Graph-Based Binary Analysis

Drawing pictures from code

Blackhat Briefings 2002

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Graph-Based Binary Analysis

Overview (I)

The speech consists of four parts:

- **Part 1: Introduction**
  - What is a Graph ?
  - Why Graphs ?
- **Part 2: Simple Flowgraphing**
  - Problems with Microsoft Optimized Binaries
  - Flowgraph reduction for manual decompilation
  - FUZZ coverage analysis
- **Part 3: Structure and Object Reconstruction**
  - Pointer Control Graphing
  - Vtable parsing
- **Part 4: Variable Control Graphing**
  - Buffer Definition Graphing

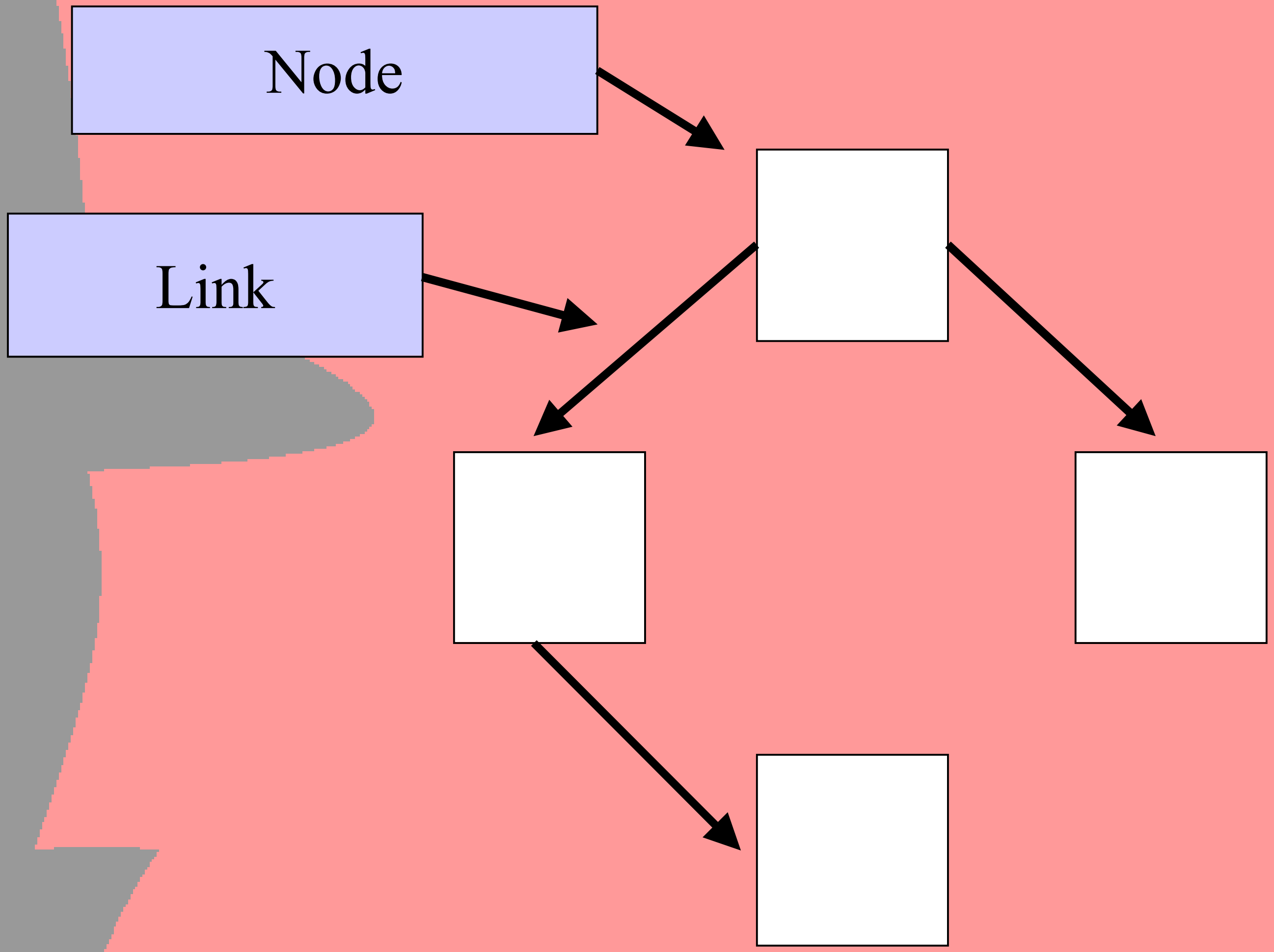
Graph-Based Binary Analysis

Speech Background

- **Reverse Engineering as main subject**
    - Not security-centered
    - No new vulnerabilities
    - Why this is relevant at a security conference ?
- **Part 2: Code understanding & Manual Decompilation**
    - Manual Binary Audits
    - Decompilation of tools only available in the binary
- **Part 3: Structure and Object Reconstruction**
    - Speeds up manual binary audits by a large factor
    - “Groundwork” for more sophisticated automated analysis
- **Part 4: Inverse Variable Tracking**
    - Speeds up manual audits a bit further
    - Allows advances in automated binary auditing

Introduction

What are Graphs ?



Introduction

Why Graphs ?

- Graphs make code understanding easier
- Graphs make complex issues more clear than sequential code
- The only valid abstraction for computer code (single-threaded) is a directed Graph
- Graphs have been extensively studied in abstract mathematics
  - Many efficient algorithms for Graph Manipulation exist
- Graphs are fairly easy to generate
- Graphs can be displayed using off-the-shelf tools

→ *Structuring Code as directed Graphs is beneficial for both manual analysis and automated tools*

Simple Flow Graphs
Applications

- Simplify Code understanding
- Clarify Code interdependences
- Allow for gradual manual decompilation
- Can be used as basic blocks from which to build more sophisticated analysis tools

→IDA 4.17 and higher include a built-in flowgraphing plugin
- – Output is only provided in a file (not as data structure)
- – The file is temporary and hard to find ☺

Simple Flow Graphs

Building a function flowgraph

Creating a flowgraph from the disassembly is trivial:

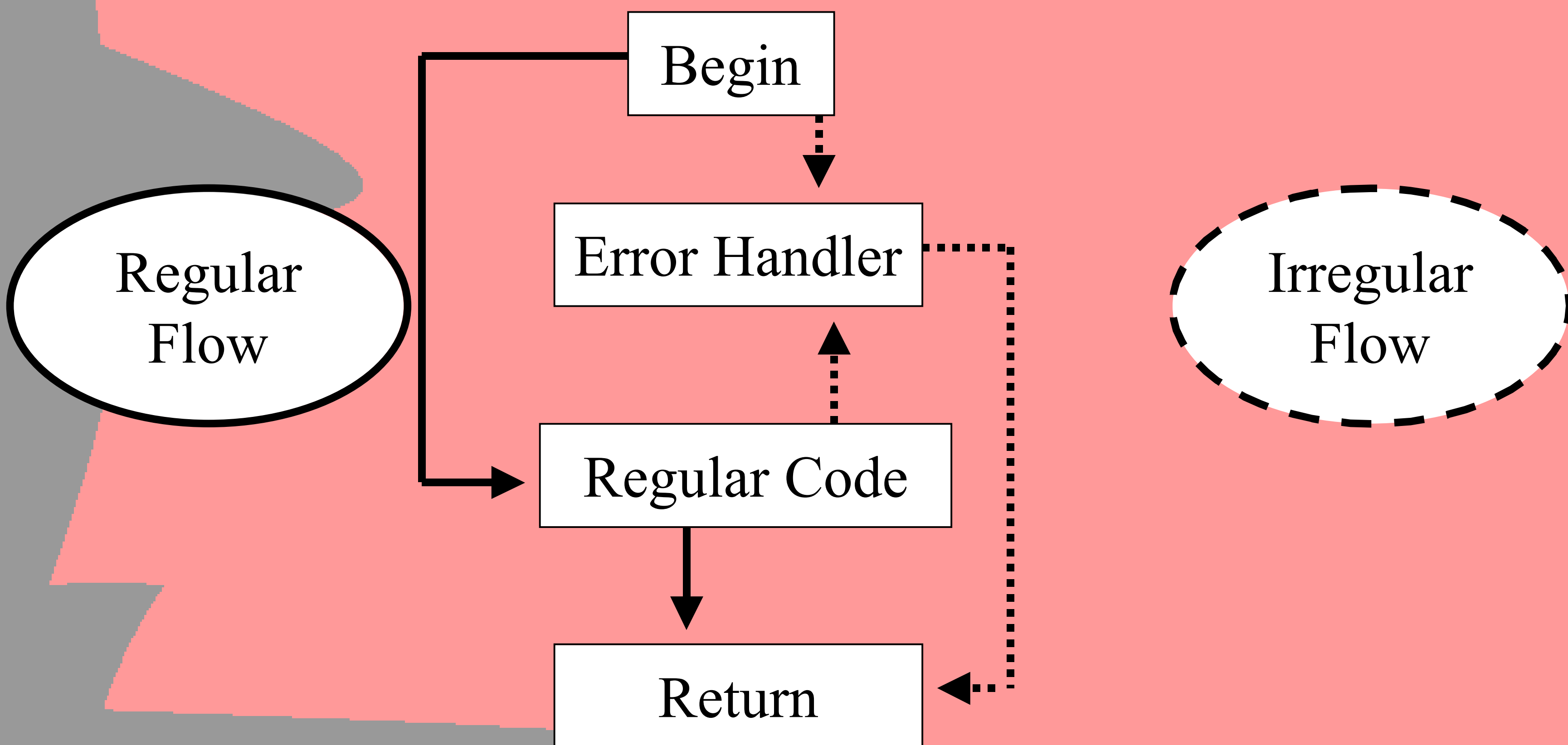
- Begin by tracing the code downwards
- If a local branch is encountered, “split” the graph and follow both branches
- Continue until a node with no further downlinks is encountered

- Heuristically scan for “switch”-constructs and handle them (special case)

Simple Flow Graphs

Microsoft Binary Optimization (I)

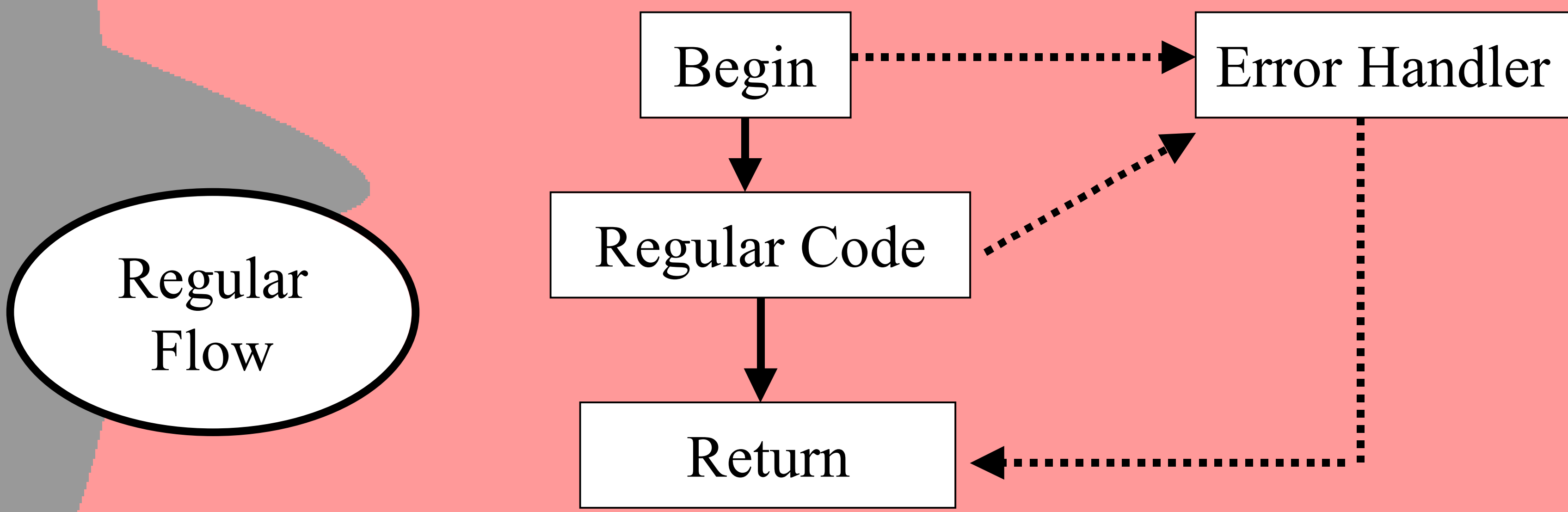
Microsoft optimizes memory footprints & page-fault-behaviour by re-arranging functions:



Simple Flow Graphs

Microsoft Binary Optimization (II)

The "less-trodden"-path is moved to a different page → Only relevant code stays on this page:



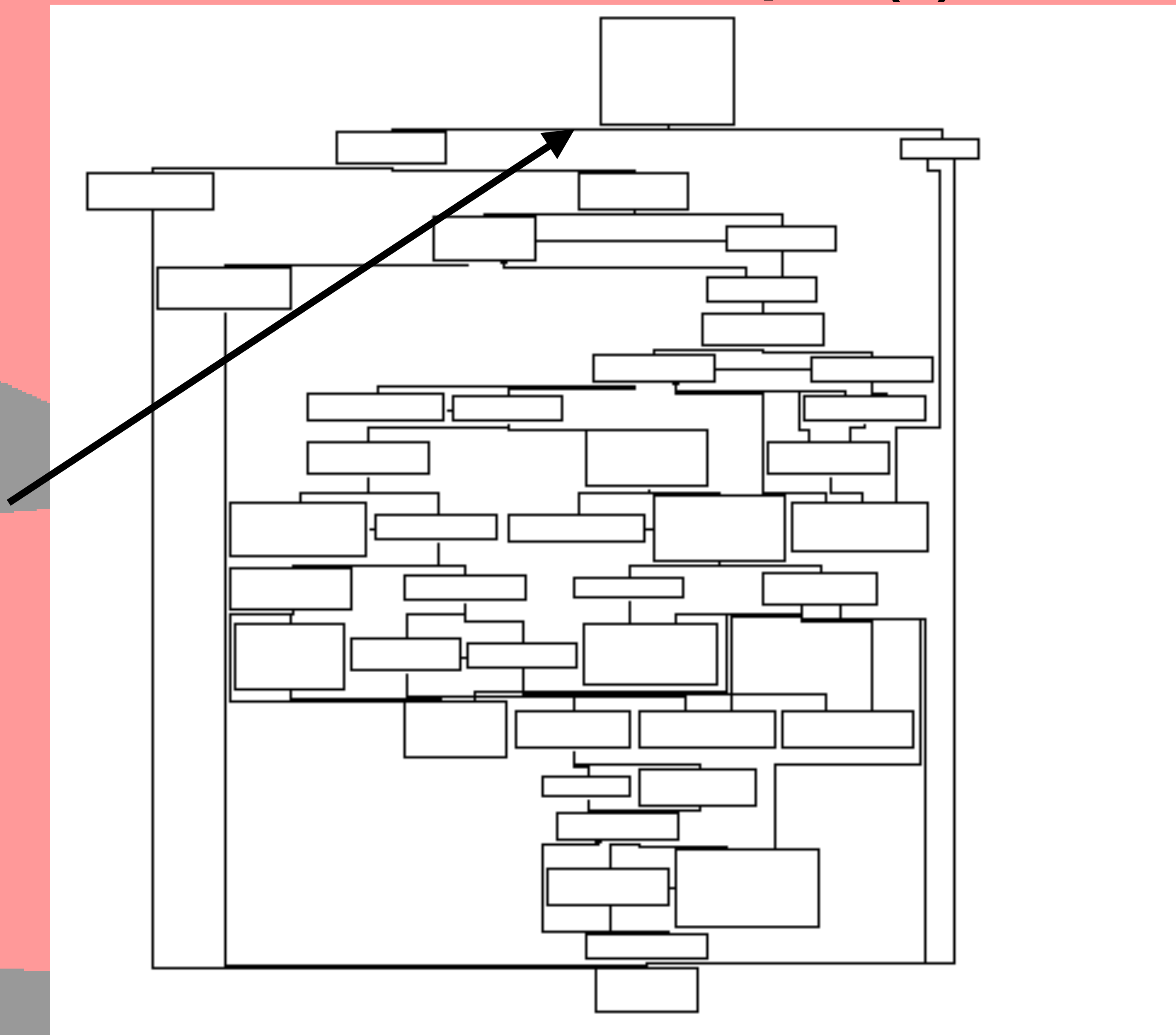
Side-Effect: IDA's built-in Flowgrapher cannot cope with non-contiguous functions: (Demonstration)

Simple Flow Graphs

Graph Coloring & Reduction

- Manual Decompilation is tedious:
  - Reverse Engineers burn out easily
  - Small mistakes get back to you
  - Hard to keep track of progress
- Graphs can be used as visual aid
  - Step 1: Color the covered code
  - Step 2: Remove outer-layer loops & branches
- Graphs will keep track of progress
  - It's good to see that you're getting somewhere

RtlFreeHeap (I)

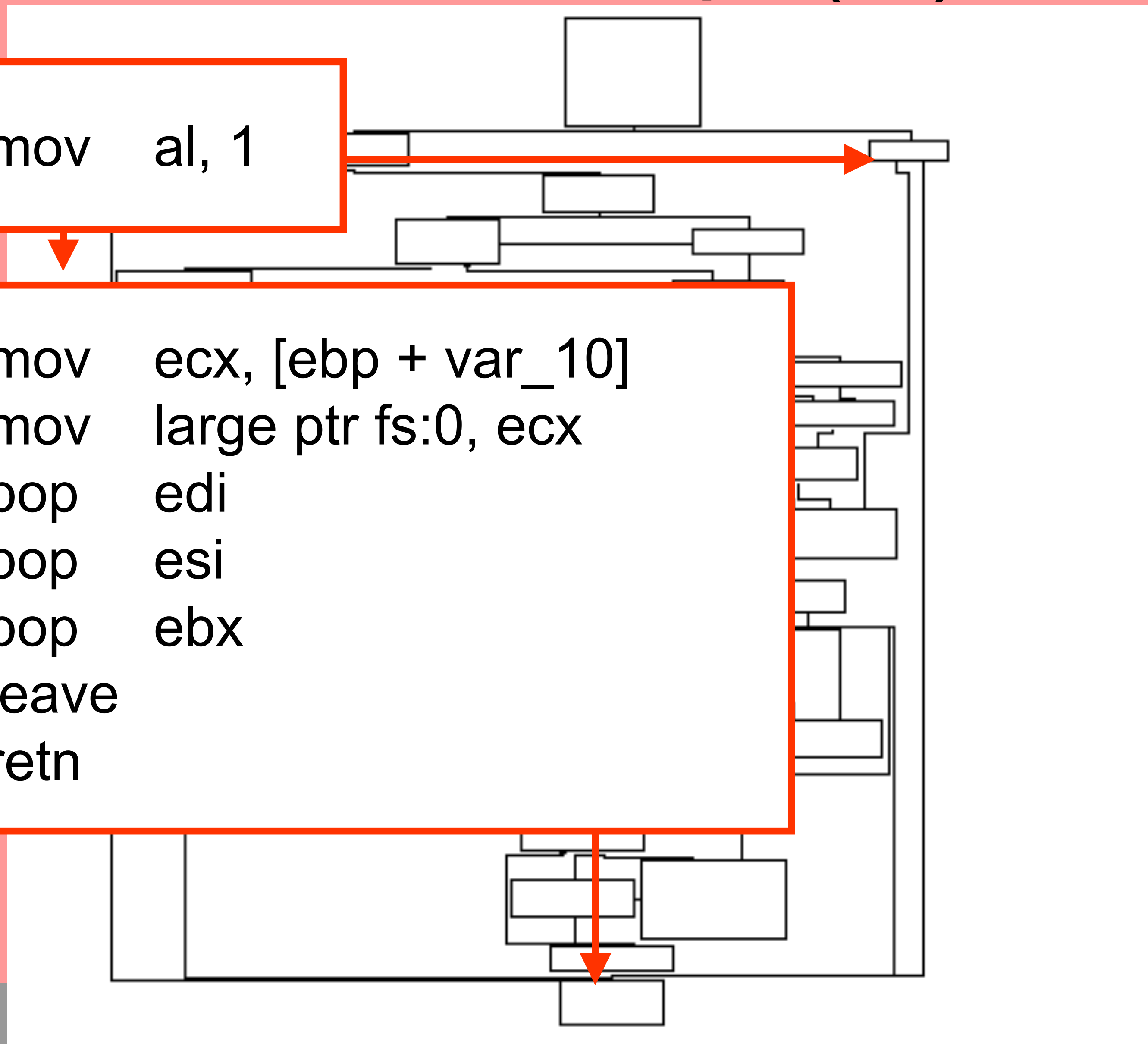


RtlFreeHeap (II)

```
NodeBegin: 77fcb633
77fcb633:              push    ebp
77fcb634:              mov     ebp, esp
                       push    0FFFFFFFFh
                       push    offset 77F82690dword_77F82690
                       push    offset 77FB9DA7__except_handler3
                       mov     eax, large fs:0
                       push    eax
                       mov     large fs:0, esp
                       push    ecx
                       push    ecx
                       sub     esp, 6Ch
77fcb655:              push    ebx
77fcb656:              push    esi
77fcb657:              push    edi
77fcb658:              mov     [ebp+var_18], esp
77fcb65b:              mov     edi, [ebp+arg_0]
77fcb65e:              mov     [ebp+var_34], edi
77fcb661:              and     [ebp+var_2C], 0
77fcb665:              mov     [ebp+var_20], 1
77fcb669:              mov     edx, [ebp+arg_8]
77fcb66c:              test    edx, edx
77fcb66e:              jz      short 77FCB6E2loc_77FCB6E2
NodeEnd:    77fcb66e
```

Checks if the pointer to the block is Non-NULL

RtlFreeHeap (III)



```
mov    al, 1
```

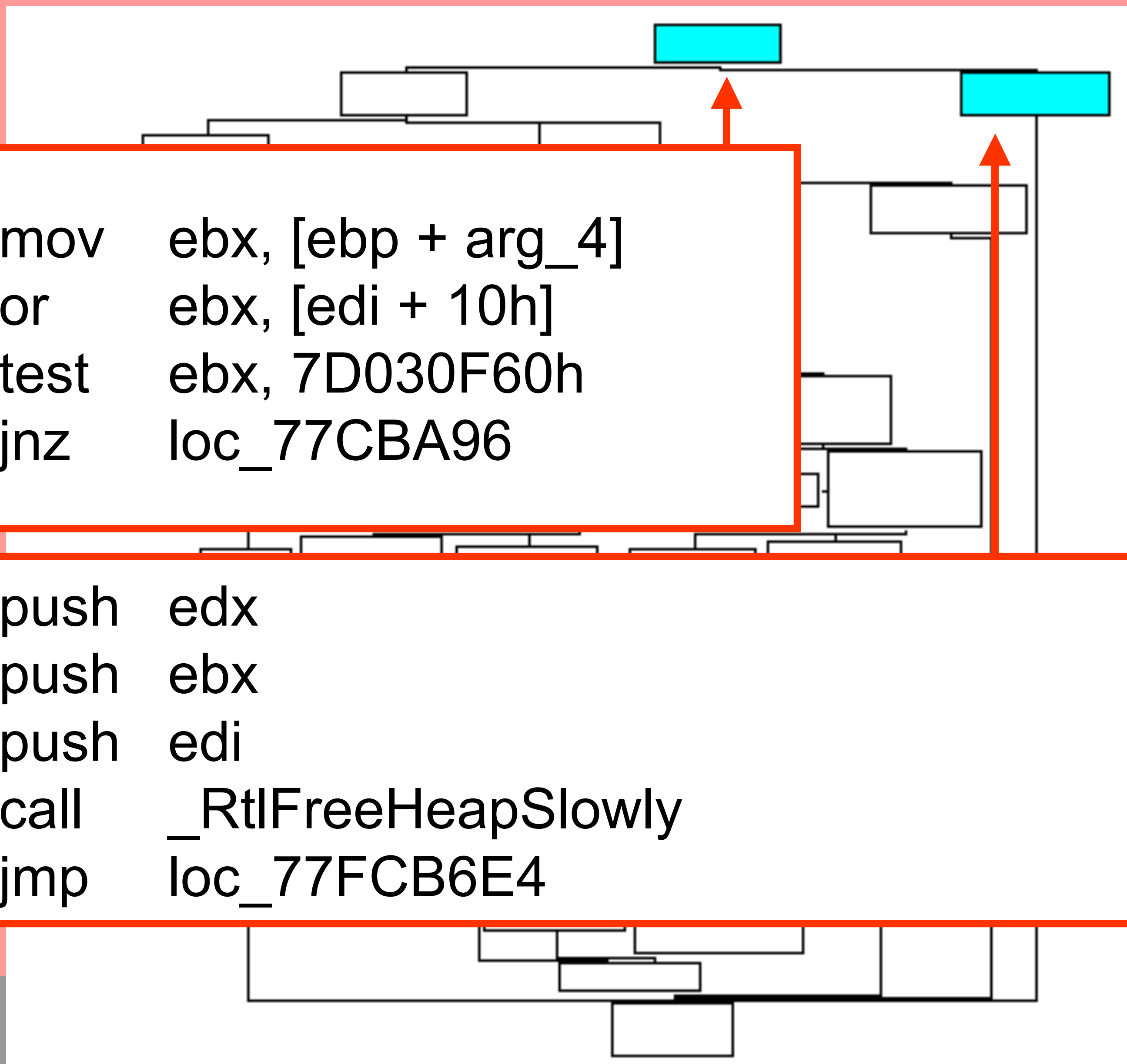
```
mov    ecx, [ebp + var_10]
mov    large ptr fs:0, ecx
pop    edi
pop    esi
pop    ebx
leave
retn
```

Simple Flow Graphs

Graph Coloring & Reduction

```
RtlFreeHeap(/* snip */ void *blk)
{
   if(blk == NULL)
        return(TRUE);
```

RtlFreeHeap (IV)



```
mov     ebx, [ebp + arg_4]
or      ebx, [edi + 10h]
test    ebx, 7D030F60h
jnz     loc_77CBA96
```

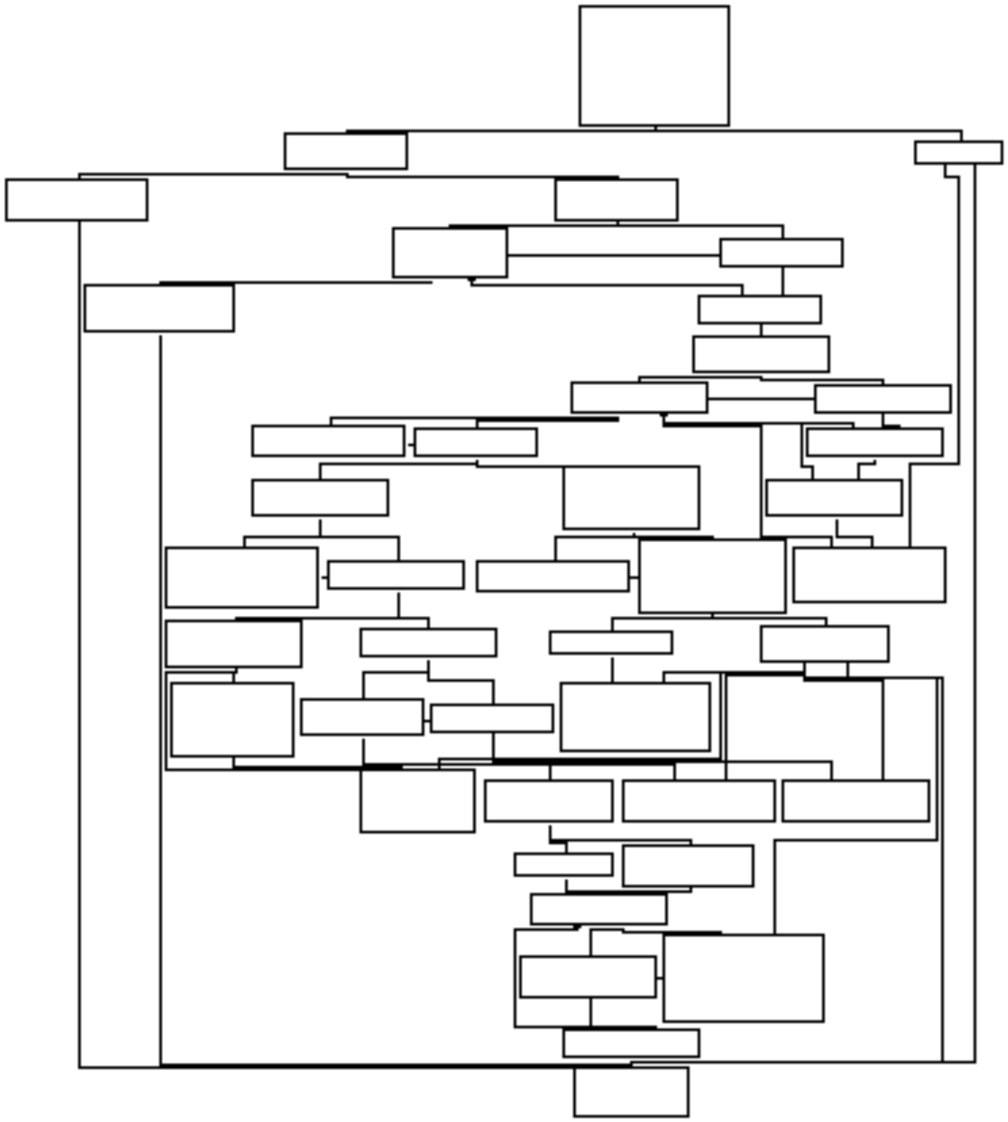
```
push    edx
push    ebx
push    edi
call    _RtlFreeHeapSlowly
jmp     loc_77FCB6E4
```

Simple Flow Graphs

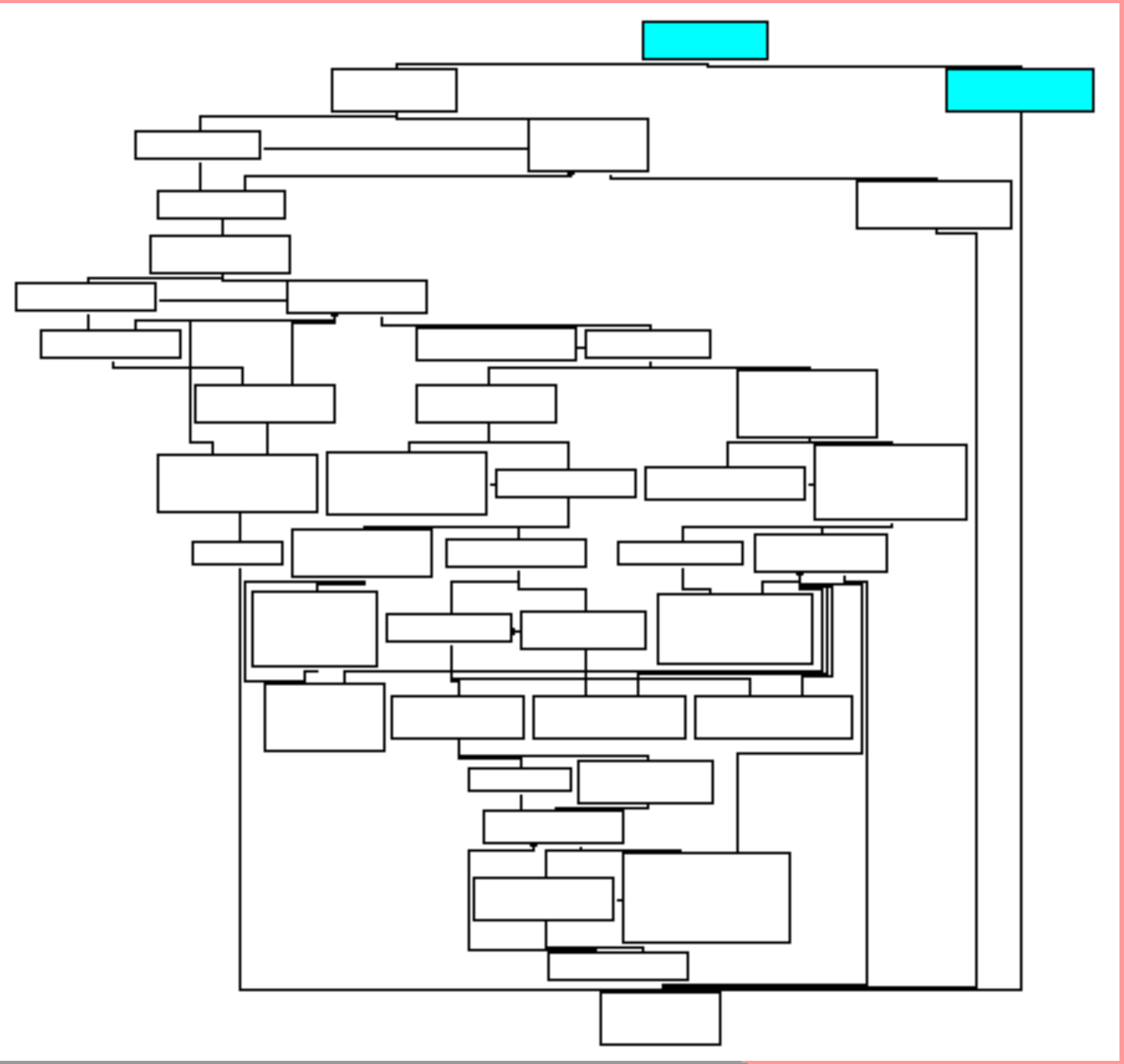
Graph Coloring & Reduction

```
RtlFreeHeap(HEAP *hHeap, DWORD flags, void *blk)
{
    if(blk == NULL)
        return(TRUE);

    if((flags | hHeap->flgs) & FLAGMASK)
        return(
            RtlFreeHeapSlowly(    hHeap,
                                  flags | (hHeap->flgs),
                                  blk        )

        );
```

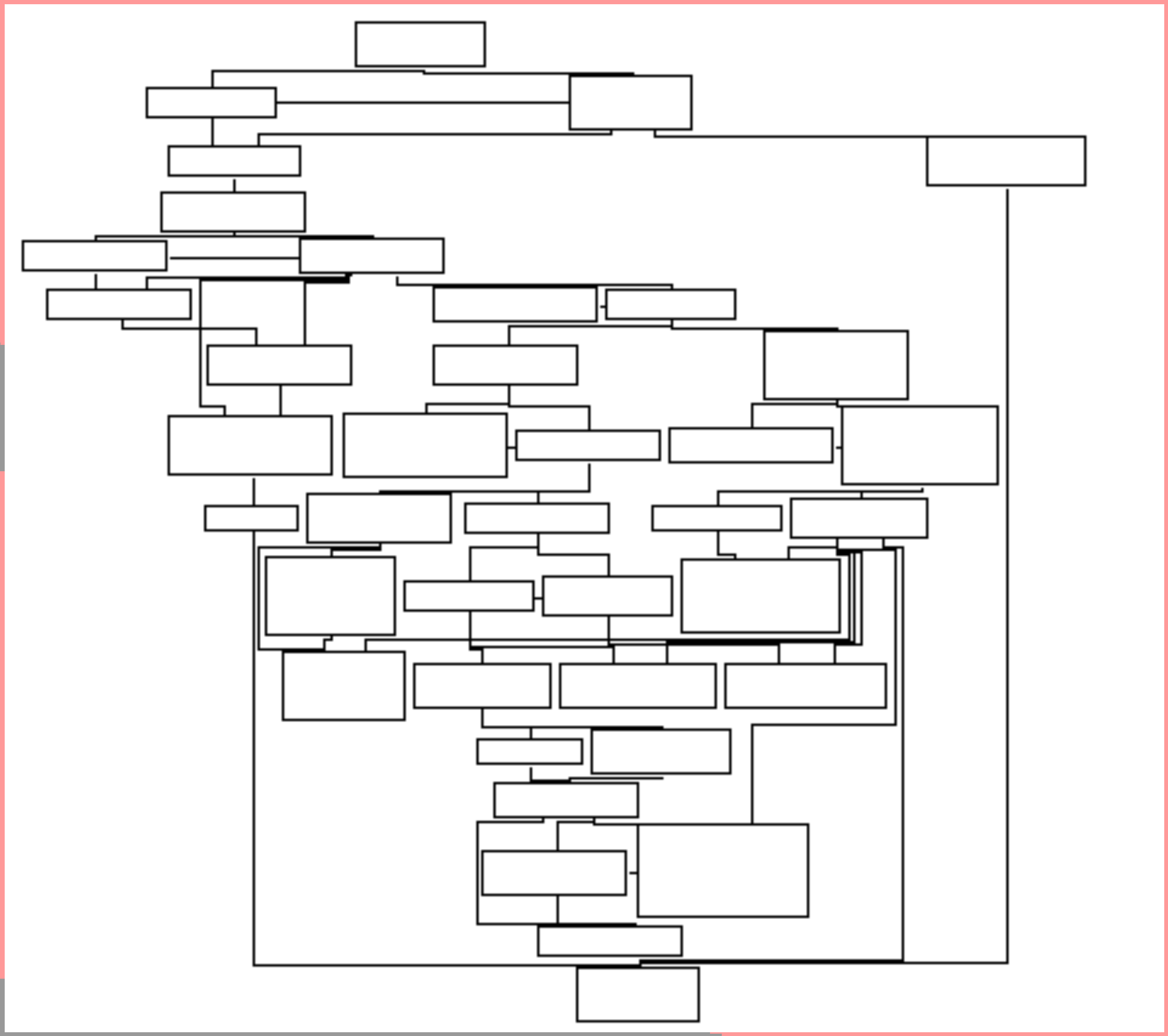
RtlFreeHeap (V)



RtlFreeHeap (VI)



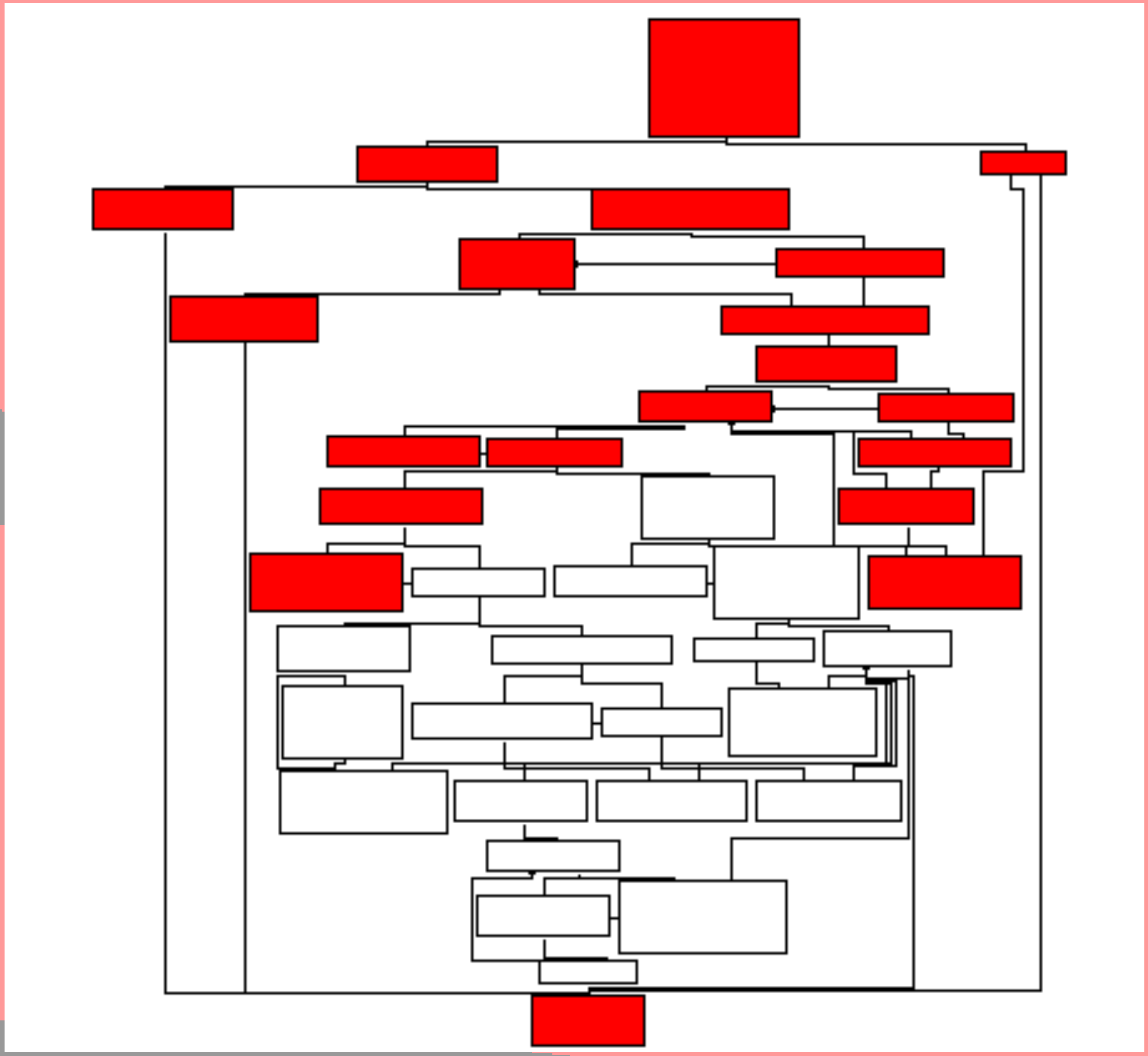
RtlFreeHeap (VII)



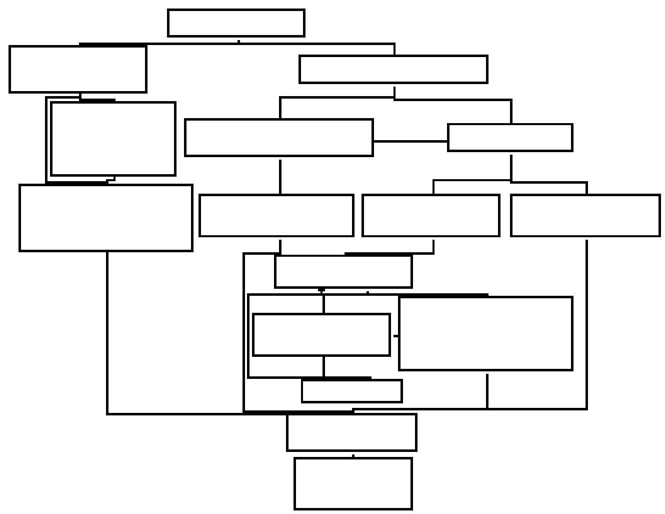
Simple Flow Graphs
Graph Coloring & Reduction

- Graph Coloring helps …
  - … to see progress (Motivation boost ☺)
  - … to keep track of covered code
  - … to ensure no codebranch is missed
  - … to “show results” to management
- Graph Reduction helps
  - … to clarify complex situations
  - … to see progress (“Only 5 Nodes left !”)
  - … to make sure nothing is missed

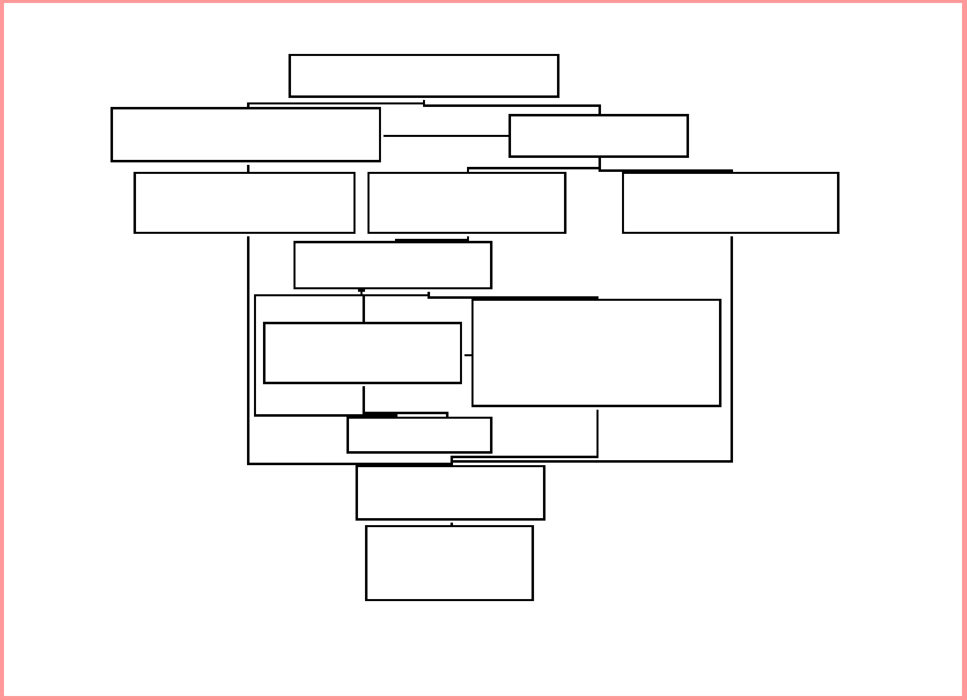
RtlFreeHeap (VIII)



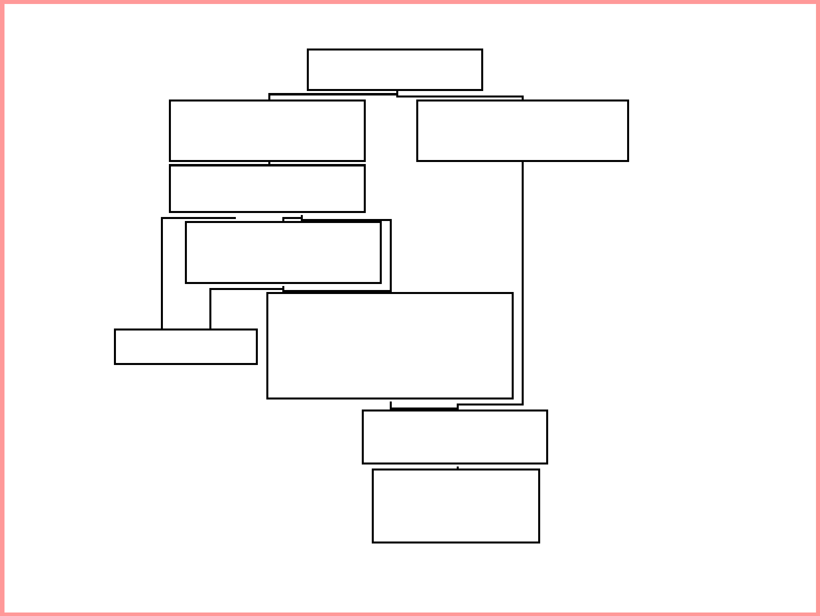
RtlFreeHeap (IX)



RtlFreeHeap (X)



RtlFreeHeap (XI)



Simple Flow Graphs
FUZZ coverage analysis

- FUZZ-testing is highly inefficient:
  - Minor desynchronisation between protocols leads to not fuzzing at all
  - Undocumented features cannot be fuzzed
  - Hard to impossible to estimate how good a certain fuzz testing program is
- Analogy: Shooting Bats in a dark apartment
- Graphs can be used as a visual aid again !
  - Step 1: Generate Flow Graph
  - Step 2: Load into a debugger, set breakpoints
  - Step 3: FUZZ the program, color touched nodes

Simple Flow Graphs
FUZZ coverage analysis

- Major advantages to conventional FUZZ:
  - Percentage of covered code can be measured
  - Fuzzing mechanisms/scripts can be dynamically improved to improve coverage
  - Quality of existing FUZZ-tools can be compared
- Analogy: Still shooting Bats in a dark appartment, but now we know that we’ve been in every room
- Demonstration

Simple Flow Graphs

Any questions concerning this part ?

Pointer Control Graphs

Structure/Class Reconstruction

- All information about structures and their layout gets lost in the compilation process
- If we look for buffer overruns, we need to know buffer sizes

- Manual structure reconstruction is an incredibly tedious, repetitive and annoying process !

→ Specialized Graphs might help

Pointer Control Graphs

Structure/Class Reconstruction

- Identifying a pointer to a structure in the binary is usually trivial:

```
mov        edi, [ebp + arg_0]
mov        eax, [edi + 03Ch]
```

- If we can follow a pointer through the code, we can find **all offsets** which are added to it

Pointer Control Graphs

Pointer Control Graphs

Pointer Control Graphs are best suited for this:

- Start tracing code at a location, tracking a specific register/stack variable
- Trace code downwards until
  - A (local) branch is encountered
  - A write access to our variable is encountered
  - A read access to our variable is encountered
  - (Optional: A far branch (subfunction call) is encountered)

Pointer Control Graphs

Pointer Control Graphs

As soon as any of the above situations are encountered, do the following:

- In case of a local branch:
  - Behave as if we're building a flowgraph → "split" the path and follow both codepaths downwards
- In case of a register/variable write
  - Abort the tracing as our register/variable has been overwritten
- In case of a register/variable read
  - "Split" the path and follow the codepaths for both the new and the old register/variable
- In case of a non-local branch (optional)
  - Trace into subfunctions and follow possible argument passing (tricky on x86 due to argument passing in both registers and stacks variables)

Pointer Control Graphs

Class Reconstruction

Example:

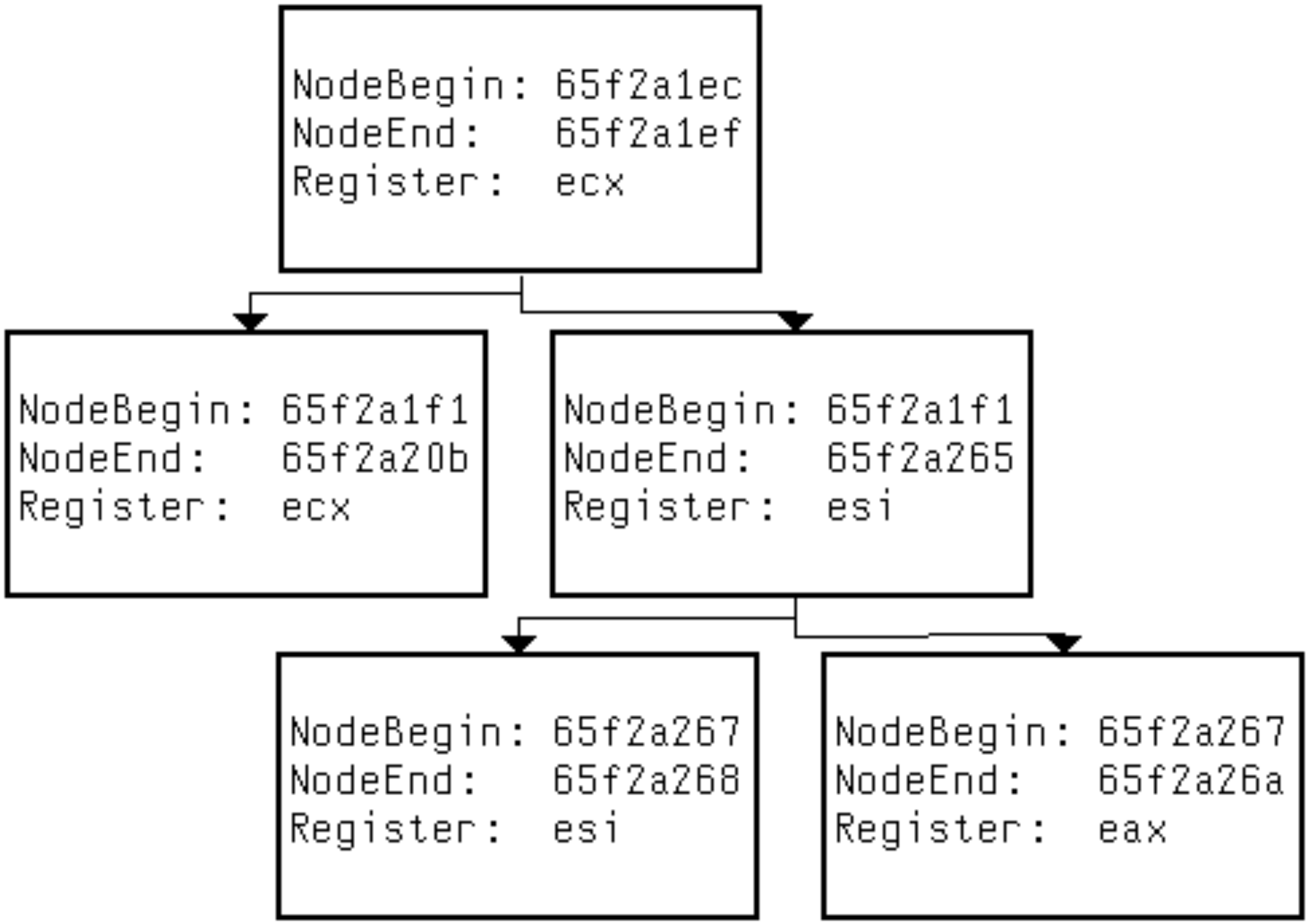
A simple Constructor for the IIS-Internal HTTP_REQUEST – Object:

- Visual C++ compiled code: **this** - Pointer in ECX
- Every move of ECX into another register needs to be tracked
- Every move of ECX into a stack variable needs to be tracked
- Tracking has to be recursive: Other registers are to be treated like ECX

- Demonstration

Pointer Control Graphs

Class Reconstruction



Pointer Control Graphs

Class Reconstruction

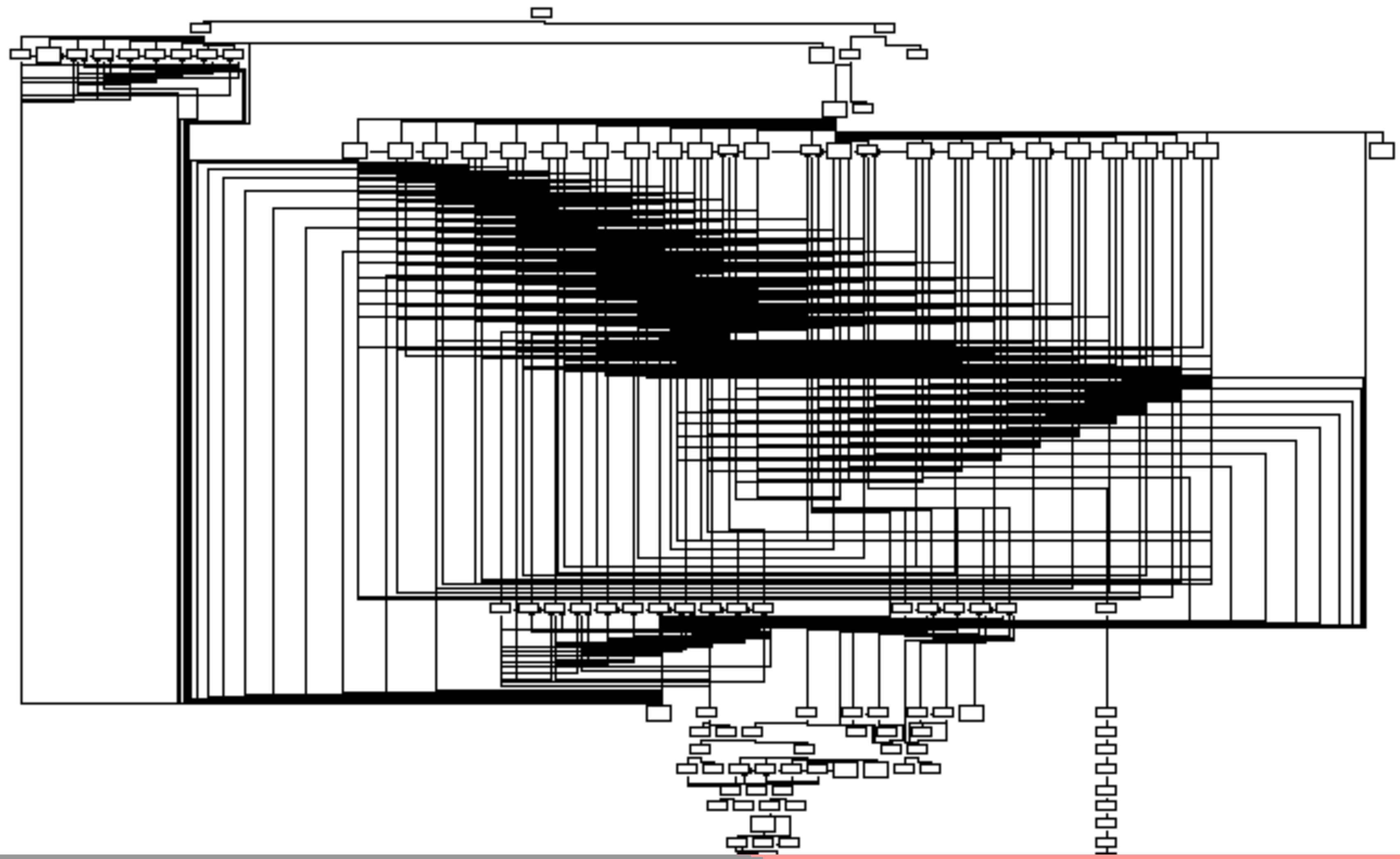
Example:

A simple Constructor for the IIS-Internal HTTP_REQUEST – Object:

- Single Functions do usually not access all structure members
- C++ Inheritance can lead to calling multiple Constructors subsequently
- **Subcall recursion and tracking of registers through subcalls** is needed for decent structure reconstruction
- Demonstration

Pointer Control Graphs

Class Reconstruction



Pointer Control Graphs

Class Reconstruction

Vtable Parsing:

- Virtual Methods are arranged in a “VTable”
- All Methods operate on the same data structure
- Very accurate reconstruction of classes by parsing this table

Pointer Control Graphs
Class Reconstruction

Summary:

- Structure data layouts can be automatically reconstructed from the binary by constructing & parsing pointer control graphs
- Class data layouts can be automatically reconstructed from the binary by constructing & parsing pointer control graphs from vtables
- Larger graphs can be too complex to display ☺
- RPC interfaces (such as COM/COM+/DCOM) help us by publically exporting vtables for certain objects

- **Structure/Class reconstruction speeds up the binary analysis process by a large factor !**
- **(TODO: Automatic type reconstruction from known library calls)**

Class/Structure Reconstruction

Any questions concerning this part ?

Buffer Definition Graphs

Finding buffer definitions

Problem:

- Many problematic functions are not dangerous if the target buffer is big enough to hold all data
- These functions work on char *, which do not tell me the size of their buffers
- Tracking down where a char * came from is slow, boring, tedious and annoying
- In complex situations (multiple recursive functions etc.) it is quite easy to get lost and miss definitions

→ Specialized Graphs might help

Buffer Definition Graphs

Inverse Variable Tracking

Trace code upwards and track a variable/register until

- The current instruction was target of a branch
- The current register is written to from another register/variable
- The current register is loaded with something
- The current register is a return value from a function

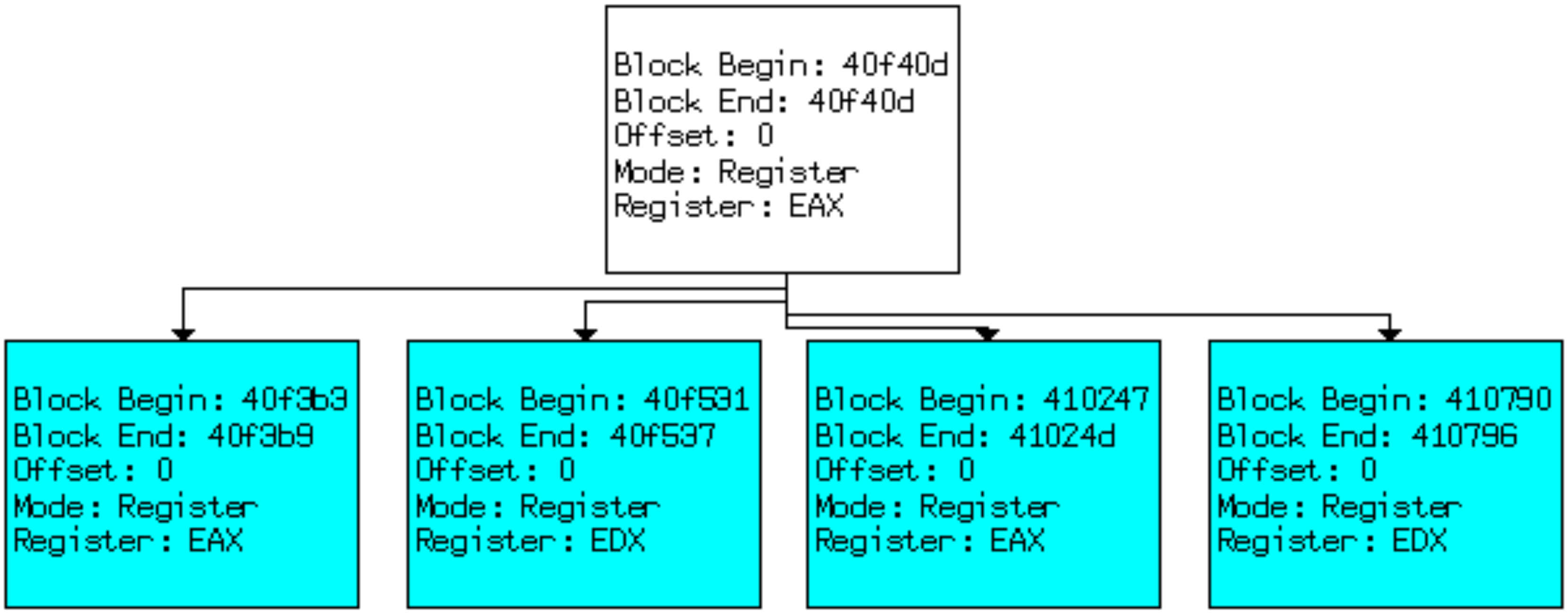
Buffer Definition Graphs

Inverse Variable Tracking

- The current instruction was target of a branch
  - "Multi-Split" the graph (there can be more than 2 references) and trace further upwards
- The current register is written to from another register/variable
  - Follow this new register/variable, no need for splitting
- The current register is loaded with something
  - Analyze the situation, color the node blue for success and red for failure (ALPHA CODE)
- The current register/variable is manipulated in a way that we cannot cope with
  - Color the node red (ALPHA CODE)

Buffer Definition Graphs

Example Graphs



Buffer Definition Graphs

Any questions ?

OBJRec and x86Graph available at:

http://www.blackhat.com/html/bh-consulting/bh-consulting-tools.html