Compiler Internals: Exceptions and RTTI

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Recon 2012
Montreal

Outline

- Visual C++
  - Structured Exception Handling (SEH)
  - C++ Exception Handling (EH)
- GCC
  - RTTI
  - SjLj exceptions
  - Zero-cost (table based)

Visual C++

- SEH vs C++ EH
- SEH (Structured Exceptions Handling) is the low-level, system layer
- Allows to handle exceptions sent by the kernel or raised by user code
- C++ exceptions in MSVC are implemented on top of SEH

Visual C++

- Keywords __try, __except and __finally can be used for compiler-level SEH support
- The compiler uses a single exception handler per all functions with SEH, but different supporting structures (scope tables) per function
- The SEH handler registration frame is placed on the stack
- In addition to fields required by system (handler address and next pointer), a few VC-specific fields are added

Visual C++

- Frame structure (fs:0 points to the **Next** member)

```
// -8 DWORD _esp;
// -4 PEXCEPTION_POINTERS xpointers;
struct _EH3_EXCEPTION_REGISTRATION
{
  struct _EH3_EXCEPTION_REGISTRATION *Next;
  PVOID ExceptionHandler;
  PSCOPETABLE_ENTRY ScopeTable;
  DWORD TryLevel;
};
```

Visual C++

- ExceptionHandler points to __except_handler3 (SEH3) or __except_handler4 (SEH4)
- The frame set-up is often delegated to compiler helper (__SEH_prolog/__SEH_prolog4/etc)
- **ScopeTable** points to a table of entries describing all __try blocks in the function
- in SEH4, the scope table pointer is XORed with the security cookie, to mitigate scope table pointer overwrite

Visual C++: Scope Table

- One scope table entry is generated per __try block
- EnclosingLevel points to the block which contains the current one (first table entry is number 0)
- Top level (function) is -1 for SEH3 and -2 for SEH4
- SEH4 has additional fields for cookie checks

SEH3

```
struct _SCOPETABLE_ENTRY
{
  DWORD EnclosingLevel;
  void* FilterFunc;
  void* HandlerFunc;
}
```

SEH4

```
struct _EH4_SCOPETABLE {
    DWORD GSCookieOffset;
    DWORD GSCookieXOROffset;
    DWORD EHCookieOffset;
    DWORD EHCookieXOROffset;
    _EH4_SCOPETABLE_RECORD ScopeRecord[];
};
```

Visual C++: mapping tables to code

- **FilterFunc** points to the exception filter (expression in the __except operator)
- **HandlerFunc** points to the __except block body
- if **FilterFunc** is NULL, **HandlerFunc** is the __finally block body
- Current try block number is kept in the **TryLevel** variable of the exception registration frame

```
; Entering __try block 0
mov     [ebp+ms_exc.registration.TryLevel], 0
; Entering __try block 1
mov     [ebp+ms_exc.registration.TryLevel], 1
[...]
; Entering __try block 0 again
mov     [ebp+ms_exc.registration.TryLevel], 0
```

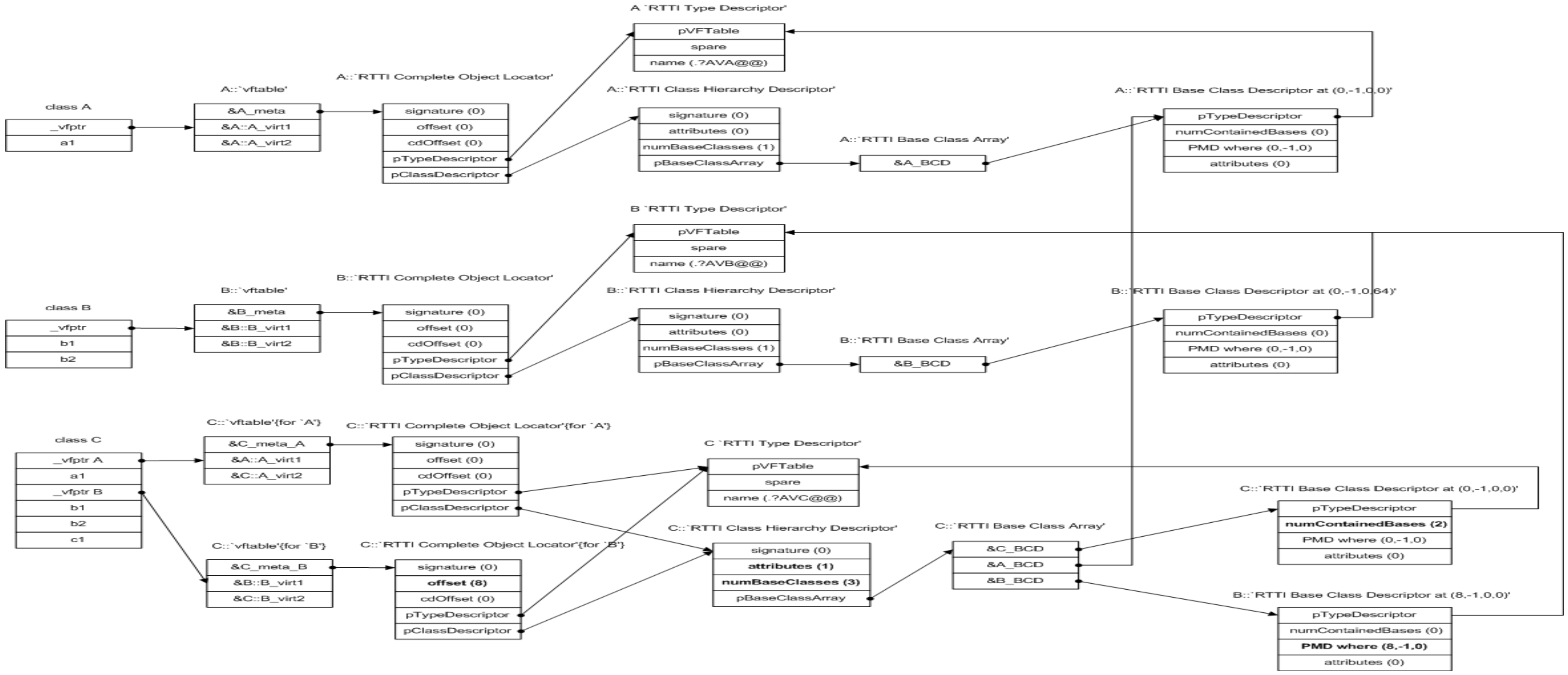
Visual C++: SEH helper functions

- A few intrinsics are available for use in exception filters and __finally block
- They retrieve information about the current exception
- GetExceptionInformation/GetExceptionCode use the **xpointers** variable filled in by the exception handler
- AbnormalTermination() uses a temporary variable which is set before entering the __try block and cleared if the __finally handler is called during normal execution of the function

Visual C++

C++ implementation

Visual C++: RTTI



- See openrce.org for more info

Visual C++: EH

- EH is present if function uses try/catch statements or automatic objects with non-trivial destructors are present
- implemented on top of SEH
- Uses a distinct handler per function, but they all eventually call a common one (_CxxFrameHandler/_CxxFrameHandler3)
- compiler-generated unwind funclets are used to perform unwinding actions (calling destructors etc) during exception processing
- A special structure (FuncInfo) is generated for the function and contains info about unwinding actions and try/catch blocks

Visual C++ EH: Registration and FuncInfo structure

```
struct EHRegistrationNode {
 // -4 void *_esp;
 EHRegistrationNode *pNext;
 void *frameHandler;
 int state;
};
```

```
typedef const struct _s_FuncInfo {
  unsigned int magicNumber:29;
  unsigned int bbtFlags:3;
  int maxState;
  const struct _s_UnwindMapEntry * pUnwindMap;
  unsigned int nTryBlocks;
  const struct _s_TryBlockMapEntry * pTryBlockMap;
  unsigned int nIPMapEntries;
  void * pIPtoStateMap;
  const struct _s_ESTypeList * pESTypeList;
  int EHFlags;
} FuncInfo;
```

Visual C++ EH: FuncInfo structure

Field	Meaning
`magicNumber`	0x19930520: original (pre-VC2005?) 0x19930521: pESTypeList is valid 0x19930522: EHFlags is valid
`maxState/pUnwindMap`	Number of entries and pointer to unwind map
`nTryBlocks/pTryBlockMap`	Number of entries and pointer to try{} block map
`nIPMapEntries` `pIPtoStateMap`	IP-to-state map (unused on x86)
`pESTypeList`	List of exceptions in the throw specification (undocumented feature)
`EHFlags`	FI_EHS_FLAG=1: function was compiled /EHs

Visual C++ EH: Unwind map

- Similar to SEH's scope table, but without exception filters
- All necessary actions (unwind funclets) are executed unconditionally
- Action can be NULL to indicate no-action state transition
- Typical funclet destroys a constructed object on the stack, but there may be other variations
- Top-level state is -1

```
typedef const struct _s_UnwindMapEntry {
  int toState;
  void *action;
} UnwindMapEntry;
```

Visual C++: changes for x64

- SEH changes completely
- Instead of stack-based frame registration, pointers to handlers and unwind info are stored in .pdata section
- Only limited set of instructions are supposed to be used in prolog and epilog, which makes stack walking and unwinding easier
- "Language-specific handlers" are used to implement compiler-level SEH and C++ EH
- However, the supporting SEH/EH structures (scope table, FuncInfo etc) are very similar

x64: .pdata section

- Contains an array of RUNTIME_FUNCTION structures
- Each structure describes a contiguous range of instructions belonging to a function
- Chained entries (bit 0 set in UnwindInfo) point to the parent entry
- All addresses are RVAs

```
typedef struct _RUNTIME_FUNCTION {
  DWORD BeginAddress;
  DWORD EndAddress;
  DWORD UnwindInfoAddress;
} RUNTIME_FUNCTION;
```

x64: Unwind Info

- Starts with a header, then a number of "unwind codes", then an optional handler and any additional data for it
- Handler is present if Flags have UNW_FLAG_EHANDLER or UNW_FLAG_UHANDLER

```
typedef struct _UNWIND_INFO {
    unsigned char Version : 3;                 // Version Number
    unsigned char Flags   : 5;                 // Flags
    unsigned char SizeOfProlog;
    unsigned char CountOfCodes;
    unsigned FrameRegister : 4;
    unsigned FrameOffset   : 4;
    UNWIND_CODE UnwindCode[1];
/*  UNWIND_CODE MoreUnwindCode[((CountOfCodes+1)&~1)-1];
 *  union {
 *      OPTIONAL ULONG ExceptionHandler;
 *      OPTIONAL ULONG FunctionEntry;
 *  };
 *  OPTIONAL ULONG ExceptionData[];
 */
} UNWIND_INFO, *PUNWIND_INFO;
```

x64: Standard VC Exception Handlers

Handler	Data
`__C_specific_handler`	Scope table
`__GSHandlerCheck`	GS data
`__GSHandlerCheck_SEH`	Scope table + GS data
`__CxxFrameHandler3`	RVA to FuncInfo
`__GSHandlerCheck_EH`	RVA to FuncInfo + GS data

```
struct _SCOPE_TABLE_AMD64 {
    DWORD Count;
    struct
    {
        DWORD BeginAddress;
        DWORD EndAddress;
        DWORD HandlerAddress;
        DWORD JumpTarget;
    } ScopeRecord[1];
};
```

```
struct _GS_HANDLER_DATA {
  union {
    union  {
      unsigned long EHandler:1;
      unsigned long UHandler:1;
      unsigned long HasAlignment:1;
    } Bits;
    int CookieOffset;
  } u;
  long AlignedBaseOffset;
  long Alignment;
};
```

x64: Visual C++ SEH

- Scope table entries are looked up from the PC (RIP) value instead of using an explicit state variable
- Since they're sorted by address, this is relatively quick
- **Handler** points to the exception filter and **Target** to the __except block body
- However, if Target is 0, then Handler is the __finally block body
- Compiler (always?) emits a separate function for __finally blocks and an inline copy in the function body
- GS cookie data, if present, is placed after the scope table

x64: VC C++ EH FuncInfo

- Pretty much the same as x86, except RVAs instead of addresses and IP-to-state map is used

```
typedef struct _s_FuncInfo
{
  int magicNumber;              // 0x19930522
  int maxState;                 // number of states in unwind map
  int dispUnwindMap;            // RVA of the unwind map
  unsigned int nTryBlocks;      // count of try blocks
  int dispTryBlockMap;          // RVA of the try block array
  unsigned int nIPMapEntries; // count of IP-to-state entries
  int dispIPtoStateMap;         // RVA of the IP-to-state array
  int dispUwindHelp;            // rsp offset of the state var
                  // (initialized to -2; used during unwinding)
  int dispESTypeList;           // list of exception spec types
  int EHFlags;                  // flags
} FuncInfo;
```

x64: IP-to-state map

- Instead of an explicit state variable on the stack (as in x86), this map is used to find out the current state from the execution address

```
typedef struct IptoStateMapEntry {
  __int32     Ip; // Image relative offset of IP
  __ehstate_t State;
} IptoStateMapEntry;
```

x64: C++ Exception Record

- Since exceptions can be caught in a different module and the ThrowInfo RVAs might need to be resolved, the imagebase of the throw originator is added to the structure

```
typedef struct EHExceptionRecord {
  DWORD       ExceptionCode; // (= EH_EXCEPTION_NUMBER)
  DWORD       ExceptionFlags;  Flags determined by NT
  struct _EXCEPTION_RECORD *ExceptionRecord; // extra  record (not used)
  void *      ExceptionAddress;       // Address at which exception occurred
  DWORD       NumberParameters;       // Number of extended parameters. (=4)
  struct EHParameters {
      DWORD       magicNumber;        // = EH_MAGIC_NUMBER1
      void *      pExceptionObject;   // Pointer to the actual object thrown
      ThrowInfo   *pThrowInfo;        // Description of thrown object
      void        *pThrowImageBase;   // Image base of thrown object
      } params;
} EHExceptionRecord;
```

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Visual C++: references

SEH

- http://uninformed.org/index.cgi?v=4&a=1
- http://www.nynaeve.net/?p=99

C++ EH/RTTI

- http://www.codeproject.com/Articles/2126/How-a-C-compiler-implements-exception-handling
- http://www.openrce.org/articles/full_view/21
- Wine sources
- Visual Studio 2012 RC includes sources of the EH implementation
  - see VC\src\crt\ehdata.h and VC\src\crt\eh\
  - includes parts of "ARMNT" and WinRT

GCC

C++ in GCC

GCC: Virtual Table Layout

- In the most common case (no virtual inheritance), the virtual table starts with two entries: offset-to-base and RTTI pointer. Then the function pointers follow
- In the virtual table for the base class itself, the offset will be 0. This allows us to identify class vtables if we know RTTI address

```
`vtable for'SubClass
  dd 0                                ; offset to base
  dd offset `typeinfo for'SubClass    ; type info pointer
  dd offset SubClass::vfunc1(void)    ; first virtual function
  dd offset BaseClass::vfunc2(void) ; second virtual function
```

GCC: RTTI

- GCC's RTTI is based on the Itanium C++ ABI [1]
- The basic premise is: typeid() operator returns an instance of a class inherited from std::type_info
- For every polymorphic class (with virtual methods), the compiler generates a static instance of such class and places a pointer to it as the first entry in the Vtable
- The layout and names of those classes are standardized, so they can be used to recover names of classes with RTTI

[1] http://sourcery.mentor.com/public/cxx-abi/abi.html

GCC: RTTI classes

- For class recovery, we're only interested in three classes inherited from type_info

```
class type_info
{
  //void *vfptr;
private:
  const char *__type_name;
};
```

```
// a class with no bases
class __class_type_info : public
std::type_info {}
```

```
// a class with single base
class __si_class_type_info: public
__class_type_info {
public:
  const __class_type_info
*__base_type;
};
```

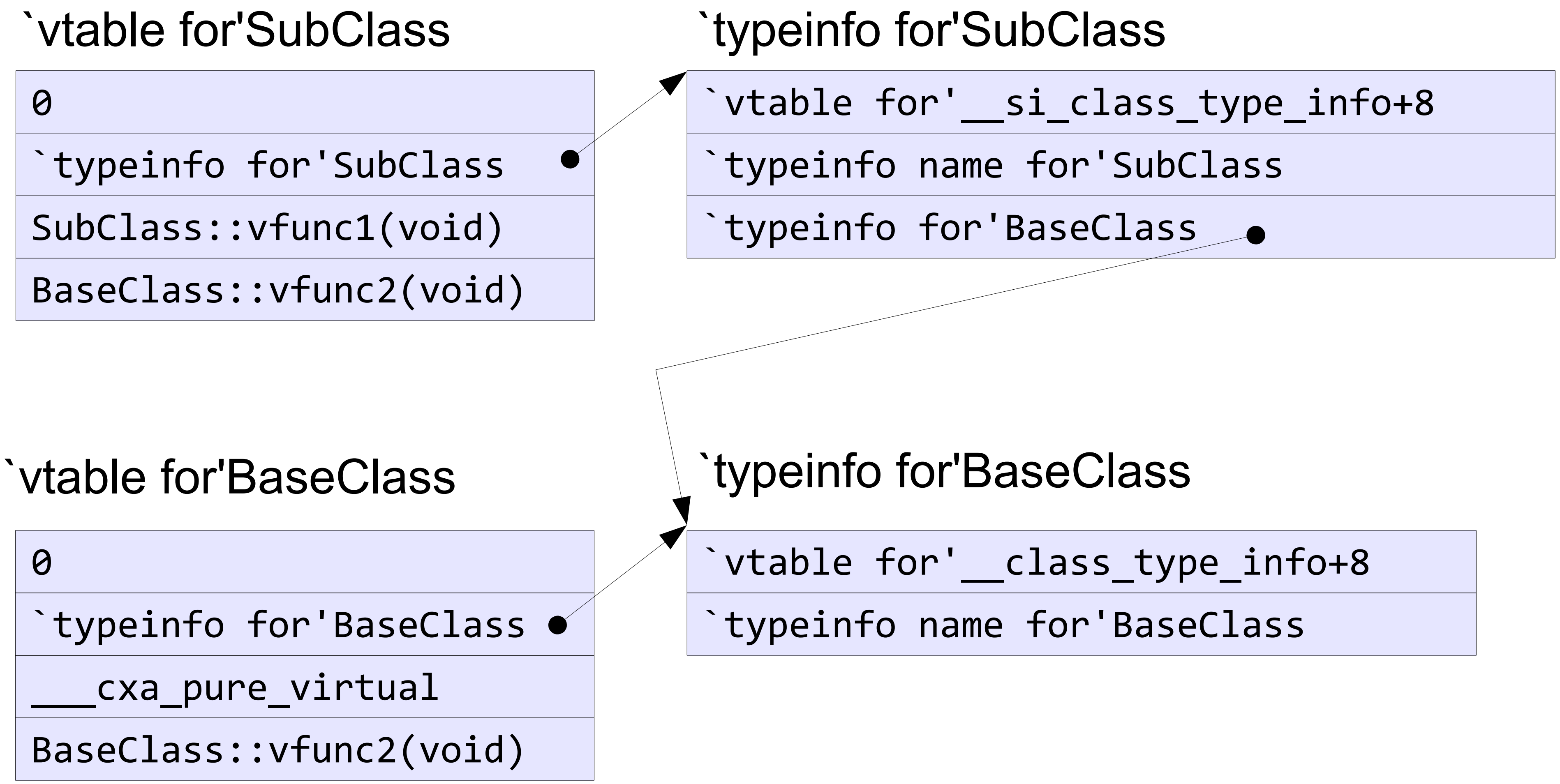
```
// a class with multiple bases
class __vmi_class_type_info : public
__class_type_info {
public:
  unsigned int __flags;
  unsigned int __base_count;
  __base_class_type_info __base_info[1];
};
struct __base_class_type_info {
public:
 const __class_type_info *__base_type;
 long __offset_flags;
}
```

GCC: recovery of class names from RTTI

- Find vtables of __class_type_info, __si_class_type_info, __vmi_class_type_info
- Look for references to them; those will be instances of typeinfo classes
- From the __type_name member, mangled name of the class can be recovered, and from other fields the inheritance hierarchy
- By looking for the pair (0, pTypeInfo), we can find the class virtual table

```
`typeinfo for'SubClass
  dd offset `vtable for'__cxxabiv1::__si_class_type_info+8
  dd offset `typeinfo name for'SubClass ; "8SubClass"
  dd offset `typeinfo for'BaseClass
```

GCC: RTTI example



`vtable for'SubClass

```
0
`typeinfo for'SubClass
SubClass::vfunc1(void)
BaseClass::vfunc2(void)
```

`typeinfo for'SubClass

```
`vtable for'__si_class_type_info+8
`typeinfo name for'SubClass
`typeinfo for'BaseClass
```

`vtable for'BaseClass

```
0
`typeinfo for'BaseClass
___cxa_pure_virtual
BaseClass::vfunc2(void)
```

`typeinfo for'BaseClass

```
`vtable for'__class_type_info+8
`typeinfo name for'BaseClass
```

GCC: exceptions

- Two kinds of implementing exceptions are commonly used by GCC:
    - SjLj (setjump-longjump)
    - "zero-cost" (table-based)
- These are somewhat analogous to VC's x86 stack-based and x64 table-based SEH implementations
- SjLj is simpler to implement but has more runtime overhead, so it's not very common these days
- MinGW used SjLj until GCC 4.3(?), and iOS on ARM currently supports only SjLj

GCC: SjLj exceptions

- Similar to x86 SEH, a structure is constructed on the stack for each function that uses exception handling
- However, instead of using list in fs:0, implementation-specific functions are called at entry and exit (_Unwind_SjLj_Register/_Unwind_SjLj_Unregister)
- The registration structure can vary but generally uses this layout:

```
struct SjLj_Function_Context
{
  struct SjLj_Function_Context *prev;
  int call_site;
  _Unwind_Word data[4];
  _Unwind_Personality_Fn personality;
  void *lsda;
  int jbuf[];
};
```

GCC: SjLj exceptions

- **personality** points to the so-called "personality function" which is called by the unwinding routine during exception processing
- **lsda** points to "language-specific data area" which contains info in the format specific to the personality routine
- **call_site** is analogous to the state variable of VC's EH and is updated by the compiler on every change which might need an corresponding unwinding action
- **jbuf** contains architecture-specific info used by the unwinder to resume execution if the personality routine signals that a handler has been found
- However, usually **jbuf[2]** contains the address of the *landing pad* for the function

SjLj setup example

```
ADD   R0, SP, #0xA4+_sjlj_ctx
LDR   R3, [R3] ; ___gxx_personality_sj0
STR   R3, [SP,#0xA4+_sjlj_ctx.personality]
LDR   R3, =_lsda_sub_14F94
STR   R7, [SP,#0xA4+_sjlj_ctx.jbuf]
STR   R3, [SP,#0xA4+_sjlj_ctx.lsda]
LDR   R3, =lp_sub_14F94
STR   SP, [SP,#0xA4+_sjlj_ctx.jbuf+8]
STR   R3, [SP,#0xA4+_sjlj_ctx.jbuf+4]
BL    __Unwind_SjLj_Register
MOV   R3, #2
STR   R3, [SP,#0xA4+_sjlj_ctx.call_site]
```

```
_sjlj_ctx.personality = &__gxx_personality_sj0;
_sjlj_ctx.jbuf[0] = &v11; // frame pointer
_sjlj_ctx.lsda = &lsda_sub_14F94;
_sjlj_ctx.jbuf[2] = &v5;  // stack pointer
_sjlj_ctx.jbuf[1] = lp_sub_14F94; // landing pad
_Unwind_SjLj_Register(&_sjlj_ctx);
_sjlj_ctx.call_site = 2;
```

SjLj landing pad: unwinding

- The SjLj landing pad handler inspects the **call_site** member and depending on its value performs unwinding actions (destruct local variables) or executes user code in the catch blocks.

```
__lp__sub_1542C
  LDR     R3, [SP,#0x114+_sjlj_ctx.call_site]
  LDR     R2, [SP,#0x114+_sjlj_ctx.data]
  CMP     R3, #1
  STR     R2, [SP,#0x114+exc_obj]
  BEQ     unwind_from_state1
  CMP     R3, #2
  BEQ     unwind_from_state2
  CMP     R3, #3
  BEQ     unwind_from_state3
  [...]
```

```
unwind_from_state3
  ADD     R0, SP, #0x114+tmp_str3
  MOV     R3, #0
  STR     R3, [SP,#0x114+_sjlj_ctx.call_site]
  BL      std::string::~string()
  MOV     R3, #0
  ADD     R0, SP, #0x114+_sjlj_ctx
  STR     R3, [SP,#0x114+_sjlj_ctx.call_site]
  [...]
  MOV     R3, 0xFFFFFFFF
  LDR     R0, [SP,#0x114+exc_obj]
  STR     R3, [SP,#0x114+_sjlj_ctx.call_site]
  BL      __Unwind_SjLj_Resume
```

SjLj landing pad: catch blocks

- If the current state corresponds to a try block, then the landing pad handler checks the *handler switch value* to determine which exception was matched

```
__lp__GpsRun
  LDR   R2, [SP,#0xD4+_sjlj_ctx.data]
  LDR   R3, [SP,#0xD4+_sjlj_ctx.call_site]
  STR   R2, [SP,#0xD4+exc_obj]
  LDR   R2, [SP,#0xD4+_sjlj_ctx.data+4]
  CMP   R3, #1
  STR   R2, [SP,#0xD4+handler_switch_val]
  BEQ   _GpsRun_lp_01
  CMP   R3, #2
  BEQ   _GpsRun_lp_02
```

```
_GpsRun_lp_02
  LDR   R2, [SP,#0xD4+handler_switch_val]
  CMP   R2, #2
  BNE   _catch_ellipsis
  LDR   R0, [SP,#0xD4+exc_obj]
  BLX   ___cxa_begin_catch
  [...]
  MOVS R3, #0
  STR   R3, [SP,#0xD4+_sjlj_ctx.call_site]
  BLX ___cxa_end_catch
```

GCC exceptions: zero-cost

- "Zero-cost" refers to no code overhead in the case of no exceptions (unlike SjLj which has set-up/tear-down code that is always executed)
- Uses a set of tables encoding address ranges, so does not need any state variables in the code
- Format and encoding is based on Dwarf2/Dwarf3
- The first-level (language-independent) format is described in Linux Standard Base Core Specification [1]
- Second-level (language-specific) is based on HP Itanium implementation [2] but differs from it in some details

[1] http://refspecs.linuxbase.org/LSB_4.1.0/LSB-Core-generic/LSB-Core-generic/ehframechpt.html
[2] http://sourcery.mentor.com/public/cxx-abi/exceptions.pdf

GCC exceptions: .eh_frame

- Format of the section is based on Dwarf's debug_frame
- Consists of a sequence of Common Frame Information (CFI) records
- Each CFI starts with a Common Information Entry (CIE) and is followed by one or more Frame Description Entry (FDE)
- Usually one CFI corresponds to one object file and one FDE to a function

```
CFI 0
  CIE 0
  FDE 0-0
  FDE 0-1
  FDE 0-2
  ...
CFI 1
  CIE 1
  FDE 1-0
  FDE 1-1
  ...
```

.eh_frame: Common Information Entry

Field	Meaning
Length (uint32)	total length of following data; 0 means end of all records
Extended Length (uint64)	present if Length==0xFFFFFFFF
CIE_id (uint32)	Must be 0 for a CIE
Version (uint8)	1 or 3
Augmentation (asciiz string)	Indicates presence of additional fields
Code alignment factor (uleb128)	Usually 1
Data alignment factor (sleb128)	Usually -4 (encoded as 0x7C)
return_address_register (uint8 (version 1) or uleb128)	Dwarf number of the return register
Augmentation data length (uleb128)	Present if Augmentation[0]=='z'
Augmentation data	Present if Augmentation[0]=='z'
Initial instructions	Dwarf Call Frame Instructions

.eh_frame: Augmentation data

- Each string character signals that additional data is present in the "Augmentation data" of the CIE (and possibly FDE)

String character	Data	Meaning
'z'	uleb128	Length of following data
'P'	personality_enc (uint8)	Encoding of the following pointer
	personality_ptr	Personality routine for this CIE
'R'	fde_enc (uint8)	Encoding of initial location and length in FDE (if different from default)
'L'	lsda_enc	Encoding of the LSDA pointer in FDE's augmentation data

.eh_frame: Frame Description Entry

Field	Meaning
Length (uint32)	total length of following data; 0 means end of all records
Extended Length (uint64)	present if Length==0xFFFFFFFF
CIE pointer (uint32)	Distance to parent CIE from this field
Initial location (fde_encoding)	Address of the first instruction in the range
Range length (fde_encoding.size)	Length of the address range
Augmentation data length (uleb128)	Present if CIE.Augmentation[0]=='z'
Augmentation data	Present if CIE.Augmentation[0]=='z'
Instructions	Dwarf Call Frame Instructions

- "Augmentation data" contains pointer to LSDA if CIE's augmentation string included the L character

.eh_frame: pointer encodings

- Bits 0:3 (0x0F): data format
- Bits 4:6 (0x70): how the value is applied
- Bit 7 (0x80): the value should be dereferenced to get final address
- Common encodings: 0xFF – value omitted; 0x00 – native-sized absolute pointer; 0x1B – self-relative 4-byte displacement; 0x9B – dereferenced self-relative 4-byte displacement

Name	Value	Name	Value
DW_EH_PE_ptr	0x00	DW_EH_PE_absptr	0x00
DW_EH_PE_uleb128	0x01	DW_EH_PE_pcrel	0x10
DW_EH_PE_udata2	0x02	DW_EH_PE_textrel	0x20
DW_EH_PE_udata4	0x03	DW_EH_PE_datarel	0x30
DW_EH_PE_udata8	0x04	DW_EH_PE_funcrel	0x40
DW_EH_PE_sleb128	0x09	DW_EH_PE_aligned	0x50
DW_EH_PE_sdata2	0x0A	DW_EH_PE_indirect	0x80
DW_EH_PE_sdata4	0x0B	DW_EH_PE_omit	0xFF
DW_EH_PE_sdata8	0x0C		

GCC: .gcc_except_table (LSDA)

- Used by both SjLj and table based implementations to encode unwinding actions and catch handlers for try blocks
- Although LSDA is indeed language-specific and GCC uses different personality functions to parse it, the overall layout is very similar across most implementations
- In fact, the SjLj (_sj0) and table-based (_v0) personality functions use almost identical format
- It also uses Dwarf encoding (LEB128) and pointer encodings from .eh_frame
- Consists of: header, call site table, action table and optional type table

GCC: LSDA

LSDA

Header
Call site table
Action table
Types table (optional)

LSDA Header

Field	Meaning
lpstart_encoding (uint8)	Encoding of the following field (landing pad start offset)
LPStart (encoded)	Present if lpstart_encoding != DW_EH_PE_omit (otherwise default: start of the range in FDE)
ttype_encoding (uint8)	Encoding of the pointers in type table
TType (uleb128)	Offset to type table from the end of the header Present if ttype_encoding != DW_EH_PE_omit

GCC: LSDA

LSDA call site table header

call_site_encoding (uint8)	Encoding of items in call site table
call_site_tbl_len (uleb128)	Total length of call site table

LSDA call site entry (SjLj)

cs_lp (uleb128)	New "IP" value (call_site variable)
cs_action (uleb128)	Offset into action table (+1) or 0 for no action

LSDA call site entry (table-based)

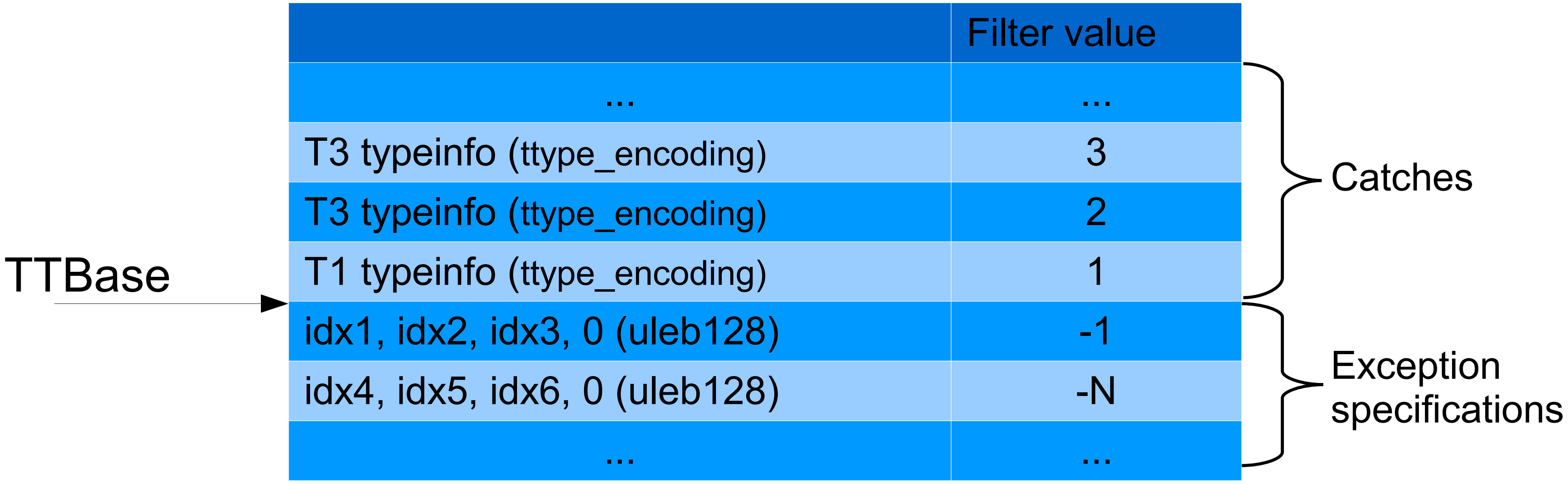
cs_start (call_site_encoding)	Start of the IP range
cs_len (call_site_encoding)	Length of the IP range
cs_lp (call_site_encoding)	Landing pad address
cs_action (uleb128)	Offset into action table (+1) or 0 for no action

GCC: LSDA

LSDA action table entry

ar_filter (sleb128)	Type filter value (0 = cleanup)
ar_disp (sleb128)	Self-relative byte offset to the next action (0 = end)

LSDA type table



	Filter value
...	...
T3 typeinfo (ttype_encoding)	3
T3 typeinfo (ttype_encoding)	2
T1 typeinfo (ttype_encoding)	1
idx1, idx2, idx3, 0 (uleb128)	-1
idx4, idx5, idx6, 0 (uleb128)	-N
...	...

GCC: LSDA processing

- The personality function looks up the call site record which matches the current IP value (for SjLj the **call_site** variable is used)
- If there is a valid action (non-zero) then it is "executed" – the chain of action records is walked and filter expressions are checked
- If there is a filter match or a cleanup record found (ar_filter==0) then the control is transferred to the landing pad
- For SjLj, there is a single landing pad handler so the **call_site** is set to the **cs_lp** value from the call site record
- For table-based exceptions, the specific landing pad for the call site record is run

GCC: EH optimizations

- The eh_frame structure uses variable-length encodings which (supposedly) saves space at the expense of slower look up at run time
- Some implementations introduce various indexing and lookup optimizations

GCC EH optimizations: .eh_frame_hdr

- A table of pairs (initial location, pointer to the FDE in .eh_frame)
- Table is sorted, so binary search can be used to quickly search
- PT_EH_FRAME header is added to ELF program headers

version (uint8)	structure version (=1)
eh_frame_ptr_enc (uint8)	encoding of eh_frame_ptr
fde_count_enc (uint8)	encoding of fde_count
table_enc (uint8)	encoding of table entries
eh_frame_ptr (enc)	pointer to the start of the .eh_frame section
fde_count (enc)	number of entries in the table
initial_loc[0] (enc)	initial location for the FDE
fde_ptr[0] (enc)	corresponding FDE
...	...

GCC EH optimizations: __unwind_info

- An additional section added to Mach-O binaries on OS X
- Contains entries for efficient lookup
- More info: compact_unwind_encoding.h in libunwind

```
struct unwind_info_section_header
{
    uint32_t    version;            // UNWIND_SECTION_VERSION
    uint32_t    commonEncodingsArraySectionOffset;
    uint32_t    commonEncodingsArrayCount;
    uint32_t    personalityArraySectionOffset;
    uint32_t    personalityArrayCount;
    uint32_t    indexSectionOffset;
    uint32_t    indexCount;
    // compact_unwind_encoding_t[]
    // uintptr_t personalities[]
    // unwind_info_section_header_index_entry[]
    // unwind_info_section_header_lsda_index_entry[]
};
```

GCC EH optimizations: ARM EABI

- .ARM.exidx contains a map from program addresses to unwind info instead of .eh_frame
- Short unwind encodings are inlined, longer ones are stored in .ARM.extab
- EABI provides standard personality routines, or custom ones can be used
- GCC still uses __gxx_personality_v0, and the same LSDA encoding
- This kind of exception handling is also used in Symbian EPOC files

Word 0

```
+-+----------------------+
|0| prel31_offset_to_fnc |
+-+----------------------+
31 30                   0
```

Word 1

```
EXIDX_CANTUNWIND           +----------------------+-+
                           |                      |1|
                           +----------------------+-+
                           31                     1 0
The ex table entry itself  +-+----------------------+
encoded in 31bit           |1|     ex_tbl_entry     |
                           +-+----------------------+
                           31 30                   0
prel31 offset of the start +-+----------------------+
of the table entry for     |0|   tbl_entry_offset   |
this function              +-+----------------------+
                           31 30                   0
```

Credit: https://wiki.linaro.org/KenWerner/Sandbox/libunwind

GCC: references

- http://www.airs.com/blog/archives/460 (.eh_frame)
- http://stackoverflow.com/questions/87220/
- apple/gcc: gcc/gcc-5493/libstdc++-v3/libsupc++/
- http://sourcery.mentor.com/public/cxx-abi/abi-eh.html
- http://sourcery.mentor.com/public/cxx-abi/exceptions.pdf
- http://www.x86-64.org/documentation/abi.pdf
- Exploiting the Hard-Working DWARF (James Oakley & Sergey Bratus)

Conclusions

- RTTI is very useful for reverse engineering
- Helps discover not just class names but also inheritance hierarchy
- Necessary for dynamic_cast, so present in many complex programs
- Not removed by symbol stripping
- Parsing exception tables is necessary to uncover all possible execution paths
- Can improve static analysis (function boundaries etc.)
- Some implementation are very complicated and are likely to have bugs – a potential area for vulnerabilities

Thank you!

Questions?