

Exceptional C++

Meeting C++ 2021

November 12th



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Abstract

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!

About me



Advanced Installer



Clang Power Tools



Q & A



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Almost 2022



Almost 2022



It's almost **2022** 

Almost 2022



It's almost **2022** 

the COVID pandemic is not over yet 

Almost 2022



It's almost **2022** 

the COVID pandemic is not over yet 

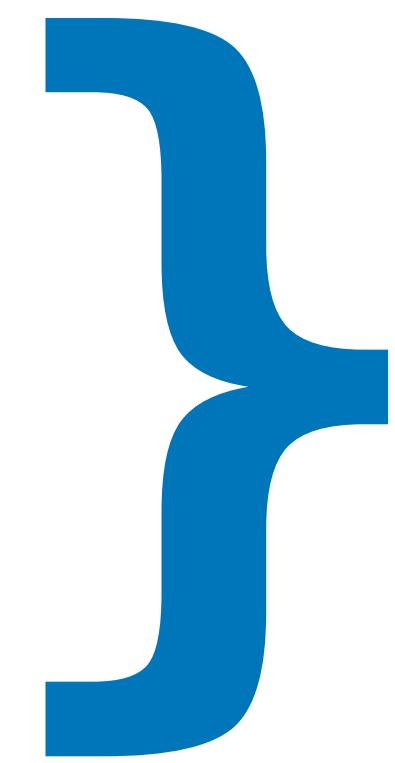
the minimum C++ version you should be using is **C++17**

Time to upgrade...

C++

Seriously, it's almost **2022**

</PSA>



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

Motivation



Exceptions... exceptions everywhere!

Exceptional C++

This talk is **not** about:

Exceptions vs Error codes vs Expected<T>

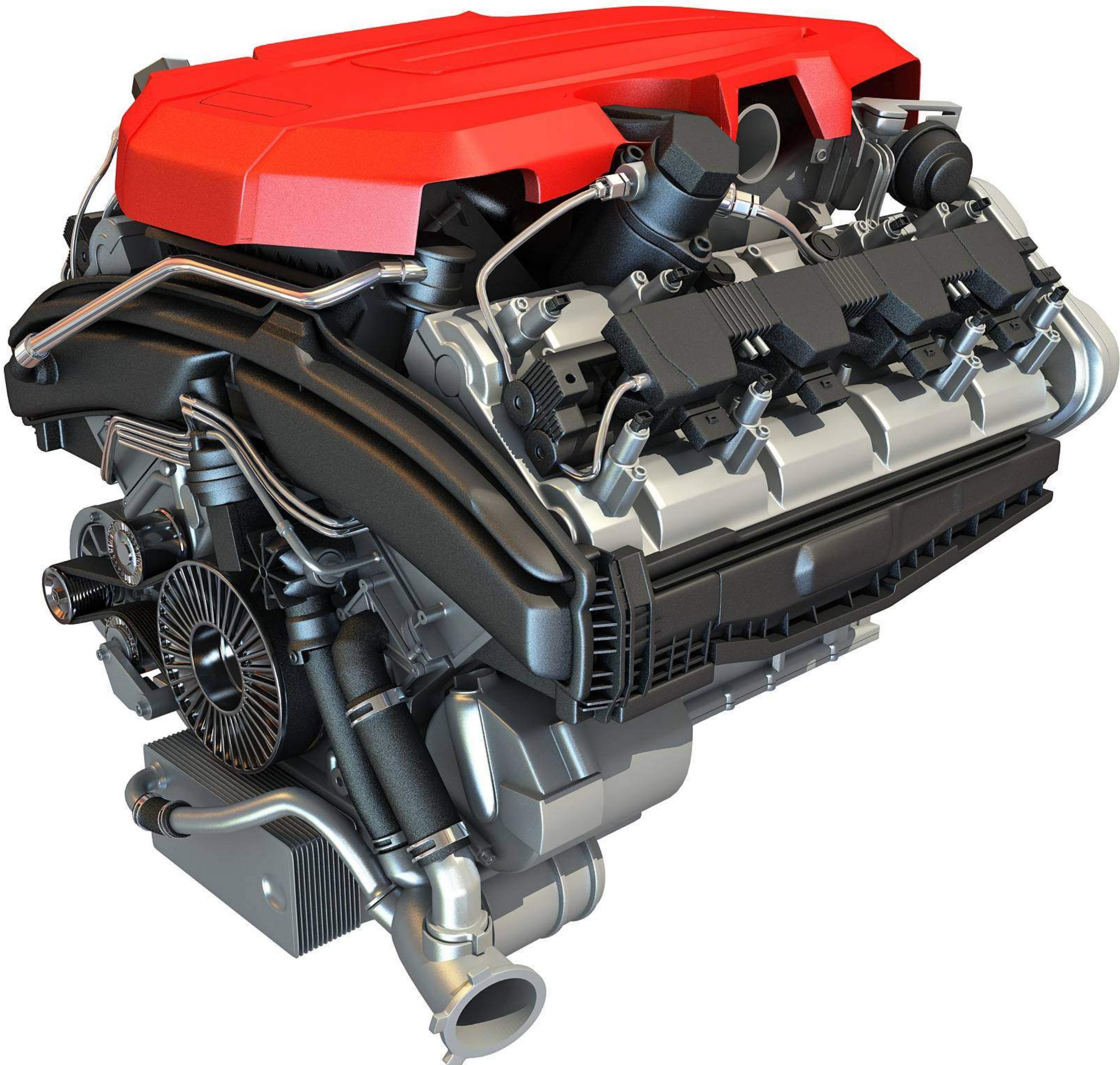
Exception safe code

Error handling best practices

This talk is **not** about



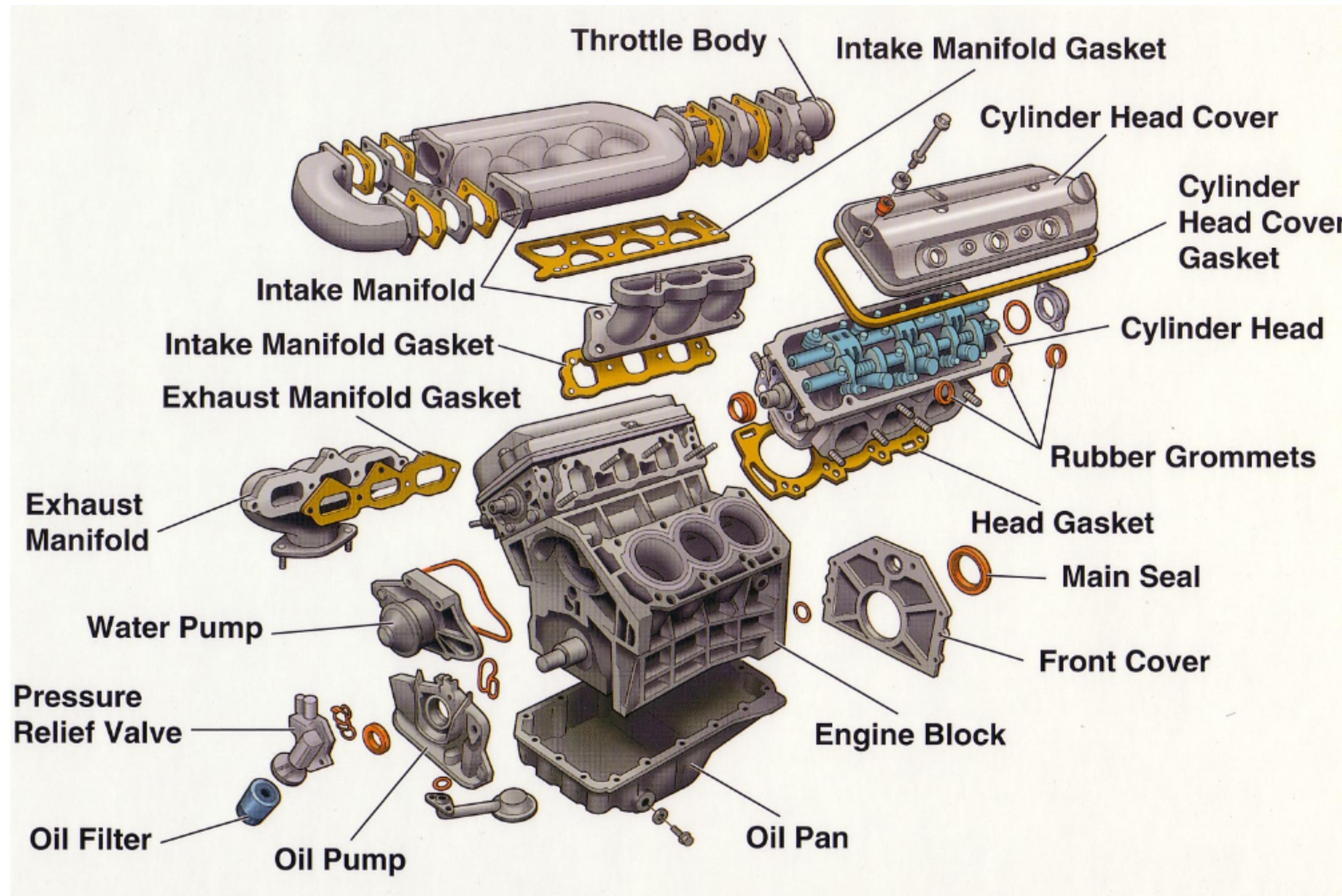
This talk is about



To be honest...



What we actually care about



This talk is about



Exception Internals

Exception Internals

Windows

x86/x64

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() -> atlDlg.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() -> atlDlg.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()
[0x0000000000a00000] MODULE_BASE_ADDRESS

Structured Exceptions

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

Structured Exception Handling (SEH)

/EH_a

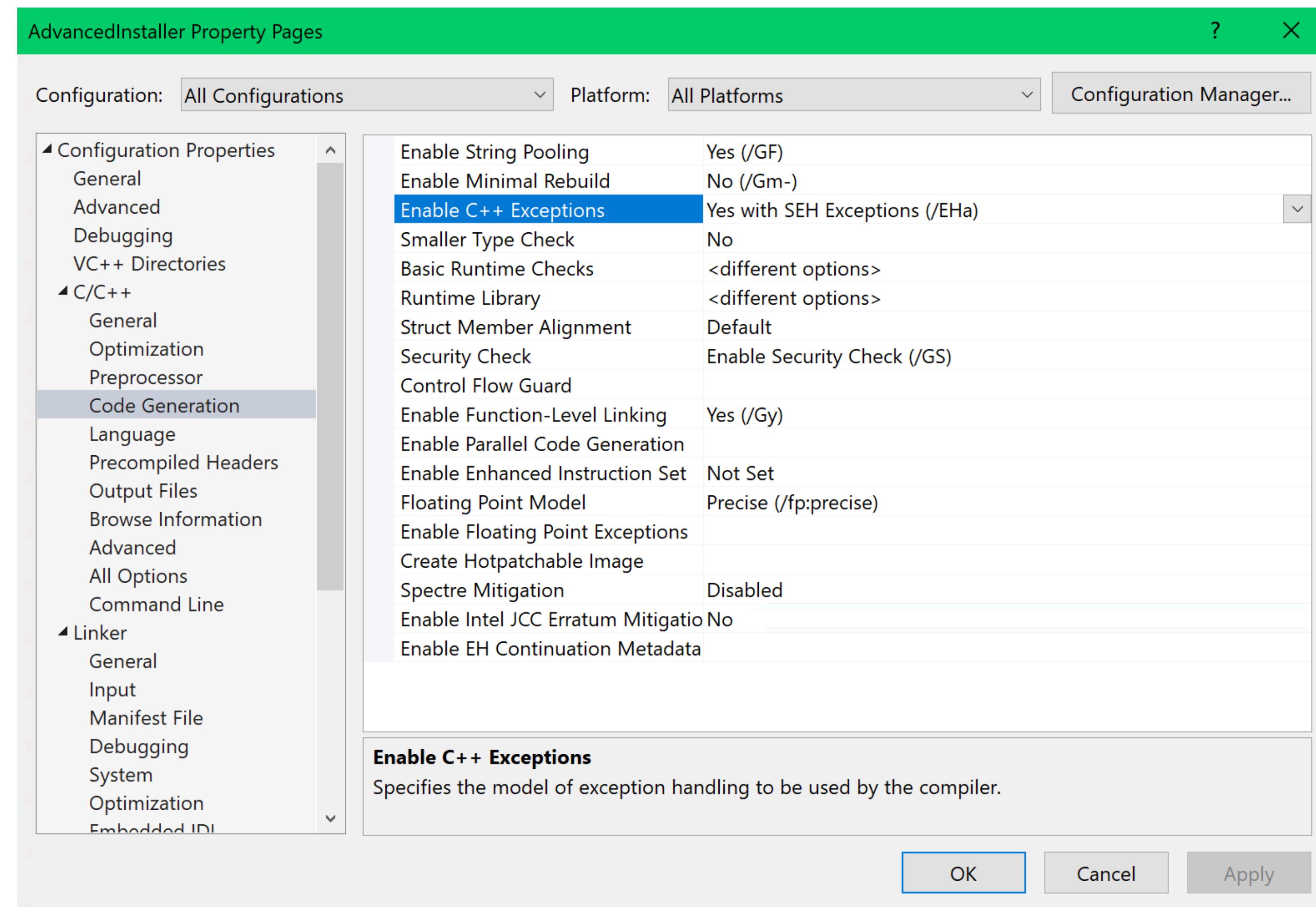
we use `async` exceptions on all modules

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

The Elephant in The Room

Structured Exception Handling (SEH)

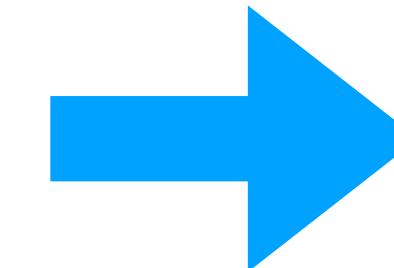
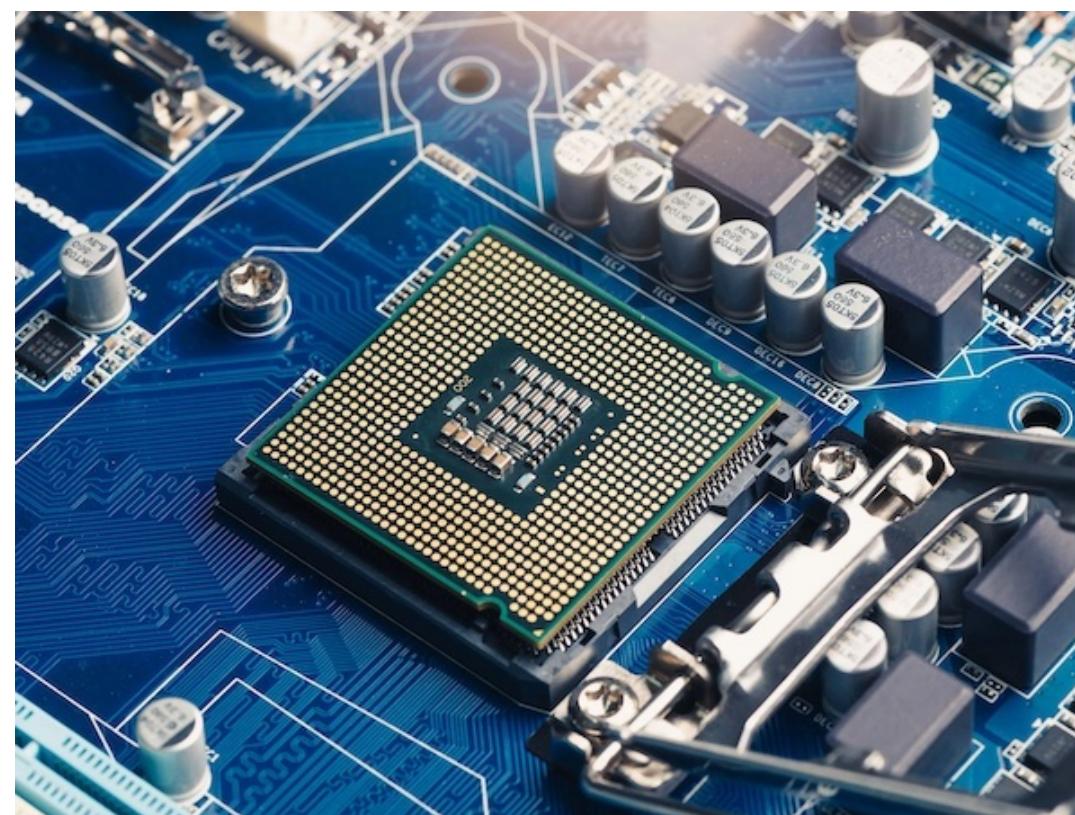
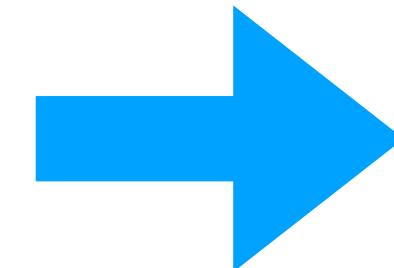


Structured Exception Handling (SEH)

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

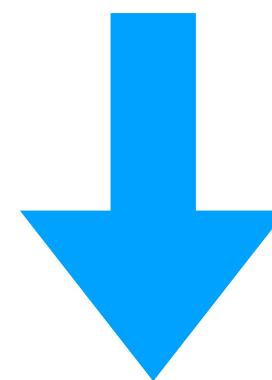
/EHs /DEBUG:FULL /Zi

SEH



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

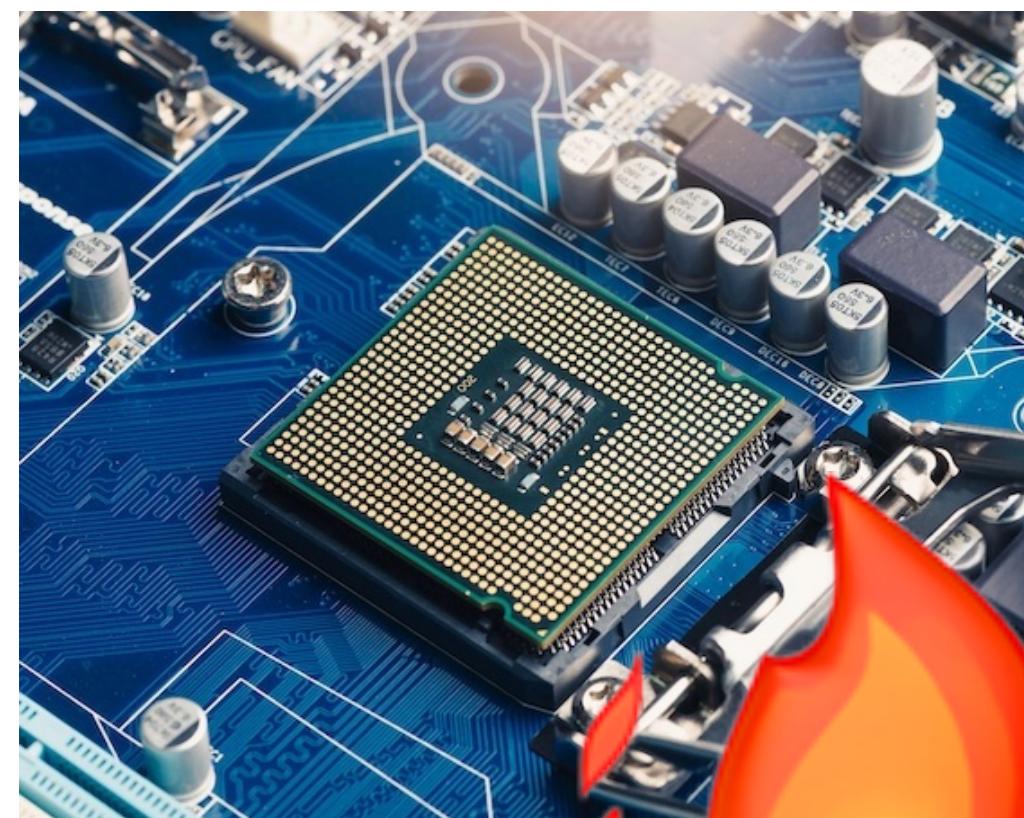
interrupt handler



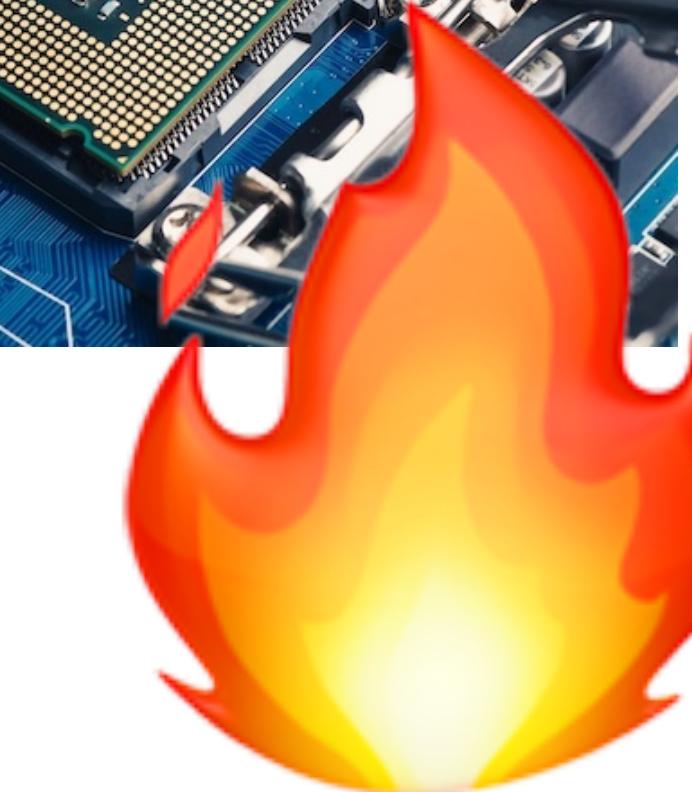
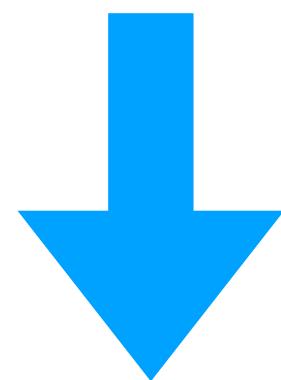
SEH

What's next?

SEH

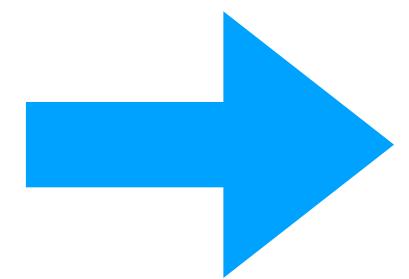
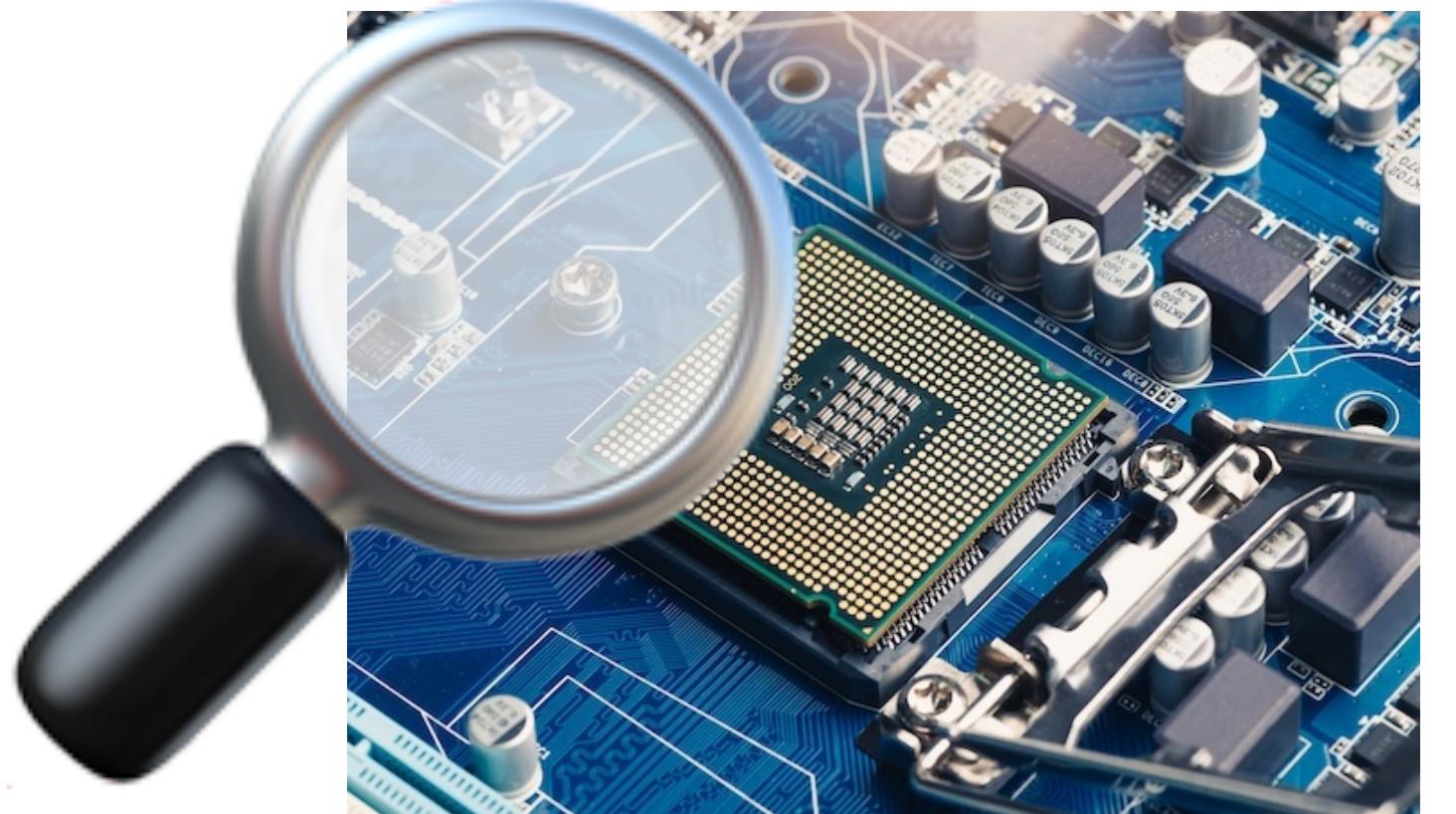


Task Manager			
File Options View			
Processes Performance App history Startup Users Details Services			
Name	11% CPU	77% Memory	0% Disk
Apps (6)			
Google Chrome (25)	0.1%	215.4 MB	0 MB/s
Microsoft Excel	0.2%	4.5 MB	0 MB/s
Microsoft Word	1.0%	64.3 MB	0 MB/s
Task Manager	3.8%	27.3 MB	0 MB/s
TIM (32 bit) (2)	0.3%	102.7 MB	0 MB/s
Windows Explorer	0.2%	11.4 MB	0 MB/s
Fewer details		End task	



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];
};
```

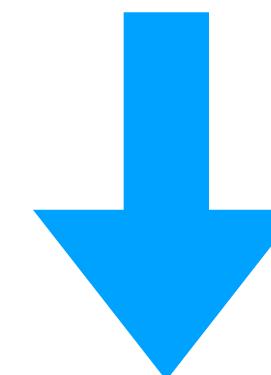
```
struct EXCEPTION_RECORD64 {
    DWORD    ExceptionCode;
    DWORD    ExceptionFlags;
    DWORD64  ExceptionRecord;
    DWORD64  ExceptionAddress;
    DWORD    NumberParameters;
    DWORD    __unusedAlignment;
    DWORD64  ExceptionInformation[EXCEPTION_MAXIMUM_PARAMETERS];
};
```

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_WRITEFAULT; // 0 = read; 1 = write; 8 = DEP
ex.ExceptionInformation[1] = 0x01ED6F42; // WHAT: the virtual address of the inaccessible data
```



?

NT_TIB

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

NT_TIB

Win32 Thread Information Block (TIB)

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

FS: [0x00]

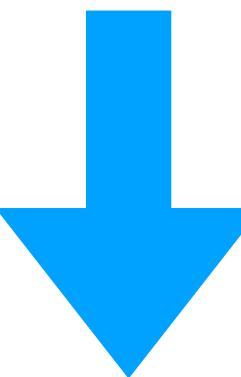
GS: [0x00]

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

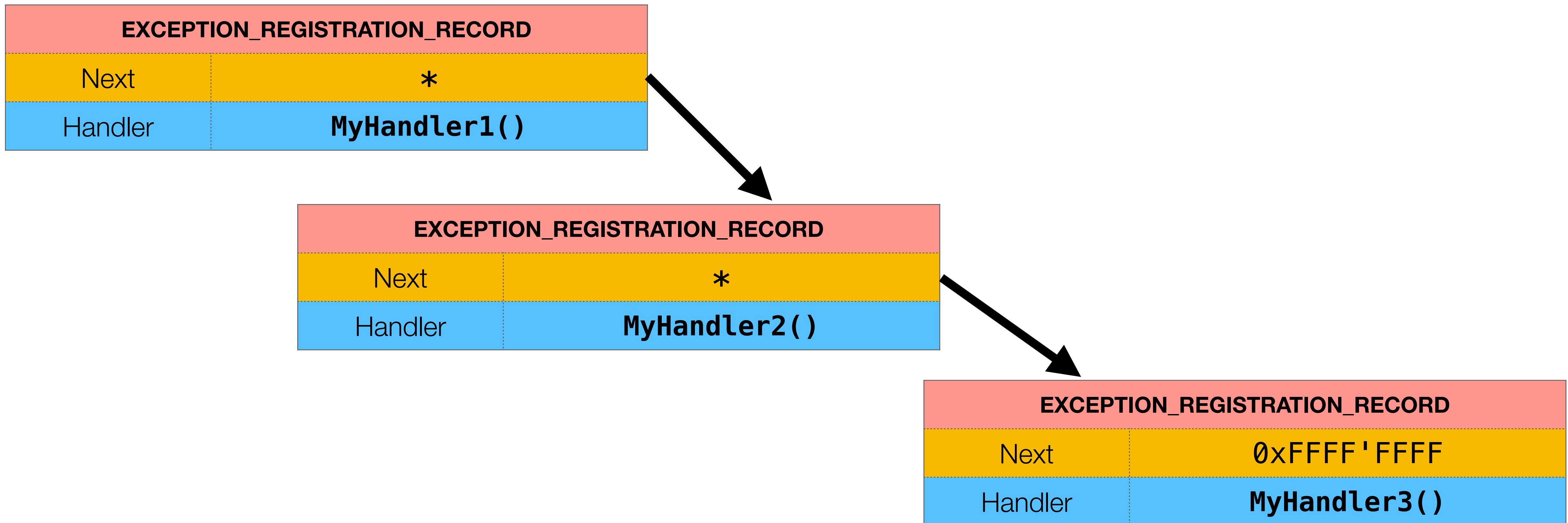
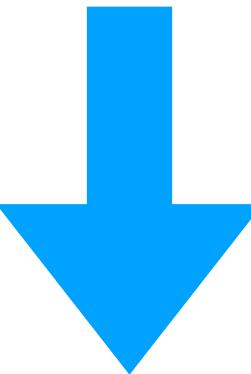


```
struct EXCEPTION_REGISTRATION_RECORD
{
    PEXCEPTION_REGISTRATION_RECORD Next;
    PEXCEPTION_DISPOSITION Handler;
}
```



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_READFAULT)
            seType = virtualAddress ? SehException::SEH_AV_READ_BADPTR : SehException::SEH_AV_READ_NULLPTR;
        else if (operationType == EXCEPTION_WRITEFAULT)
            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?
    }
}
```

The diagram illustrates the flow of an exception from the try block to the handler and then to the continuation. A yellow rounded rectangle surrounds the code within the try block. An arrow points from the end of the try block to the start of the __except block. Another arrow points from the __except block to the start of the continuation code. The continuation code is labeled with two red text labels: **EXCEPTION_CONTINUE_SEARCH** and **EXCEPTION_CONTINUE_EXECUTION**. A black arrow points from the continuation code back to the start of the __except block.

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( ExceptionFilter( GetExceptionInformation() ) )
    {
        // pretend it never happened?
    }
}
```

The diagram illustrates the flow of an exception from the try block to the exception filter. A yellow rounded rectangle surrounds the code within the try block. An arrow points from the end of the try block's brace to the start of the __except block. Another arrow points from the __except block's brace to the start of the handler code.

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_WRITEFAULT)
    {
        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;
}
```

C++ Exceptions

Why are we bothering to understand all this ?

C++ Exceptions

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>_CxFrameHandler()</code>	<code>_except_handler3()</code>

C++ Exceptions

`throw MyException{};` \Rightarrow `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 * aEx0bject, _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)aEx0bject;  
    exception.ExceptionInformation[2] = (ULONG_PTR)aThrowInfo;  
  
    ::RaiseException(exception.ExceptionCode,  
                    exception.ExceptionFlags,  
                    exception.NumberParameters,  
                    exception.ExceptionInformation);  
}
```

`_CxxThrowException()`

a C++ exception is born 

C++ Exceptions

Let's flip this around...

SEH => 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

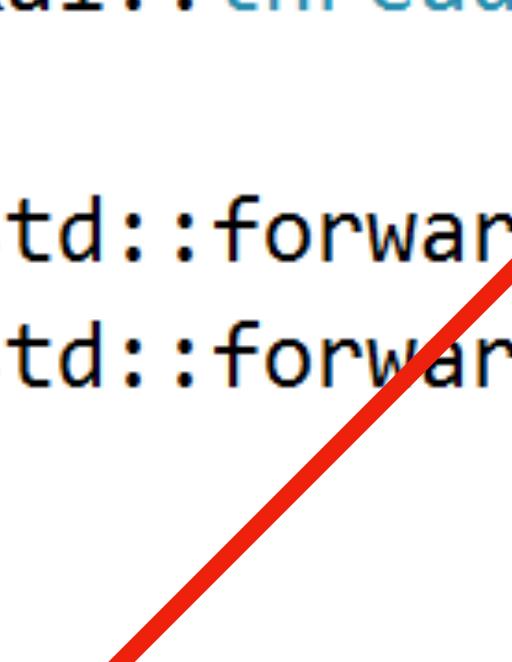
Structured Exception Handling (SEH)

```
|class thread
{
public:
    using id = std::thread::id;

    thread() noexcept {}

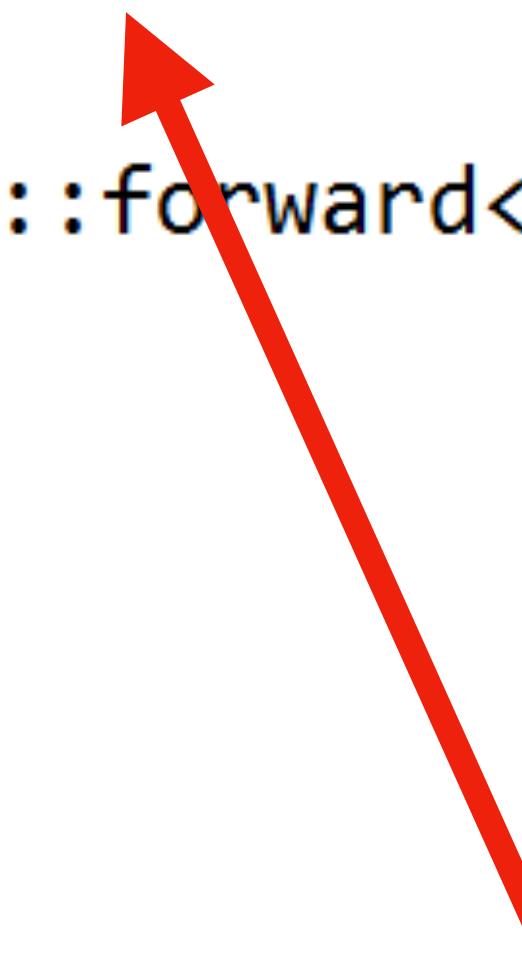
    template <
        class FunType,
        class... ArgTypes,
        class = typename enable_if<!is_same<typename decay<FunType>::type, thread>::value>::type>
    explicit thread(FunType && aFun, ArgTypes &&... aArgs)
        : mTh(&ai::thread::shim_proc<typename std::decay<FunType>::type,
         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

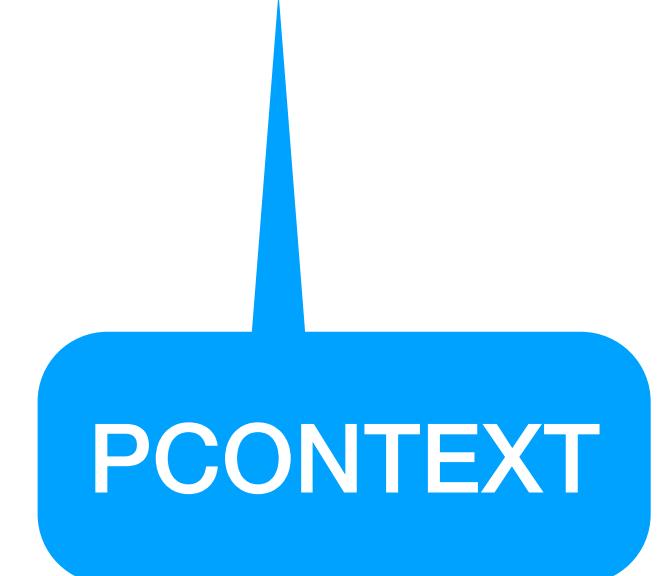
What's the catch ?

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;
}
```



PCONTEXT

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;

#ifndef _DLL // Multi-Threaded DLL /MD or /MDd

    pTid = (_tiddata *)(((BYTE *)__pxcptinfoptrs())
                         - offsetof(_tiddata, __pxcptinfoptrs));

#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;
#endif
#endif
};
```

PCONTEXT à-la carte

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);
}
```

PCONTEXT ...

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));

#ifndef _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;

#endif // _M_IX86

    .....

#endif // _M_X64

    return imageType;
}
```

Walk the stack - frame setup

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

#ifndef _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;

#endif // _M_IX86

    .....

#endif // _M_IX86

    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_INF0>(mSymMemBuffer);
    pSymbol->SizeOfStruct = sizeof(SYMBOL_INF0);

    // 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;
}
```

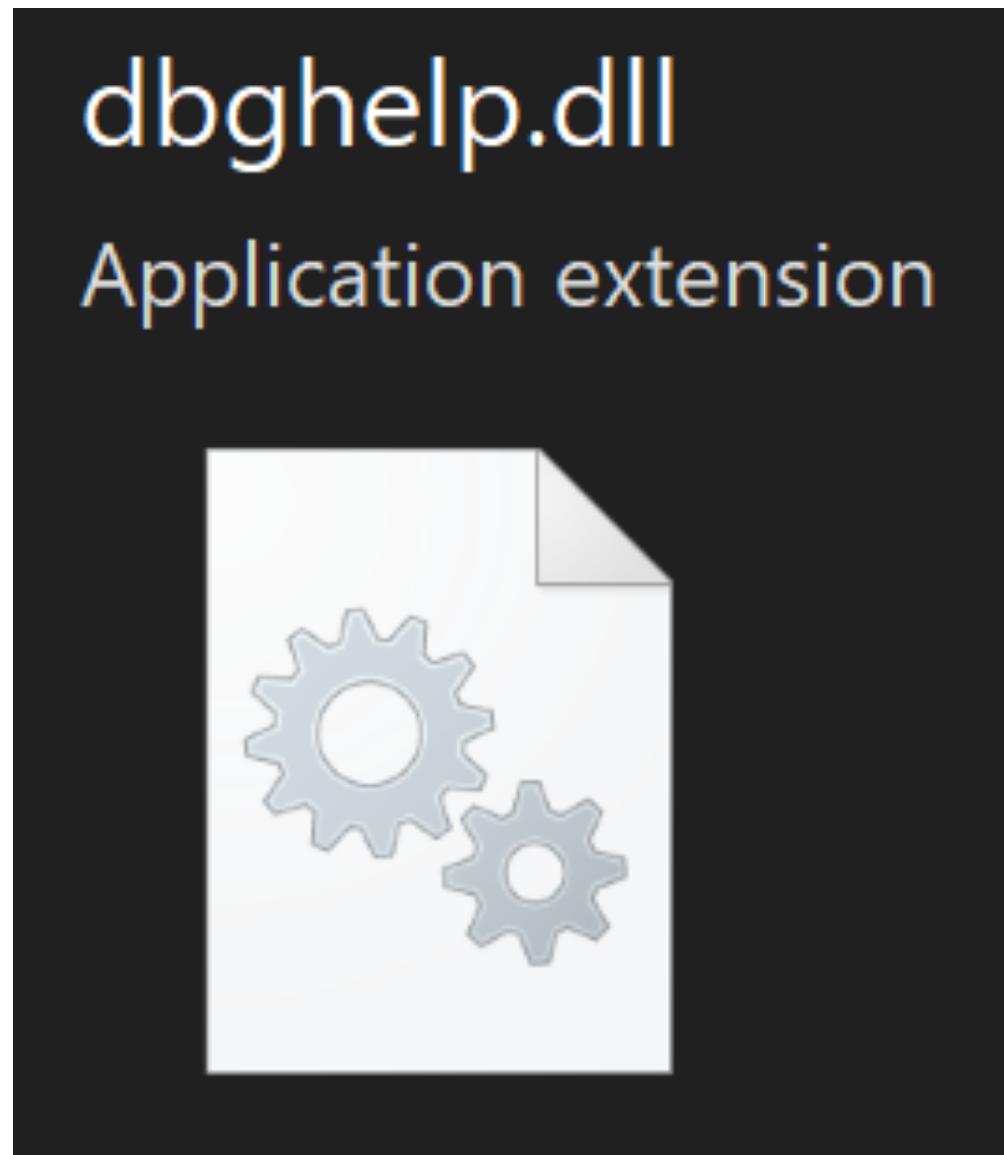
Walk the stack - SymbolUtil

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

    IMAGEHELP_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;
    }
}
```

<dbghelp.h>



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's a circular logo with "C++ now". The main title "The Quest For A Better Crash" is displayed in white text on a dark green rectangular background. Below the title, the text "C++ Now 2021" and "May 7" are shown. To the right of the title, there's a photo of a man with glasses and a green polo shirt, identified as "Victor Ciura". On the far left, there's a vertical bar with logos for "JET BRAINS" and "Bloomberg". At the bottom of the screen, there are playback controls (rewind, fast forward, volume), a timestamp "1:27 / 1:24:49", a category "Engineering", and a URL "CppNow.org". On the right side, there's a bio for Victor Ciura, listing him as a "Principal Engineer" at "CAPHYON" with a blue cube logo.

C++ now

The Quest For A Better Crash

The Quest For A Better Crash

C++ Now 2021

May 7

Victor Ciura

JET BRAINS Bloomberg

1:27 / 1:24:49 Engineering CppNow.org CC HD

@ciura_victor

Victor Ciura Principal Engineer CAPHYON

youtube.com/watch?v=pJPRdNTxL-E

Unhandled Exceptions

Handle the unhandled...

Unhandled Exceptions

**JUST WHEN
I THOUGHT
I WAS OUT**

THEY PULL ME BACK IN

imgflip.com

Unhandled Exceptions

No matching catch block 😞

```
void __scrt_setUnhandledExceptionFilter()
{
    ::SetUnhandledExceptionFilter(__scrtUnhandledExceptionFilter);
}

LONG __scrtUnhandledExceptionFilter(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;
}
```

Bonus Slides

C++23

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>



The first major library feature for #Cpp23 will be a stack trace library

7:34 PM · Nov 9, 2020 · Twitter Web App

1 Quote Tweet 18 Likes

Kilian @kilian_ukilele · Nov 10
Replying to @AlisdairMered
Awesome! Will std::exception also get a function to query the callstack from where it got thrown?

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

C++ 23 <stacktrace>

Key features (desired):

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- 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

C++ 23 <stacktrace>

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- information about **inlined functions** that have no separate stacktrace entries is welcomed -> `to_string(stacktrace)`

C++ 23 <stacktrace>

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()`

C++ 23 <stacktrace>

```
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;
};
```

C++ 23 <stacktrace>

```
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;
```

C++ 23 <stacktrace>

It can't get any simpler than that.

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

Exceptional C++

Meeting C++ 2021

November 12th



@ciura_victor

Victor Ciura
Principal Engineer

