Correct Relocation: Do You Trust a Mutated Binary?

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Binary Manipulation

- We want to:
  - Insert new code
  - Modify or delete code
  - These operations move program code
- Binaries are brittle
  - Code movement may affect program semantics
- We want to move code without breaking the program

Relocation

- Relocation moves code while maintaining its original execution semantics
  - May radically transform the code
- Does not rely on external information
- Binary tools use relocation extensively
  - Execute original + relocated code (Dyninst)
  - Always execute relocated code (PIN, Valgrind, DynamoRIO, VMWare, DELI)

Relocation is critical for binary manipulation

Relocation Examples

```
foo:
0x1000: push ebp
0x1001: mov esp, ebp
0x1003: mov 0x8(ebp), eax
0x1006: cmp 0x5, eax
0x1009: ja 0x30
0x100b: call ebx_thunk
0x1011: add ebx, eax
        ...
ebx_thunk:
0x2000: mov (esp), ebx
0x2003: ret
```

```
0x4000: ja -0x2ff7
        ...
```

```
0x5000: push $0x1011
0x5005: jmp ebx_thunk'
        ...
ebx_thunk':
0x6000: mov (esp), ebx
0x6003: call map_return
0x6008: ret
```

Current Approaches

- Strict Relocation
  - Maintains the semantics of each individual instruction
  - Safe in nearly all cases
  - Can impose severe slowdown
  - Trades speed for strictness

- Ad-Hoc Relocation
  - Emit more efficient code by partially emulating the original code
  - Pattern matching may fail and generate incorrect code
  - Trades strictness for speed

Benefits and Drawbacks

	Safe	Fast
Strict Relocation	Good	Poor
Ad-Hoc Relocation	Poor	Good
Partial Relocation	Good	Good

Our Approach

- Develop a formal model of relocation
  - Reason about the relationship of the moved code to:
    - Its new location
    - Surrounding code
  - Based on semantics of code instead of pattern-matching against syntax
- Strictness of emulation based on demands of the moved code (and surrounding code)

Effects of Code Movement

- Moving certain instructions will change their semantics
  - Relative branches, loads, stores
  - We call these *PC referencing* instructions
- Patching tools overwrite program code
  - Other code that references this code will be affected
- Relocation may affect non-relocated code!

Effects of Moving Code

```
foo:
0x1000: push ebp
0x1001: mov esp, ebp
0x1003: mov 0x8(ebp), eax
0x1004: cmp 0x5, eax
0x1006: ja 0x30
0x1008: call ebx_thunk
0x100d: add ebx, eax
0x100f: mov (eax), edx
0x1011: jmp edx
```

- No change
- Relative branch
- Relative load
- Branch to result of relative load

Effects of Overwriting Code

```
main:
        ...
0x0050: call foo
        ...
foo:
0x1002: jmp 0xf000
        ...
        ...
bar:
        ...
0x2010: mov (0x1000), eax
0x2015: add (0x1004), eax
```

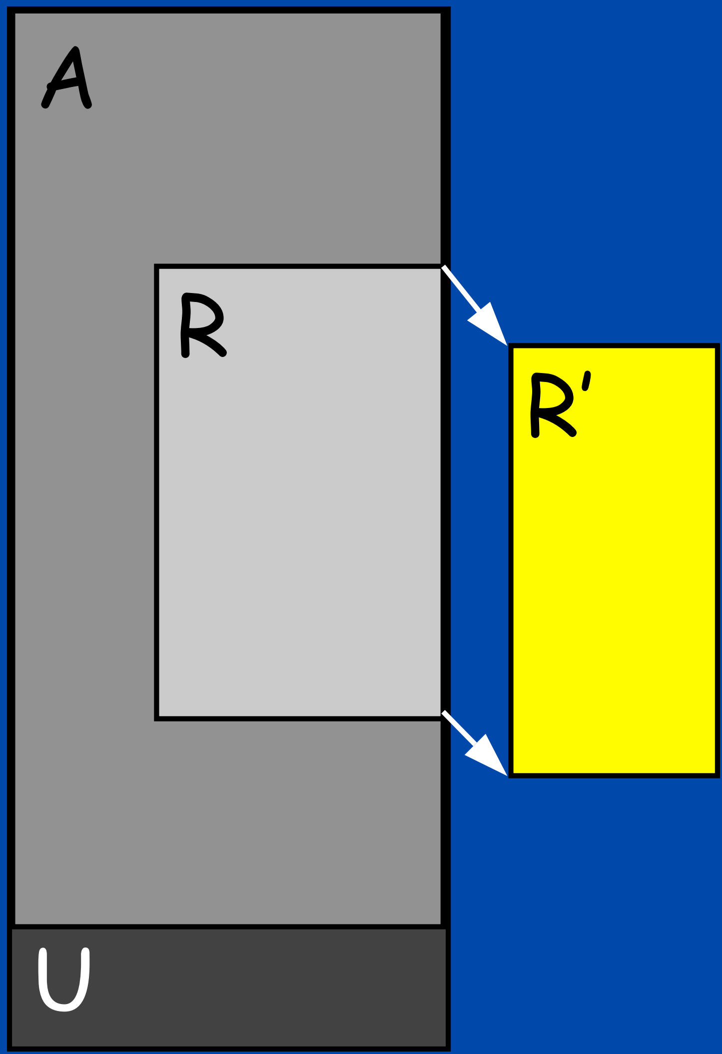
Approach

- Model
  - Relocated code, surrounding code
  - Properties of code affected by relocation
- Analysis
  - Deriving these properties from the binary
- Transformations
  - How do we modify code to run correctly and efficiently?

Model

- Define properties of code that relocation affects
  - PC referencing
  - Dependence on moved or overwritten code
- A single instruction may have multiple properties
- These combinations of properties determine how to relocate the instruction
  - Or compensate non-relocated instructions

Program Regions



- $R = \{i_i, \ldots, i_j\}$
  - Instructions to relocate
- $A = \{i_k, \ldots, i_l\}$
  - Analyzed region
  - Surrounds R
- $U = \{i_0, \ldots\ i_n\} - R - A$
  - Unanalyzed region
  - Models limits of analysis
- $R' = \{i_p, \ldots, i_q\}$
  - Relocated instructions

Properties of Moved Code

```
foo:
0x1000: push ebp
0x1001: mov esp, ebp
0x1003: mov 0x8(ebp), eax
0x1004: cmp 0x5, eax
0x1006: ja 0x30
0x1008: call ebx_thunk
0x100d: add ebx, eax
0x100f: mov (eax), edx
0x1011: jmp edx
```

- Direct (REF)
  - Control (REF_C)
  - Data (REF_D)
  - Predicate (REF_P)
- Indirect (REF*)
  - Control (REF^*_C)
  - Data (REF^*_D)
  - Predicate (REF^*_P)

Predicate PC References

```
bool dl_open_check(char *name,
                   void *calladdr)
{
  // Check if the caller is
  // from libdl or libc
  bool safe_open = false;
  if (IN(libc_obj, calladdr)
     || IN(libdl_obj, calladdr)
      safe_open = true;
  if (!safe_open) return false;

  // Perform further checks
  ...
}
```

- Safety check in library load
  - Address of caller passed in
  - Checked against legal callers
- Predicate expressions

Properties of Overwritten Code

```
main:
        ...
0x0050: call foo
        ...
foo:
        ...
0x1004: cmp 0x5, eax
0x1006: ja 0x30
        ...
bar:
        ...
0x2010: mov (0x1000), eax
0x2015: add (0x1004), eax
```

A

R

A

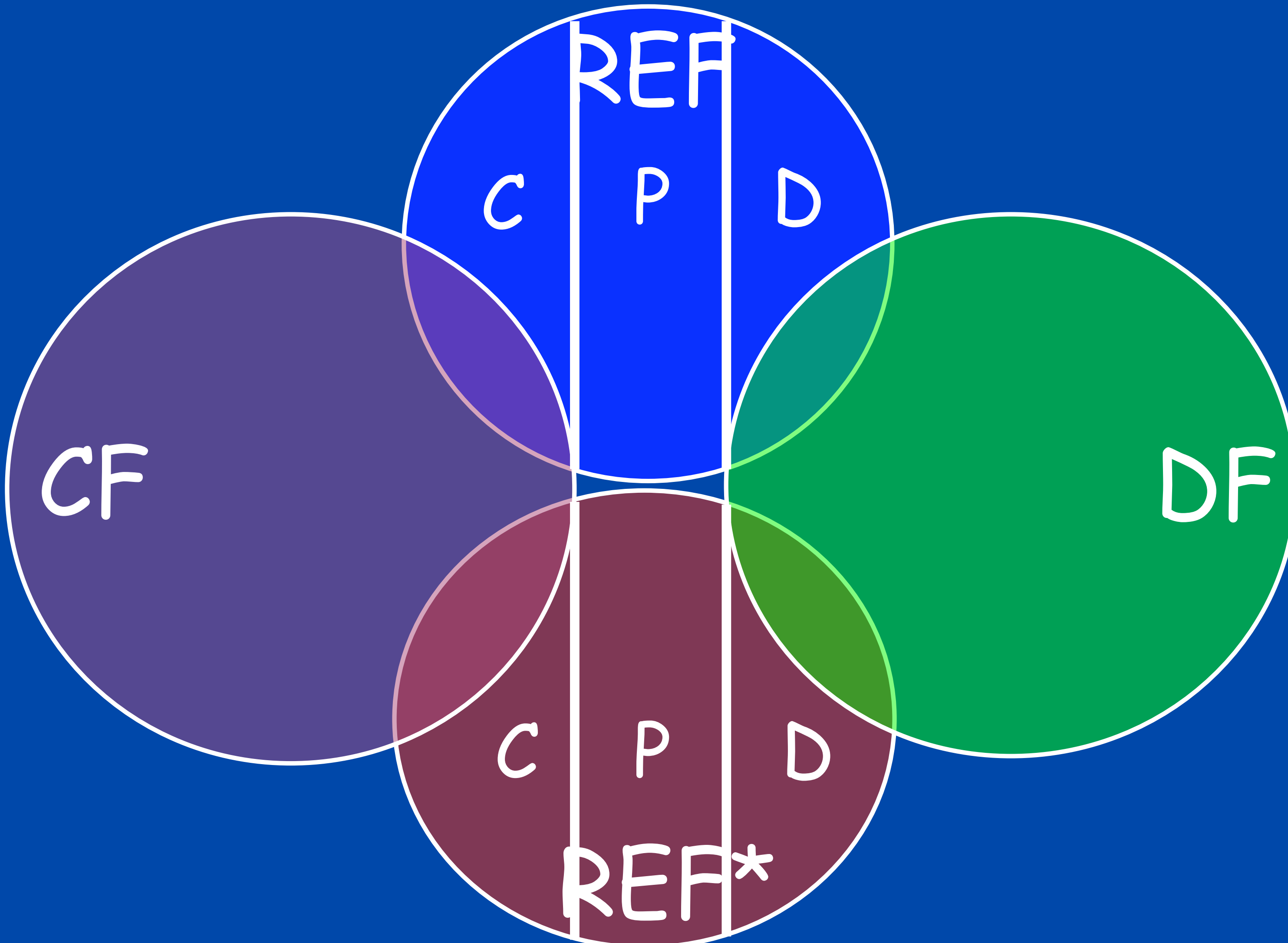
- Control (CF)
  - Instructions with successors in R

$\{0x0050, 0x1004\}_{CF}$

- Data (DF)
  - Loads from R
  - Stores to R

$\{0x2010, 0x2015\}_{DF}$

Properties Summary



Analysis Overview

1. Choose R and A
   - R: instruction, basic block, function, …
   - A: how much do we analyze?
2. Identify sources of REF and REF* in R
   - Follow data dependence chains into A and U
3. Determine $\{\ldots\}_{CF}$ and $\{\ldots\}_{DF}$
   - Begin with interprocedural CFG and points-to analysis
   - Be conservative and assume incomplete information

REF/REF* Analysis

```
foo:
        ...
0x1004: cmp 0x5, eax
0x1006: ja 0x30
0x1008: call ebx_thunk
0x100d: add ebx, eax
0x100f: mov (eax) edx
0x1011: jmp edx
```

REF*$_c$

- Create the Program Dependence Graph
  - Covering R + A
- Identify source instructions
- Follow data dependence edges
  - Into A (or U)

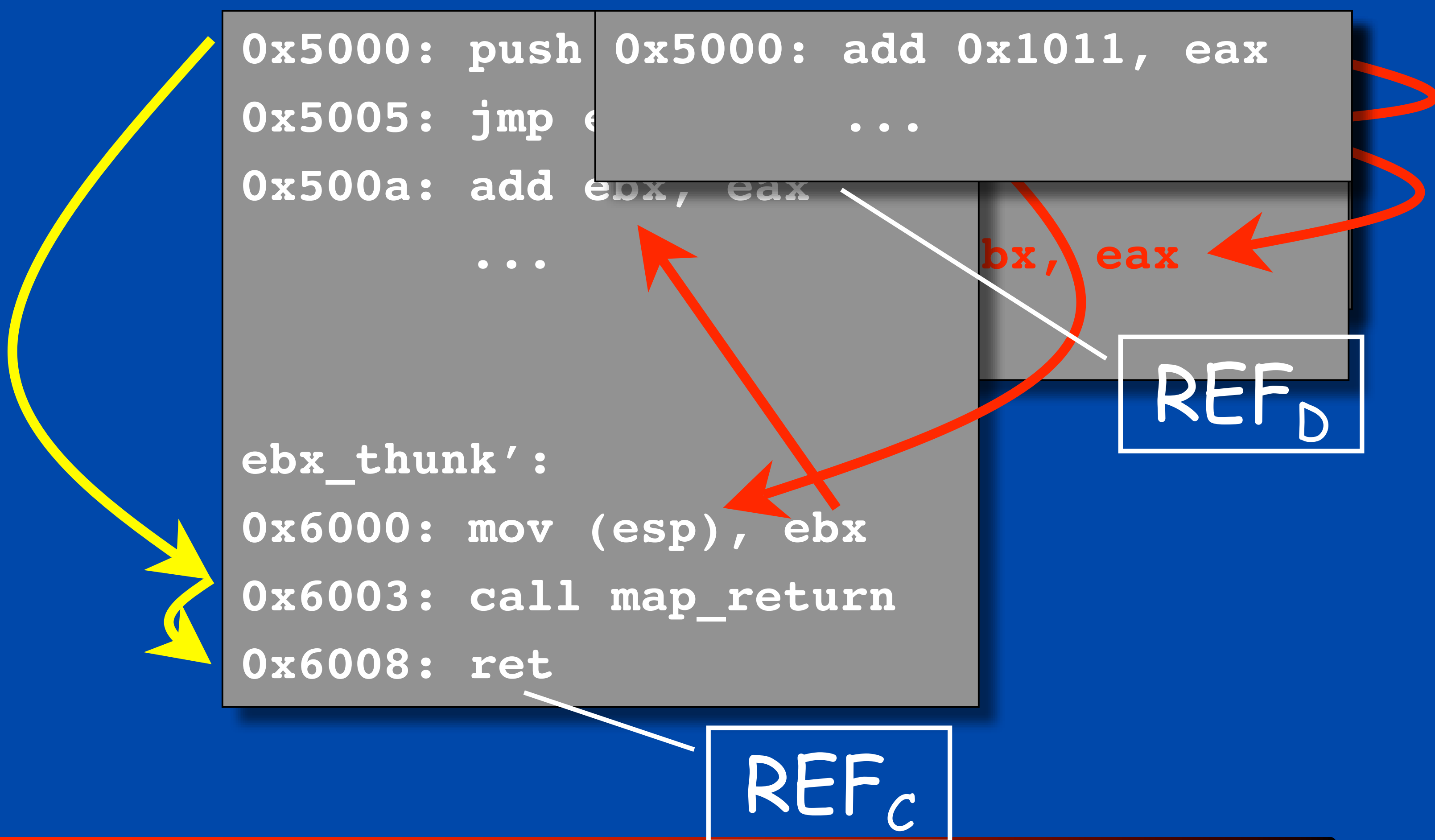
Transformation Goals

- We want to emulate the smallest set of original code semantics
- Transformations must maintain the properties determined by analysis
  - But any others are not required
- Our approach: define transformations for each combination of properties

Granularity of Relocation

- Current methods relocate by instruction
  - Maintain equivalence at the instruction boundary
- "Unobserved" results
- Relocate instructions as a group
  - Maintain boundary semantics of the code
  - Reduce complexity and improve efficiency

Partial Relocation Example



Research Plan

- This work is preliminary
  - Properties are defined
  - Analysis requirements are defined
- Still a lot to do
  - Determine transformations
  - Implementation in Dyninst
  - Performance analysis

Questions?

Relocating a Jump Table

```
foo2:
0x1008: jmp <0xf008>



0x1012: <jump table data>
        ...
0x1040: jmp <0xf040>
0x1060: jmp <0xf060>
0x1080: jmp <0xf080>
0x10a0: jmp <0xf0a0>
```

```
foo3:
0xf008: call ebx_thunk
0xf00d: add ebx, eax
0xf00f: mov (eax, 4), ebx
0xf011: jmp ebx
0xf012: <relocated jump
            table data>
0xf040: <reloc case 1>
0xf060: <reloc case 2>
0xf080: <reloc case 3>
0xf0a0: <reloc case 4>
```

Complex Instructions

- Instructions may have multiple properties
  - Example: a relative branch in R may be both CF and REF_C
- Some overlap is due to implicit control flow
  - Instructions in R may be tagged as REF_C due to fallthrough to next instruction
- We can model instructions as combinations of independent operations if necessary
  - Separate out the "next PC" calculation