Reversing Disassembly Reconstruction

Accelerated

Version 3.0

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Software Diagnostics Services

Prerequisites

- Working C or classic C++ knowledge
- Basic assembly language knowledge
- Builds upon the book:

Practical Foundations of Windows Debugging, Disassembling, Reversing, 2nd Edition

Audience

- Novices

Improve x64 assembly language knowledge

- Experts

Learn the new pattern language approach

Pattern-Oriented RDR

- Complex crashes and hangs (victimware analysis)
- Malware analysis
- Studying new products

Training Goals

- Review fundamentals
- Review of x64 disassembly
- Learn patterns and techniques

Training Principles

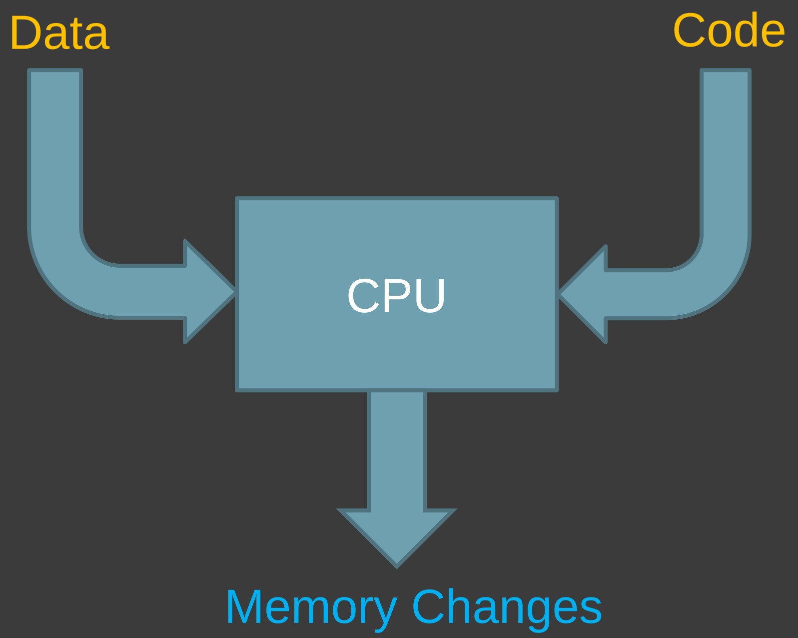
- Talk only about what I can show
- Lots of pictures
- Lots of examples
- Original content and examples

Course Idea

- Implicit memory leak resulted from wrong API call parameter
- Debugging.TV episode 0x31

Part 1: Theory

Computation



Disassembly

Data/Code numbers

↓

Data/Code symbolic

```
488d0d2cce0000  lea rcx,[CPUx64+0xe2f8 (00000001`3f85e2f8)]  ; "Hello World!"
```

Annotated Disassembly memory analysis pattern

The Problem of Reversing

- Compilation to **M**achine Language_M

Language_1 → Language_M ← Language_2

- Decompilation

Language_M → ?

The Solution to Reversing

- **M**emory Language_M Semantics

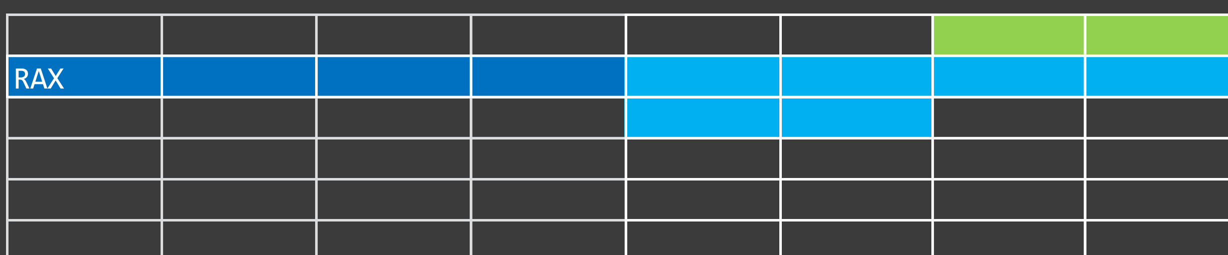
Language_1 → Language_M ← Language_2

- Decompilation

Understanding of Language_M

The Reversing Tool

Memory Cell Diagrams



Idea when reading The Mathematical Structure of Classical and Relativistic Physics: A General Classification Diagram book

Re(De)construction

- Time dimension: sequence diagrams
- Space dimension: component diagrams

How does it work temporally and structurally?

ADDR Patterns

- Accelerated
- Disassembly patterns
- De(Re)construction patterns
- Reversing patterns

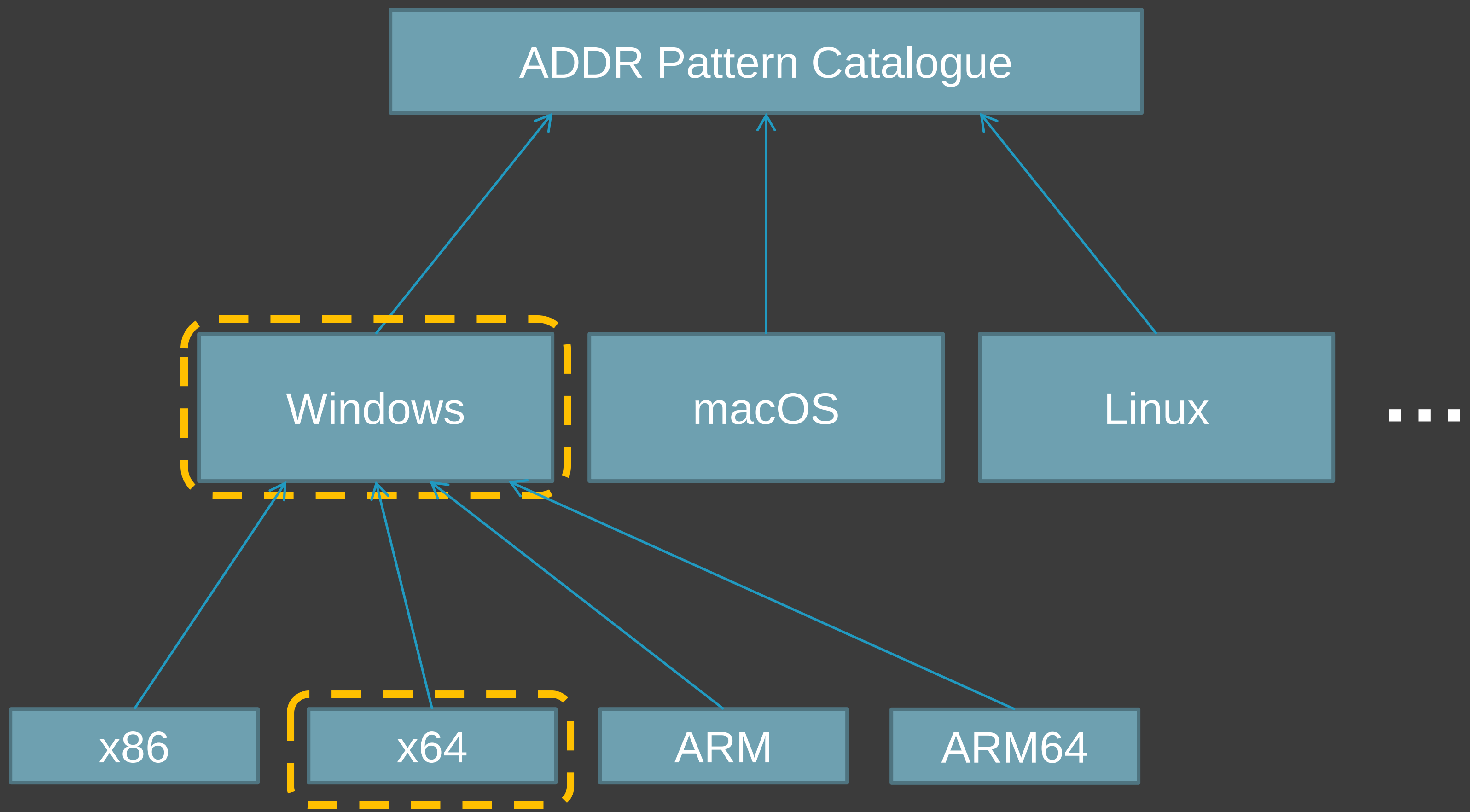
ADDR Patterns (II)

- Accelerated
- Disassembly patterns
- Decompilation patterns
- Reconstruction patterns

ADDR Schemas

- Function Prologue → Function Epilogue
- Call Prologue → Function Call → Call Epilogue
- Potential Functionality → Call Skeleton → Call Path
- Call Parameter → Function Parameter → Local Variable

ADDR Implementations



Pattern Catalogues

- Elementary Software Diagnostics Patterns
- Memory Analysis Patterns
- Trace and Log Analysis Patterns
- Unified Debugging Patterns
- ADDR Patterns

Pattern Orientation

- Pattern-Driven ADDR

- Pattern-Based ADDR

Part 2: x64 Disassembly

x64 CPU Registers

- Illustrated in memory cell diagrams: \ADDR\MCD-R1.xlsx
- **RAX** ⊃ **EAX** ⊃ **AX** ⊇ {**AH**, **AL**}

RAX 64-bit	EAX 32-bit

- ALU: **RAX**, **RDX**
- Counter: **RCX**
- Memory copy: **RSI** (src), **RDI** (dst)
- Stack: **RSP**
- Next instruction: **RIP**
- New: **R8** – **R15**, **Rx**(**D**|**W**|**B**)

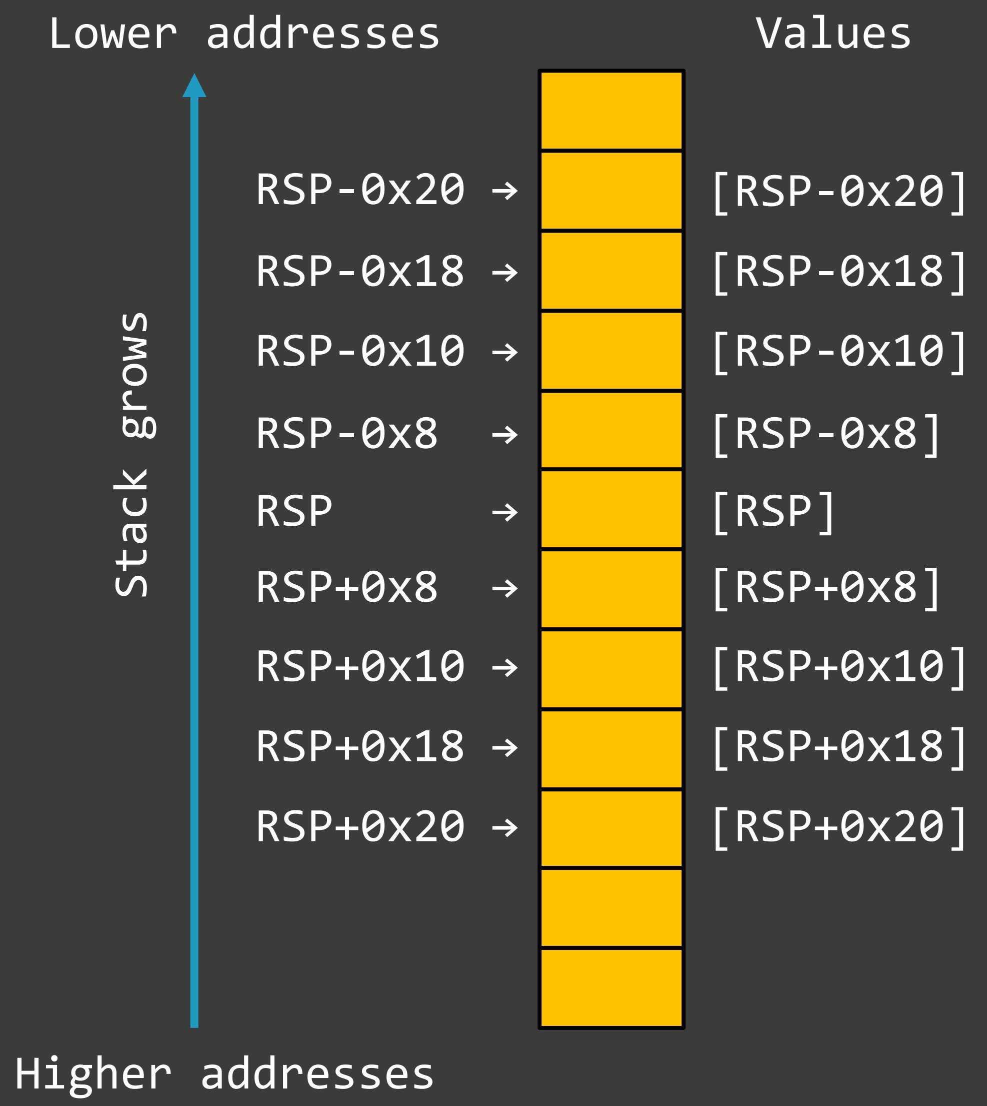
Instructions and Registers

- `Opcode DST, SRC`

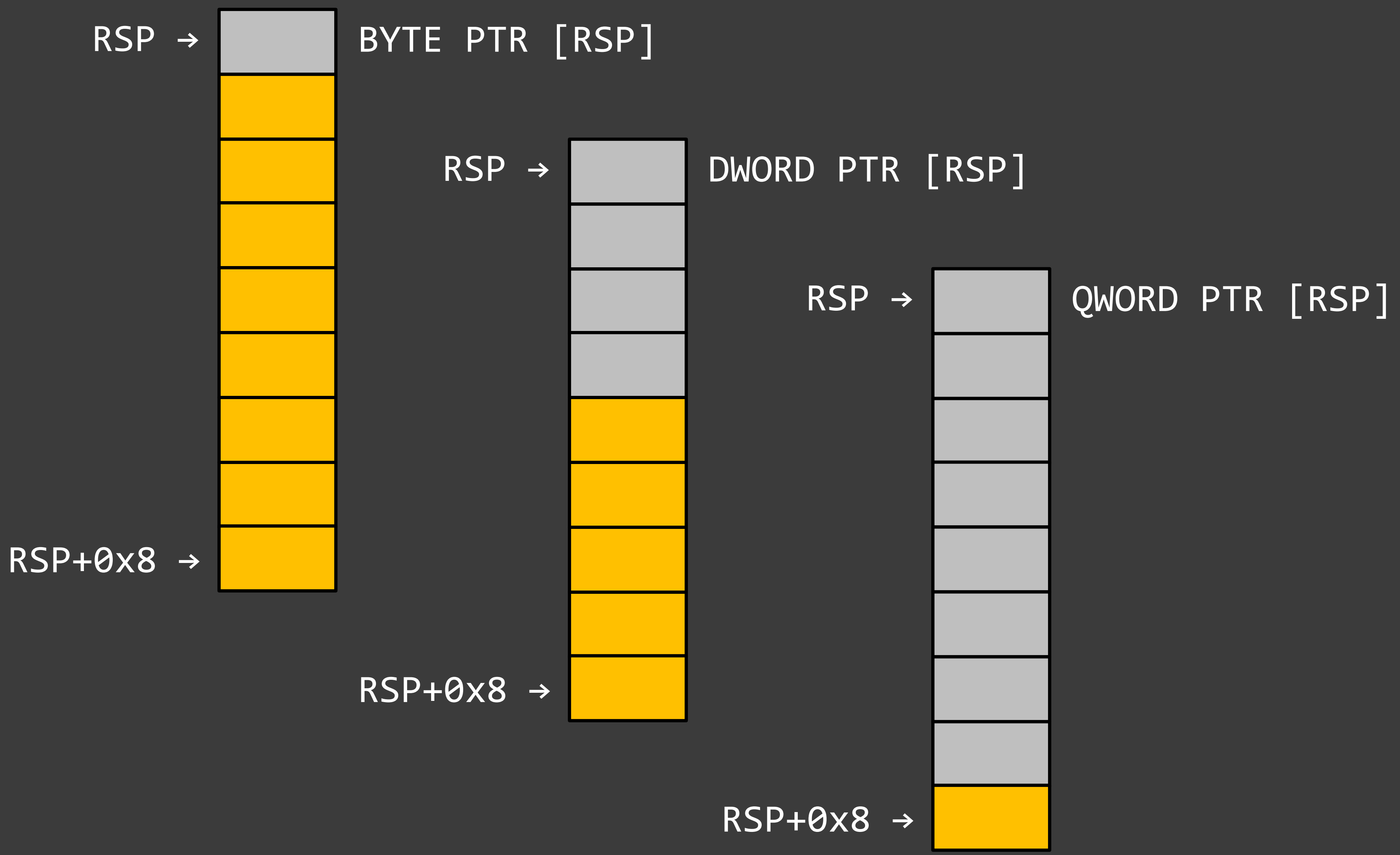
- Examples:

```
mov   rax, 10h          ; RAX ← 0x10
mov   r13, rdx          ; R13 ← RDX
add   r10, 10h          ; R10 ← R10 + 0x10
imul  edx, ecx          ; EDX ← EDX * ECX
call  rdx               ; RDX already contains
                        ;    the address of func (&func)
                        ; PUSH RIP; &func → RIP
sub   rsp, 30h          ; RSP ← RSP-0x30
                        ; make room for local variables
```

Memory and Stack Addressing



Memory Cell Sizes



Memory Load Instructions

- `Opcode DST, PTR [SRC+Offset]`
- `Opcode DST`
- Examples:

```
mov   rax, qword ptr [rsp+10h] ; RAX ←
                               ; 64-bit value at address RSP+0x10
mov   ecx, dword ptr [20]      ; ECX ←
                               ; 32-bit value at address 0x20
pop   rdi                      ; RDI ← value at address RSP
                               ; RSP ← RSP + 8
lea   r8, [rsp+20h]            ; R8 ← address RSP+0x20
```

Memory Store Instructions

- Opcode PTR [DST+Offset], SRC
- Opcode DST|SRC
- Examples:

```
mov   qword ptr [rbp-20h], rcx ; 64-bit value at address RBP-0x20
                               ;   ← RCX
mov   byte ptr [0], 1          ; 8-bit value at address 0 ← 1
push  rsi                      ; RSP ← RSP - 8
                               ; value at address RSP ← RSI
inc   dword ptr [rcx]          ; 32-bit value at address RCX ←
                               ;   1 + 32-bit value at address RCX
```

Flow Instructions

- Opcode DST
- Opcode PTR [DST]
- Examples:

```
jmp   00007ff6`9ef2f008   ; RIP ← 0x7ff69ef2f008
                          ; (goto 0x7ff69ef2f008)
jmp   qword ptr [rax+10h] ; RIP ← value at address RAX+0x10
call  00007ff6`9ef21400   ; RSP ← RSP – 8
00007ff6`9ef21057:        ; value at address RSP ← 0x7ff69ef21057
                          ; RIP ← 0x7ff69ef21400
                          ; (goto 0x7ff69ef21400)
```

Function Parameters

- x86: Right to left PUSH

  `Args to Child` are parameters

- x64: Left to right RCX, RDX, R8, R9, stack

  `Args to Child` are not parameters

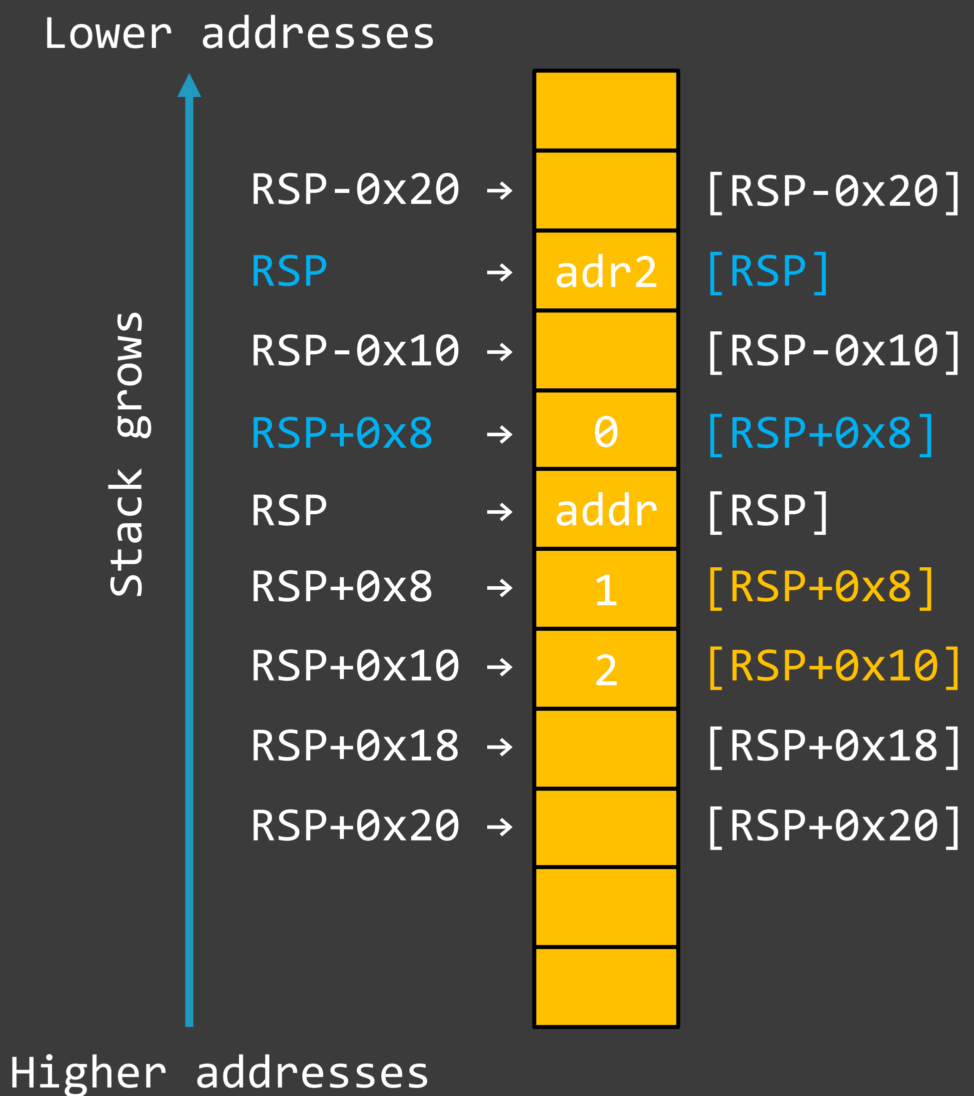
WinDbg Commands

```
0:000> kv
 # Child-SP    RetAddr    : Args to Child    : Call Site
...
```

Function Call and Prolog

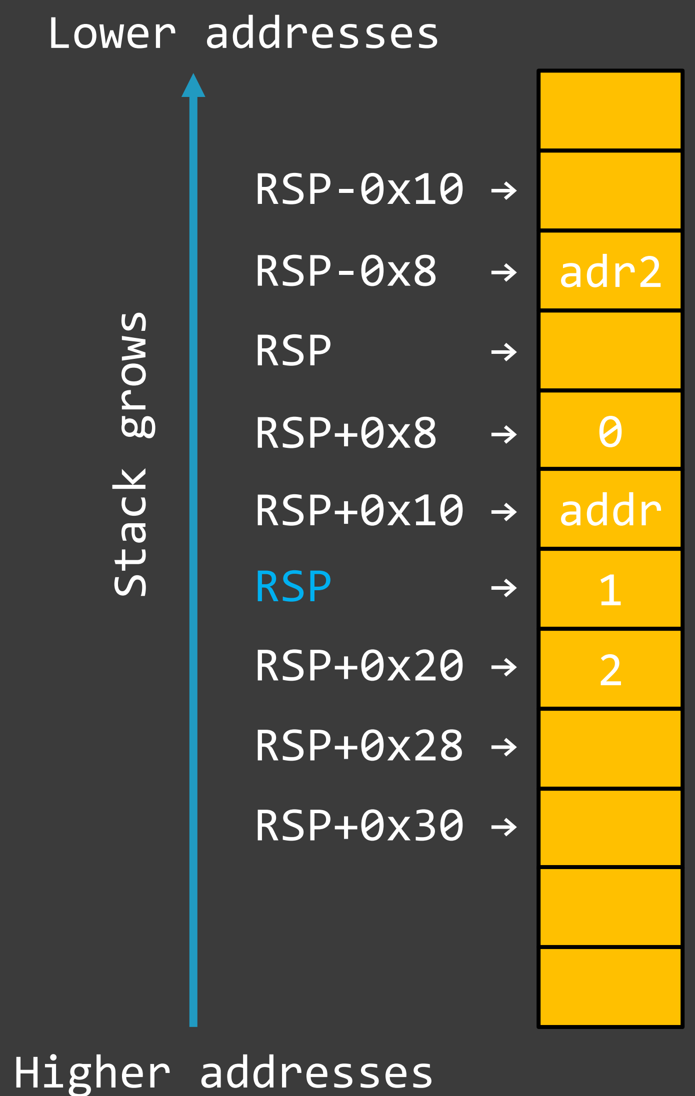
```
; void proc(int p1, long long p2);
mov  edx, 2
mov  ecx, 1
call proc
addr:

; void proc2();
; void proc(int p1, long long p2) {
;   long long local = 0;
;   proc2();
; }
proc:
mov  qword ptr [rsp+10h],rdx
mov  dword ptr [rsp+8],ecx
sub  rsp, 10h
mov  qword ptr [rsp+8],0
call proc2
adr2:
...
```



Function Epilog and Return

```
; void proc2();
; void proc(int p1, long long p2) {
;   long long local = 0;
;   proc2();
; }
proc:
mov  qword ptr [rsp+10h],rdx
mov  dword ptr [rsp+8],ecx
sub  rsp, 10h
mov  qword ptr [rsp+8],0
call proc2
adr2:
add  rsp, 10h
ret
```



Part 3: Practice Exercises

Links

- Memory dumps:

Download links are in the exercise R0.

- Exercise Transcripts:

Included in this book.

Exercise R0

- **Goal:** Install WinDbg or Debugging Tools for Windows, or pull Docker image, and check that symbols are set up correctly

- \ADDR\Exercise-R0.pdf

Exercise R1

- **Goal:** Review x64 assembly fundamentals; learn how to reconstruct stack trace manually
- **ADDR Patterns:** Universal Pointer, Symbolic Pointer S^2, Interpreted Pointer S^3, Context Pyramid
- **Memory Cell Diagrams:** Register, Pointer, Stack Frame
- \ADDR\Exercise-R1.pdf
- \ADDR\MCD-R1.xlsx

Stack Reconstruction

1. Top frame from the current RIP_1, RSP_1 (**r**)
2. Disassemble around the current RIP_n (**ub** or **uf** RIP_n)*
3. Find out the beginning of the function prologue*
4. Check RSP_n usage (**sub**, **push**) and count offsets
5. Get RIP_{n+1} for the next frame (**dps** RSP_n + offset)
6. Get RSP_{n+1} for the next frame (RSP_n + offset + 8)
7. ++n
8. goto #2

* If symbols are available, disassemble the function corresponding to RIP_n (**uf name**)

ADDR: Universal Pointer

- A memory cell value interpreted as a pointer to memory cells
- A memory address that was not specifically designed as a pointer

ADDR: Symbolic Pointer, S^2

- A memory cell value associated with a symbolic value from a symbol file or a binary file (exported symbol)

ADDR: Interpreted Pointer, S^3

- Interpretation of a memory cell pointer value and its symbol
- Implemented via a typed structure or debugger (extension) command

ADDR: Context Pyramid

- When we move down stack trace frames, we can recover less and less contextual memory information due to register and memory overwrites

Exercise R2

- **Goal:** Learn how to map source code to disassembly
- **ADDR Patterns:** Potential Functionality, Function Skeleton, Function Call, Call Path, Local Variable, Static Variable, Pointer Dereference
- **Memory Cell Diagrams:** Pointer Dereference
- \ADDR\Exercise-R2.pdf
- \ADDR\MCD-R2.xlsx

ADDR: Potential Functionality

- A list of function symbols, for example, a list of imported functions, a list of callbacks, a structure or table with function pointers

ADDR: Function Skeleton

- Function calls inside a function body
- Splits a function body into regions
- Helps in understanding a function

ADDR: Function Call

- Simply the call of a function
- Call or jmp instruction

ADDR: Call Path

- Following a sequence of Function Calls
- Example: call procA, call procC

```
…
call procA
call procB
…

procA:
…
call procC
…
```

ADDR: Local Variable

- A variable is a memory cell with an address
- A variable with stack region storage
- Usually, a local variable memory cell is referenced by stack pointer or frame pointer registers

ADDR: Static Variable

- A variable is a memory cell with an address
- A variable with non-stack and non-register storage
- Usually, there is a direct memory reference

ADDR: Pointer Dereference

- A pointer is a memory cell that contains the address of (references) another memory cell
- Dereference is a sequence of instructions to get a value from a memory cell referenced by another memory cell

Exercise R3

- **Goal:** Learn function structure and associated memory operations
- **ADDR Patterns:** Function Prologue, Function Epilogue, Variable Initialization, Memory Copy
- **Memory Cell Diagrams:** Function Prologue, Function Epilogue
- \ADDR\Exercise-R3.pdf
- \ADDR\MCD-R3.xlsx

ADDR: Function Prologue

- The code emitted by a compiler that is necessary to set up the working internals of a function
- Such code doesn't have a real counterpart in actual source code
- Example: allocating memory on the stack for all local variables

ADDR: Function Epilogue

- The code emitted by a compiler that is necessary to finish the working internals of a function
- Such code doesn’t have a real counterpart in actual source code
- Example: deallocating memory on the stack for all local variables

ADDR: Variable Initialization

- Code to initialize an individual local variable
- Not part of a function prologue

ADDR: Memory Copy

- Repeated memory move instructions

Exercise R4

- **Goal:** Learn how to recognize call and function parameters and track their data flow
- **ADDR Patterns:** Call Prologue, Call Parameter, Call Epilogue, Call Result, Control Path, Function Parameter, Structure Field
- \ADDR\Exercise-R4.pdf

ADDR: Call Prologue

- The code emitted by a compiler that is necessary to set up a function call and its parameters

ADDR: Call Parameter

- Data passed to a function before a function call

ADDR: Call Epilogue

- The code emitted by a compiler to finish a function call and its return results

ADDR: Call Result

- Data returned by a function

ADDR: Control Path

- A possible execution path inside a function consisting of direct and conditional jumps

ADDR: Function Parameter

- Data passed to a function inside a function (on the receiver side)
- Such a parameter can be translated to a local variable if passed by stack or copied to a stack location, or it can still be an original register or copied to another register

ADDR: Structure Field

- An offset to the structure memory address

Exercise R5

- **Goal:** Master memory cell diagrams as an aid to understanding complex disassembly logic
- **ADDR Patterns:** Last Call, Loop, Memory Copy
- **Memory Cell Diagrams:** Memory Copy
- \ADDR\Exercise-R5.pdf
- \ADDR\MCD-R5.xlsx

ADDR: Last Call

- A function possibly called before the current instruction pointer

ADDR: Loop

- An unconditional jump to the previous code address

Virtual Function Call

Class Methods (Inheritance)

```
class Base
{
public: int method (int i) { return i; }
} myBase;

class Derived : public Base
{
public: int method (int i) { return ++i; }
} myDerived;

myDerived.method(0);
myDerived.Base::method(0);

Base *pMyBase = &myDerived;
pMyBase->method(0);
```

Class Virtual Methods

```
class Base
{
public:         int method (int i) { return i; }
        virtual int vmethod (int i) { return i; }
} myBase;

class Derived : public Base
{
public:         int method (int i) { return ++i; }
        virtual int vmethod (int i) override { return ++i; }
} myDerived;
```

```
Base *pMyBase = &myDerived;
pMyBase->method(0);
pMyBase->vmethod(0);
pMyBase->Base::vmethod(0);
```

```
myBase.vmethod(0);
myDerived.vmethod(0);
```

VTBL Memory Layout

```
class Base
{
public: virtual void vmethod1 () {}
        virtual void vmethod2 () {}
} myBase;
```

Base::`vftable':

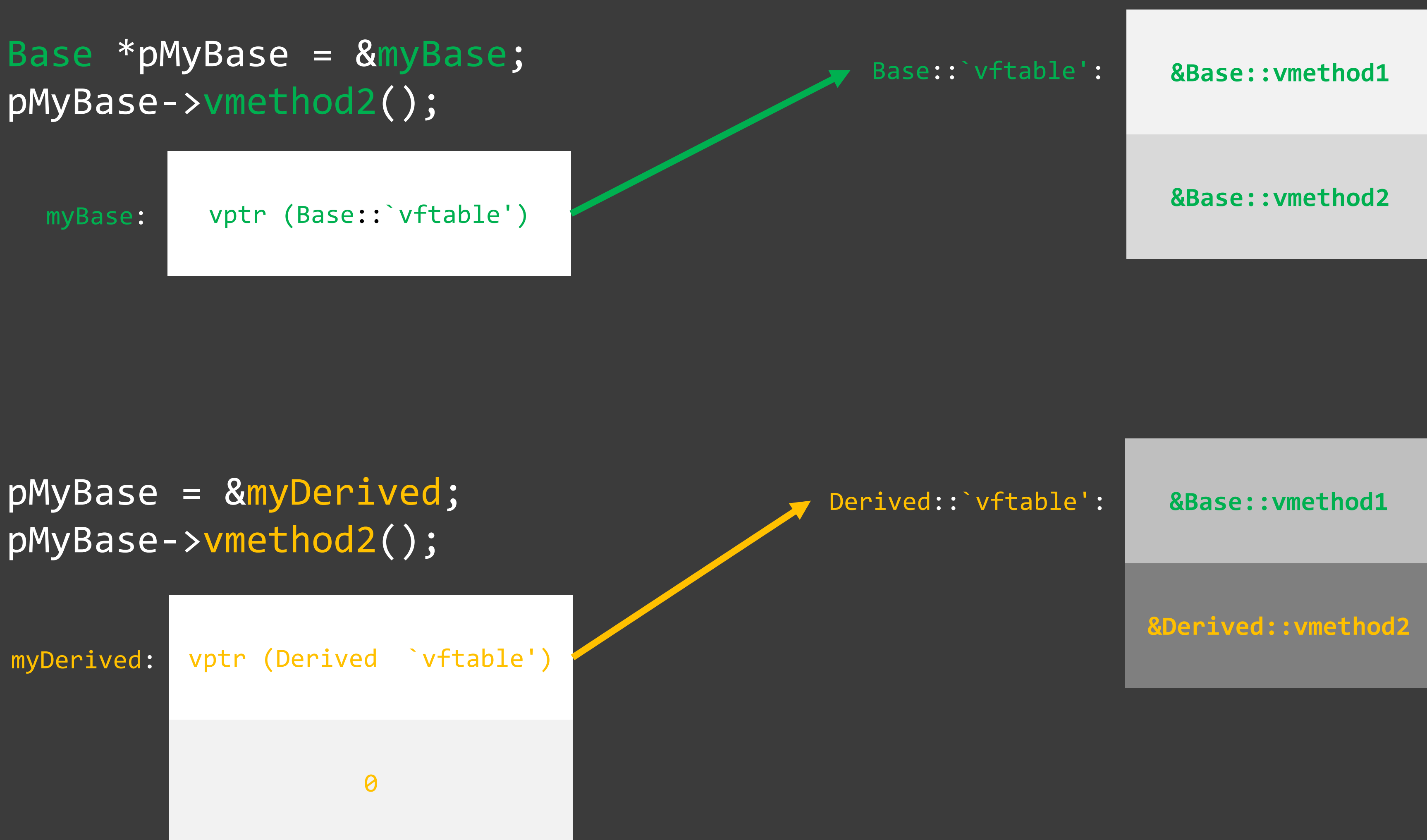
&Base::vmethod1
&Base::vmethod2

```
class Derived : public Base
{
        int  field;
public: void vmethod2 () override {}
} myDerived;
```

Derived::`vftable':

&Base::vmethod1
&Derived::vmethod2

VPTR and Class Memory Layout



Exercise R6

- **Goal:** Learn how to map code to execution residue and reconstruct past behaviour; recognise previously introduced ADDR patterns in the context of compiled classic C++ code
- **ADDR Patterns:** Separator Frames, Virtual Call
- **Memory Cell Diagrams:** Virtual Call
- \ADDR\Exercise-R6.pdf
- \ADDR\MCD-R6.xlsx

ADDR: Separator Frames

- Frames that divide a stack trace into separate analysis units

ADDR: Virtual Call

- A call through virtual function table structure field
- Usually involves a double Pointer Dereference

Live Debugging Techniques

- **ADDR Patterns:** Component Dependencies, API Trace, Fibre Bundle (trace and log analysis pattern)
- Some dependencies can be learned from crash dump stack traces
- Debugging.TV / YouTube
- Live debugging training: Accelerated Windows Debugging[4]

Memory Analysis Patterns

- Regular Data
- Injected Symbols
- Execution Residue
- Rough Stack Trace
- Annotated Disassembly
- Historical Information

Resources

- WinDbg Help / WinDbg.org (quick links)
- DumpAnalysis.org / SoftwareDiagnostics.Institute
- PatternDiagnostics.com
- Debugging.TV / YouTube.com/DebuggingTV / YouTube.com/PatternDiagnostics
- Practical Foundations of Windows Debugging, Disassembling, Reversing, Second Edition
- Accelerated Windows API for Software Diagnostics
- Accelerated C & C++ for Windows Diagnostics
- Memory Dump Analysis Anthology (Diagnomicon)

Q&A

Please send your feedback using the contact form on PatternDiagnostics.com

Thank you for attendance!