionRecord->ExceptionAddress);

            break;
        case EXCEPTION_DATATYPE_MISALIGNMENT:
            break;
        case EXCEPTION_INT_DIVIDE_BY_ZERO:
            break;
        case EXCEPTION_INT_OVERFLOW:
            break;
        case EXCEPTION_ILLEGAL_INSTRUCTION:
            break;
        case EXCEPTION_STACK_OVERFLOW:
            break;
        ...
    }
}
```

docs.microsoft.com/en-us/windows/win32/api/winnt/ns-winnt-exception_record

SEH Translator

```
void ExceptionHandling::TransFunc(unsigned int aSECode, EXCEPTION_POINTERS * aExInfo)
{
    ...
    SehException::SEType seType = SehException::SEH_GENERIC;

    // for AV exception, we can determine the type of operation that caused it
    if (aSECode == EXCEPTION_ACCESS_VIOLATION)
    {
        // the first element of the array contains a read-write flag
        // that indicates the type of operation that caused the access violation
        ULONG_PTR operationType = aExInfo->ExceptionRecord->ExceptionInformation[0];

        // the second array element specifies the virtual address of the inaccessible data
        ULONG_PTR virtualAddress = aExInfo->ExceptionRecord->ExceptionInformation[1];

        if (operationType == 0)
            seType = virtualAddress ? SehException::SEH_AV_READ_BADPTR : SehException::SEH_AV_READ_NULLPTR;
        else if (operationType == 1)
            seType = virtualAddress ? SehException::SEH_AV_WRITE_BADPTR : SehException::SEH_AV_WRITE_NULLPTR;
        else if (operationType == 8)
            seType = virtualAddress ? SehException::SEH_AV_DEP_BADPTR : SehException::SEH_AV_DEP_NULLPTR;
    }

    // record SEH type info in exception message
    exceptionMsg.insert(0, L "[" + SehException::SeTypeToString(seType) + L "] ");
}
```

SEH Translator

```
void ExceptionHandling::TransFunc(unsigned int aSECode, EXCEPTION_POINTERS * aExInfo)
{
    // write the exception prolog (type, code, address, etc.)
    // decode SEH exception type
    ...

    // walk the function call stack and gather information about each frame
    StackWalker::TraceFromContext(exceptionMsg, aExInfo->ContextRecord);

    // for AV exception, we can determine the type of operation that caused it
    ... => seType

    // extract SEH exception origin from StackTrace
    SymbolUtil::SrcPos exOrigin = GetExceptionOrigin(aExInfo->ContextRecord);

    // throw a C++ typed exception with the necessary fault information (attached)
    throw SehException(exOrigin.mFile, exOrigin.mLine, seType, exceptionMsg);
}
```

So we end up with a regular C++ exception wrapping the **SEH** info

What's the catch ?

What about an exception **in flight** ?

Get the stack trace for the raised exception on the *current thread*.

What's the catch ?

What about an exception **in flight** ?

Get the stack trace for the raised exception on the *current thread*.

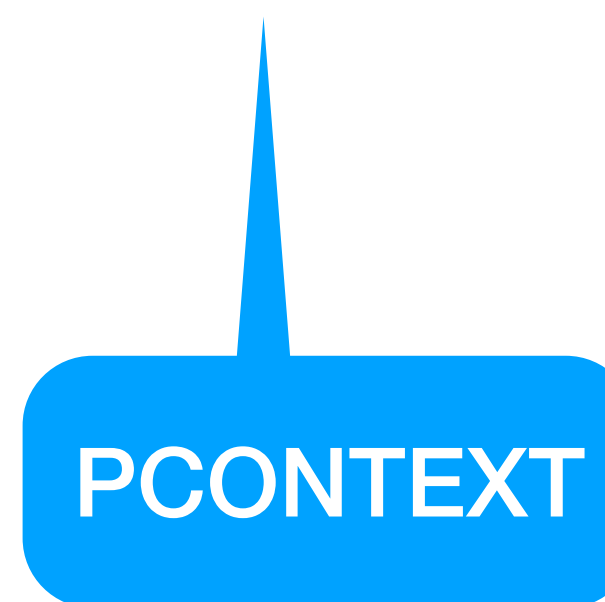
```
wstring ExceptionHandling::GetStackTraceForCurrentException()  
{  
    wstring stackTrace;  
    StackWalker::TraceFromContext(stackTrace, ExceptionHandling::GetCurrentExceptionContext());  
  
    return stackTrace;  
}
```

What's the catch ?

What about an exception **in flight** ?

Get the stack trace for the raised exception on the *current thread*.

```
wstring ExceptionHandling::GetStackTraceForCurrentException()  
{  
    wstring stackTrace;  
    StackWalker::TraceFromContext(stackTrace, ExceptionHandling::GetCurrentExceptionContext());  
  
    return stackTrace;  
}
```



EXCEPTION_POINTERS >> PCONTEXT

We've already seen this (**PCONTEXT**)

```
void ExceptionHandling::TransFunc(unsigned int aSECode, EXCEPTION_POINTERS * aExInfo)
{
    StackWalker::TraceFromContext(exceptionMsg, aExInfo->ContextRecord);
    ...
}
```

```
struct EXCEPTION_POINTERS
{
    PEXCEPTION_RECORD ExceptionRecord;
    PCONTEXT ContextRecord;
};
```

docs.microsoft.com/en-us/windows/win32/api/winnt/ns-winnt-exception_pointers

Where to start ?

So, how do we get this `PCONTEXT` ?



Where to start ?

So, how do we get this `PCONTEXT` ?

#if _MSC_VER >= 1900
Visual Studio 2015-2022

```
PCONTEXT ExceptionHandling::GetCurrentExceptionContext()  
{  
    __vcrt_ptd * pTid = nullptr;  
  
    #ifdef _DLL // Multi-Threaded DLL /MD or /MDd  
        pTid = (__vcrt_ptd *)(((BYTE *)__current_exception_context())  
            - offsetof(__vcrt_ptd, _curcontext));  
    #else // Multi-Threaded /MT or /MTd  
        pTid = __vcrt_getptd();  
    #endif  
  
    return (CONTEXT *)pTid->_curcontext;  
}
```

Where to start ?

So, how do we get this `PCONTEXT` ?

#if _MSC_VER < 1900
Visual Studio 2013

```
PCONTEXT ExceptionHandling::GetCurrentExceptionContext()  
{  
    _tiddata * pTid = nullptr;  
  
    #ifdef _DLL // Multi-Threaded DLL /MD or /MDd  
        pTid = (_tiddata *)(((BYTE *)__pxcptinfoptrs())  
            - offsetof(_tiddata, _tpxcptinfoptrs));  
    #else // Multi-Threaded /MT or /MTd  
        pTid = _getptd();  
    #endif  
  
    return (CONTEXT *)pTid->_curcontext;  
}
```

CRT Power - undocumented APIs

```
#include <eh.h>

#include <signal.h> // for use of void ** __pxcptinfoptrs()

#if _MSC_VER >= 1900

#include <../CRT/src/vcruntime/vcruntime_internal.h>

extern "C" __vcrt_ptd * __cdecl __vcrt_getptd();
extern "C" void ** __cdecl __current_exception_context();

#else

#include <../CRT/src/mtdll.h>

_tiddata * _getptd();

#endif
```

CRT Power

```
// per-thread data
struct __vcrt_ptd          // #include <../CRT/src/vcruntime/vcruntime_internal.h>
{
    // C++ Exception Handling (EH) state
    unsigned long         _NLG_dwCode;           // Required by NLG routines
    unexpected_handler    _unexpected;          // unexpected() routine
    void *                _translator;         // S.E. translator
    void *                _purecall;           // called when pure virtual happens
    void *                _curexception;       // current exception
    void *                _curcontext;        // current exception context
    int                   _ProcessingThrow;    // for uncaught_exception
    void *                _curexcspec;        // for handling exceptions thrown from std::unexpected
    int                   _cxxReThrow;        // true if it's a rethrown C++ exception

#if defined _M_X64 || defined _M_ARM || defined _M_ARM64
    void *                _pExitContext;
    void *                _pUnwindContext;
    void *                _pFrameInfoChain;
    uintptr_t             _ImageBase;
    uintptr_t             _ThrowImageBase;
    void *                _pForeignException;
#elif defined _M_IX86
    void *                _pFrameInfoChain;
#endif
};
```

What if we want to get the current StackTrace from the *context of the caller* ?
(**on demand** - eg. assertions, logging)

When **no exception** is in flight!

How to get the **caller's PCONTEXT** ?

Caller PCONTEXT ...

```
void StackWalker::TraceFromCaller(wstring & aStackMsg)
{
    using PF_RtlCaptureContext = void(WINAPI *) (PCONTEXT aContextRecord);

    // dynamically load the RtlCaptureContext() kernel API
    static auto CaptureCtx = (PF_RtlCaptureContext)::GetProcAddress(
        ::LoadLibraryA("Kernel32.dll"),
        "RtlCaptureContext");

    CONTEXT context;
    ::ZeroMemory(&context, sizeof(context));

    // retrieve the context record of the caller function
    CaptureCtx(&context);

    StackWalker::TraceFromContext(aStackMsg, &context);
}
```

So now we know how to get this **PCONTEXT**

How do we *walk the stack* ?

```
wstring stackTrace;  
StackWalker::TraceFromContext(stackTrace, GetCurrentExceptionContext());
```


Walk the stack - init

```
void StackWalker::TraceFromContext(wstring & aStackMsg, PCONTEXT aContext, int MaxFrameCount)
{
    // All <DbgHelp> functions, such as StackWalk(), are single threaded
    // => we must synchronize all concurrent calls to this function
    SyncGuard guard(sEHSyncSupport);

    // Copy the given machine CONTEXT structure because the StackWalk() API
    // might modify it and subsequent calls needing the CONTEXT will fail
    CONTEXT context;
    ::CopyMemory(&context, aContext, sizeof(context));

    HANDLE hProcess = ::GetCurrentProcess();
    HANDLE hThread = ::GetCurrentThread();

    // create a symbol explorer
    SymbolUtil symMgr;
    if (!symMgr.Init(hProcess))
        return;

    ...
}
```

Walk the stack

```
void StackWalker::TraceFromContext(wstring & aStackMsg, PCONTEXT aContext, int MaxFrameCount)
{
    ...

    // initialize the STACKFRAME according to the platform we are working on (PE type)
    STACKFRAME sf;
    DWORD imageType = InitStackFrameFromContext(&sf, &context);

    for (int frmIndex = 0; frmIndex < MaxFrameCount; frmIndex++)
    {
        // get the current frame info
        BOOL result = ::StackWalk(imageType, hProcess, hThread, &sf, &context, nullptr,
                                SymFunctionTableAccess, SymGetModuleBase, nullptr);
        if (!result)
            break;

        aStackMsg += symMgr.ComposeStackFrame(sf.AddrPC.Offset);
    }

    // write the module load address – needed because of ASLR (Address Space Layout Randomization)
    aStackMsg += symMgr.ComposeModuleBaseAddress();
}
```

Walk the stack - frame setup

```
DWORD InitStackFrameFromContext(LPSTACKFRAME aStackFrame, PCONTEXT aContext)
{
    ::ZeroMemory(aStackFrame, sizeof(STACKFRAME));

    #if defined _M_IX86

        DWORD imageType = IMAGE_FILE_MACHINE_I386;

        aStackFrame->AddrStack.Offset = aContext->Esp;
        aStackFrame->AddrStack.Mode   = AddrModeFlat;

        aStackFrame->AddrFrame.Offset = aContext->Ebp;
        aStackFrame->AddrFrame.Mode   = AddrModeFlat;

        aStackFrame->AddrPC.Offset    = aContext->Eip;
        aStackFrame->AddrPC.Mode      = AddrModeFlat;

    #elif defined _M_X64

        .....

    #endif

    return imageType;
}
```

Walk the stack - frame setup

```
DWORD InitStackFrameFromContext(LPSTACKFRAME aStackFrame, PCONTEXT aContext)
{
    ::ZeroMemory(aStackFrame, sizeof(STACKFRAME));

    #if defined _M_IX86

        DWORD imageType = IMAGE_FILE_MACHINE_I386;

        aStackFrame->AddrStack.Offset = aContext->Esp;
        aStackFrame->AddrStack.Mode = AddrModeFlat;

        aStackFrame->AddrFrame.Offset = aContext->Ebp;
        aStackFrame->AddrFrame.Mode = AddrModeFlat;

        aStackFrame->AddrPC.Offset = aContext->Eip;
        aStackFrame->AddrPC.Mode = AddrModeFlat;

    #elif defined _M_X64

        ....

    #endif

    return imageType;
}
```

```
#elif defined _M_X64
```

```
    DWORD imageType = IMAGE_FILE_MACHINE_AMD64;
```

```
    aStackFrame->AddrStack.Offset = aContext->Rsp;
    aStackFrame->AddrStack.Mode = AddrModeFlat;
```

```
    aStackFrame->AddrFrame.Offset = aContext->Rbp;
    aStackFrame->AddrFrame.Mode = AddrModeFlat;
```

```
    aStackFrame->AddrPC.Offset = aContext->Rip;
    aStackFrame->AddrPC.Mode = AddrModeFlat;
```

```
#endif
```

Walk the stack - SymbolUtil

```
wstring SymbolUtil::SymbolNameFromAddress(DWORD_PTR aAddress) const
{
    ...

    auto pSymbol = reinterpret_cast<PSYMBOL_INFO>(mSymMemBuffer);
    pSymbol->SizeOfStruct = sizeof(SYMBOL_INFO);

    // get symbol name (de-mangled function name)
    if (DynSymFromAddr(mProcess, aAddress, nullptr, pSymbol))
        return pSymbol->Name;
    else
        return SW_NO_SYMBOL;
}
```

```
PF_SymFromAddr DynSymFromAddr()
{
    static auto symProc = (PF_SymFromAddr)::GetProcAddress(
        ::LoadLibraryA("Dbghelp.dll"), "SymFromAddr");

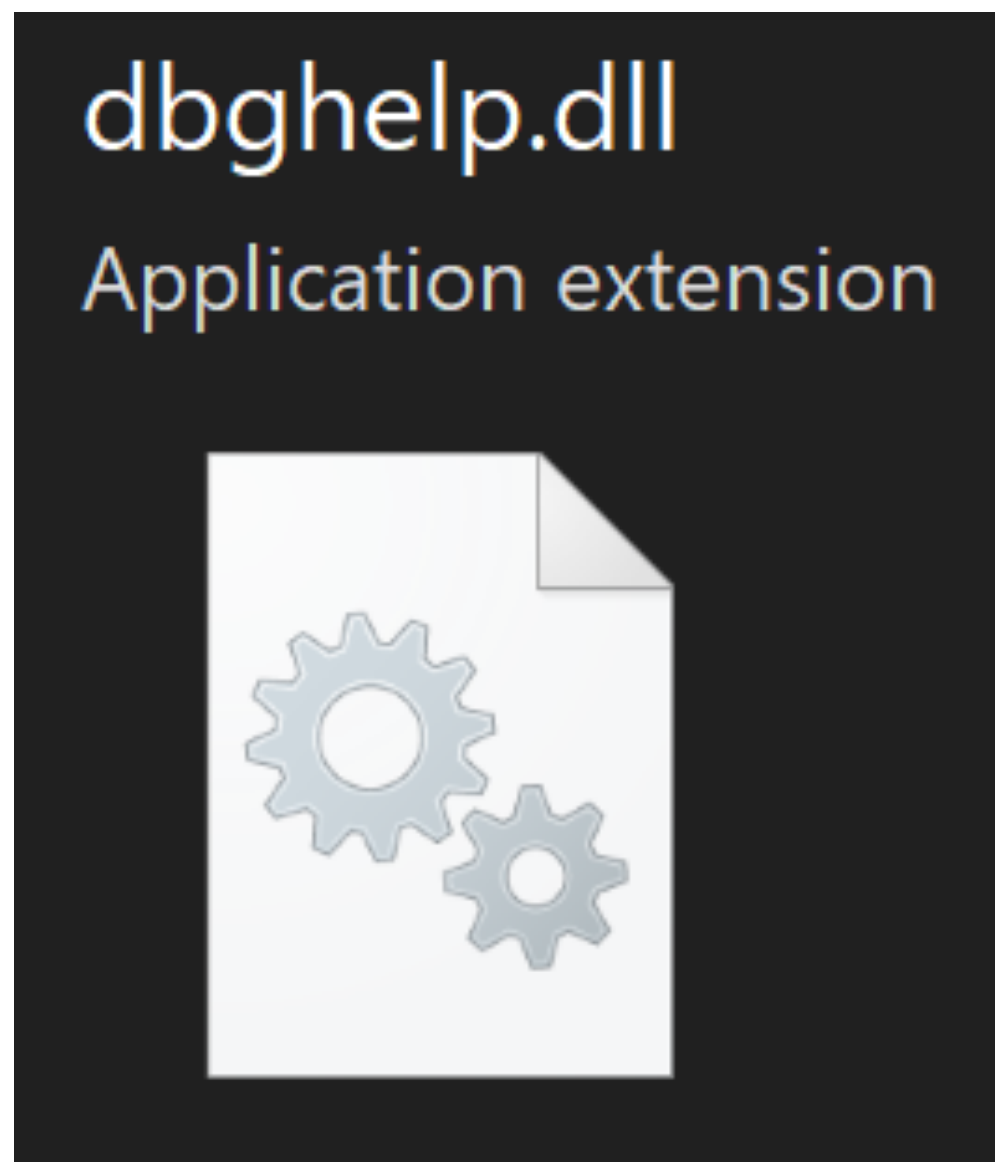
    return symProc;
}
```

Walk the stack - SymbolUtil

```
wstring SymbolUtil::SymbolSourceFromAddress(DWORD_PTR aAddress) const
{
    DWORD displacement = 0;

    IMAGEHLP_LINE line;
    ::ZeroMemory(&line, sizeof(line));
    line.SizeOfStruct = sizeof(line);

    // get location information for symbol "sourceFile:lineNo"
    if (::SymGetLineFromAddr(mProcess, aAddress, &displacement, &line))
    {
        wchar_t origin[MAX_PATH];
        swprintf_s(origin, MAX_PATH, L"%s:%ld", line.FileName, line.LineNumber);
        return origin;
    }
}
```



x86/x64

```
#include <dbghelp.h>
```

```
/LINK Dbghelp.lib
```

Dynamic dependency on `Dbghelp.dll`

My Quest For A Better Crash

The screenshot shows a video player interface. In the top left corner, there is a logo for 'C++ now'. The main content area displays a presentation slide with the following text: 'The Quest For A Better Crash' in a large green box, 'C++ Now 2021' in bold, and 'May 7' below it. At the bottom of the slide, there is a Twitter handle '@ciura_victor' and the name 'Victor Ciura' with the title 'Principal Engineer' and the CAPHYON logo. The video player controls at the bottom show a play button, a progress bar at 1:27 / 1:24:49, a volume icon, and a 'Engineering' category tag. The CppNow.org logo is visible in the bottom right corner of the video frame.

youtube.com/watch?v=pJPRdNTxL-E

Handle the unhandled...

Unhandled Exceptions



Unhandled Exceptions

No matching catch block 😞

```
void __srt_set_unhandled_exception_filter()
{
    ::SetUnhandledExceptionFilter(__srt_unhandled_exception_filter);
}

LONG __srt_unhandled_exception_filter(EXCEPTION_POINTERS * aPointers)
{
    if (aPointers->ExceptionRecord->ExceptionCode == EH_EXCEPTION_NUMBER)
        std::terminate();

    return EXCEPTION_CONTINUE_SEARCH;
}
```

Unhandled Exceptions

```
static bool installedFilter = false;  
if (!installedFilter)  
{  
    ::SetUnhandledExceptionFilter(ExceptionHandling::UnhandledException);  
    installedFilter = true;  
}
```

If an exception occurs in a process that is not being debugged,
and the exception makes it to the **Unhandled** exception filter => [we intercept it](#)

This replaces the existing top-level exception filter for ALL existing and
ALL future threads in the calling process.

Unhandled Exceptions

```
LONG ExceptionHandling::UnhandledException(EXCEPTION_POINTERS * aExceptionInfo)
{
    wstring message(L"[EXCEPTION_UNHANDLED] ");

    wchar_t buf[MSG_BUFFER_LEN];
    swprintf_s(buf, MSG_BUFFER_LEN, L"(0x%.8x) at address " ADDRESS_FORMAT SW_EOL,
               aExceptionInfo->ExceptionRecord->ExceptionCode,
               aExceptionInfo->ExceptionRecord->ExceptionAddress);
    message += buf;

    StackWalker::TraceFromContext(message, aExceptionInfo->ContextRecord);

    ErrMsgPresenter::Message(message);

    return EXCEPTION_EXECUTE_HANDLER;
}
```



Exceptional C++

CPPP 2021

December 1st



@ciura_victor

Victor Ciura
Principal Engineer

