steg86: hiding messages in x86 binaries

rust munich meetup

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agenda

- yours truly
- steganography?
- steg on programs
- x86 instruction encoding
- steg86

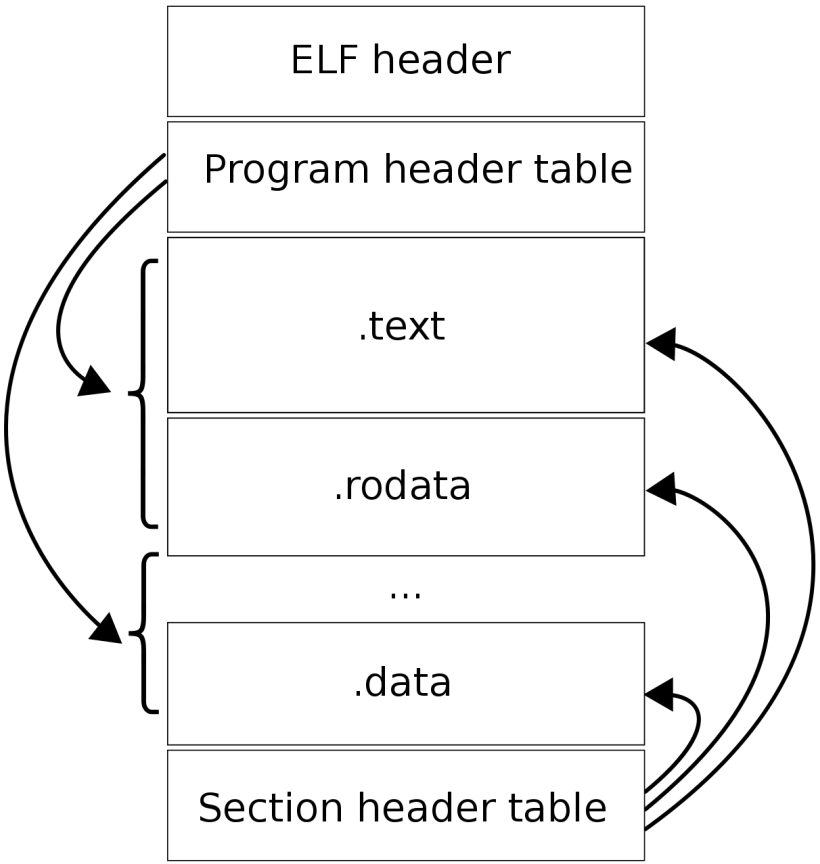
yours truly

- william woodruff
  - @8x5cIPW2 ▪ yossarian.net ▪ blog.yossarian.net
- senior security engineer @ trail of bits
- work: program analysis research, mostly in LLVM
  - disclaimer: independent talk, not representing employer
- open source: member of homebrew, miscellaneous contributor

steganography?

- "hiding data within data"
- *not* cryptography
- different techniques for different data
- popular targets:
  - images
  - sound files
  - plain text
- what about programs?

steg on programs



programs are a natural choice for steg

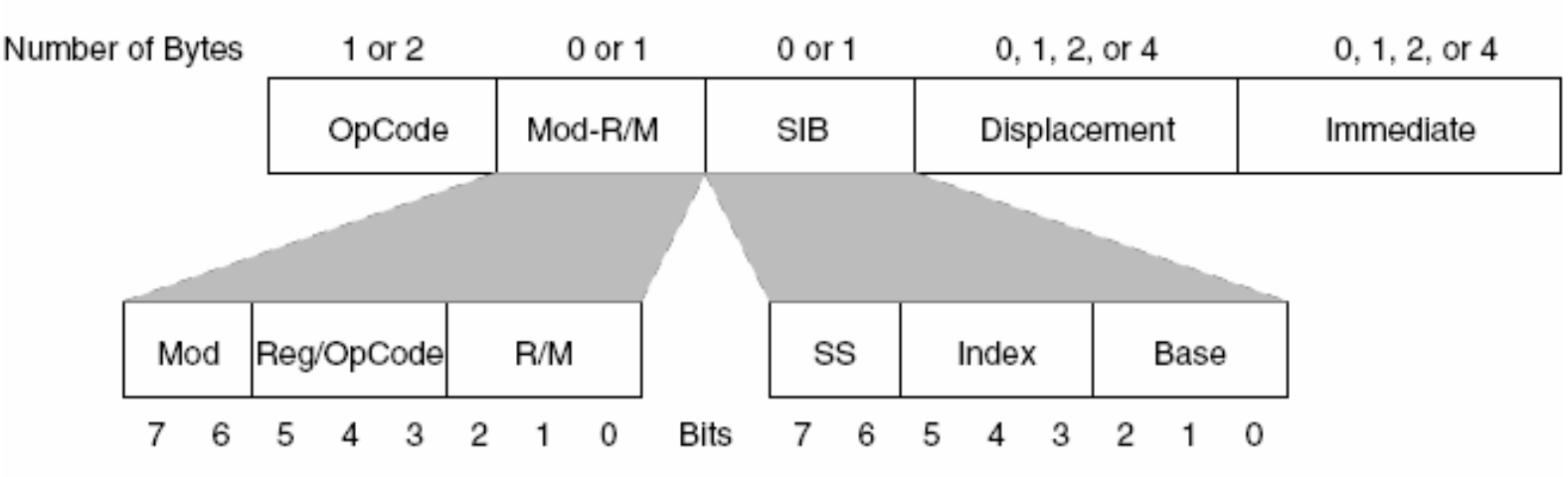
- can be very large (lots of info capacity)
- complex binary formats (PE, Mach-O, ELF)
- complex instruction encodings (x86/AMD64, ARM w/ Thumb)
- present on every computer, not inherently suspicious

steg on programs: approaches

- hide information in stack layout, register selection
  - problem: need the program's source
  - problem: need to maintain a compiler...
- hide information in the format itself (e.g. segment order)
  - problem: specific to a format, may not apply to others
- rewrite the program after compilation
  - ex: `add eax, -50` $\rightarrow$ `sub eax, 50`
  - problem: code/data disambiguation (difficult to solve)
  - problem: relocations, position independent code (`-fPIC`)
  - problem: CPU-level semantics (arithmetic, status flags)
- can we do better?

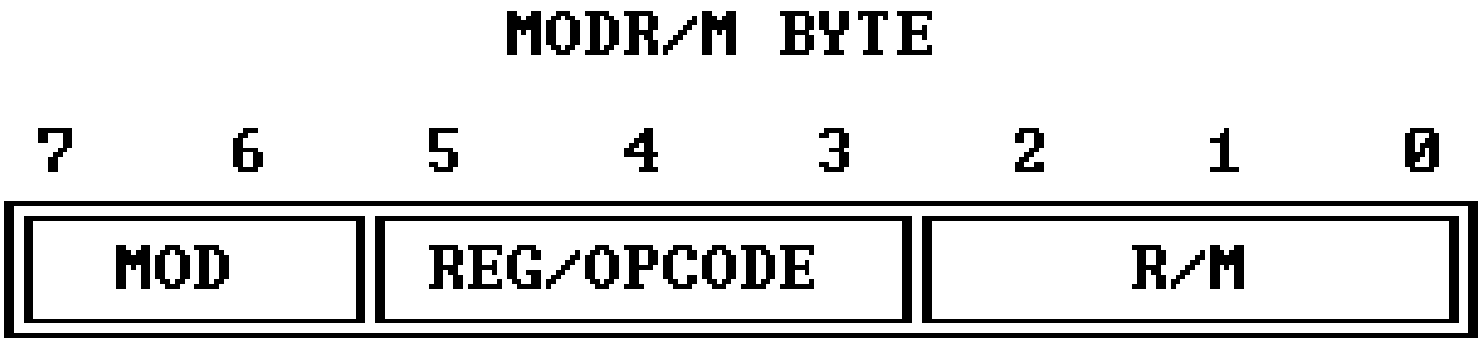
x86 instruction encoding

- variable length (up to 15 bytes)
- extremely complex (decades of compat, overloaded fields)
- rich source/sink combinations
  - register-to-register (`mov ebx, eax`)
  - register-to-memory (`mov dword [1337], eax`)
  - memory-to-register (`mov eax, dword [1337]`)
  - immediate-to-register (`mov eax, 1337`)
  - immediate-to-memory (`mov dword [1337], 1337`)



x86 instruction encoding: modr/m

- essentially an 8-bit lookup table of (some) operand encodings
  - doesn't cover all possible operands, for historical reasons...
- simplest case: encodes one or two operands
  - `reg/opcode` field: one register operand
  - `r/m field`: one register **or** memory operand
  - enables mem-to-reg, reg-to-mem, reg-to-reg operations



x86 instruction encoding: xor

opcode	instruction
`31 /r`	`xor r/m32, r32`
`33 /r`	`xor r32, r/m32`

- reg-to-mem, mem-to-reg, reg-to-reg,  ...
- there are **two** reg-to-reg encodings!
- `31 C0` → `mov eax, eax`
- `33 C0` → **also** `mov eax, eax`!
- they're even the same size!
- 64-bit variants (w/ REX prefix) work too!

steg86

- central conceit: each reg-to-reg pair represents one bit of information
  - with enough bits, we can hide messages!
- binary format independent
  - uses goblin to unpack PE/ELF/Mach-O binaries
- encodings are the same size, so PIC/relocations aren't broken
  - uses iced for decoding/encoding/semantics
- ~700 lines of rust total (much of it constants)
- CLI: `steg86 {profile,embed,extract}`

steg86: semantic duals

- it turns out there are a bunch of these
- 9 instructions (`add`, `adc`, `sub`, `sbb`, `and`, `or`, `xor`, `mov`, `cmp`)
  - 4 variants (8, 16, 32, 64-bit) each[1]
- each dual gives us 1 bit of information
  - minus a little space for a header with metadata
- how common are these instructions?

```
$ steg86 profile /bin/bash
Summary for /bin/bash:
  175828 total instructions
  27957 potential semantic pairs
  27925 bits of information capacity (3490 bytes)
```

- not bad!

[1] actually 3 in any particular CPU mode...

steg86: semantic duals

each pair represents (false, true)...

```
static SEMANTIC_PAIRS: &[(Code, Code)] = &[
    // ADD
    (Code::Add_rm8_r8, Code::Add_r8_rm8),
    (Code::Add_rm16_r16, Code::Add_r16_rm16),
    (Code::Add_rm32_r32, Code::Add_r32_rm32),
    (Code::Add_rm64_r64, Code::Add_r64_rm64),

    // ... snip ...
];
```

steg86: profiling

for every instruction in the program...

```
// skip instructions we don't support
if !SUPPORTED_OPCODES.contains(&instruction.code()) {
    continue;
}

// skip non reg-to-reg instructions
if instruction.op0_kind() != OpKind::Register
    || instruction.op1_kind() != OpKind::Register
{
    continue;
}

offsets.push(instruction.ip() as usize);
```

steg86: embedding

for each candidate instruction...

```
let new_code = {
    let tuple = SEMANTIC_PAIRS
        .iter()
        .find(|&&t| old_code == t.0 || old_code == t.1)
        .unwrap();

    match (bit, tuple.0 == old_code) {
        (false, true) | (true, false) => {
            // already correct!
            continue;
        }
        (false, false) => tuple.0,
        (true, true) => tuple.1,
    }
};
```

steg86: embedding

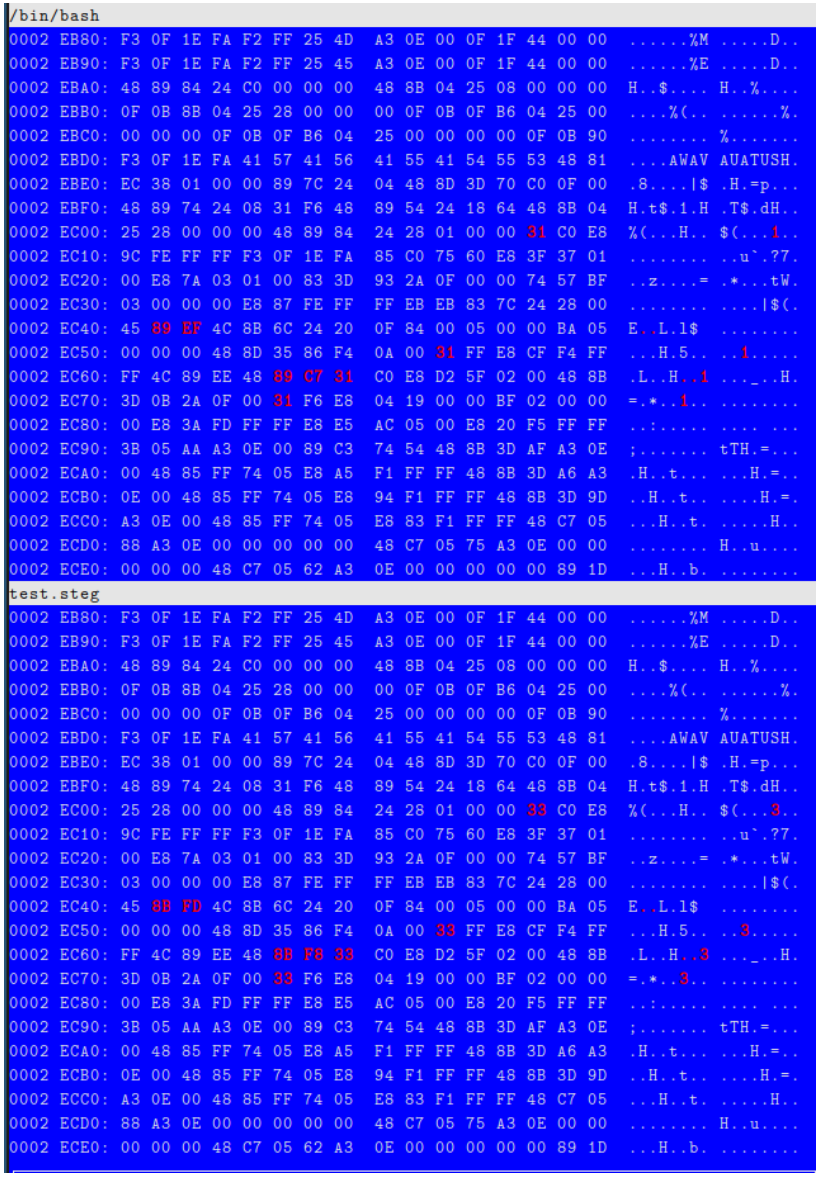
```
let new_instruction = Instruction::with_reg_reg(
    new_code,
    instruction.op0_register(),
    instruction.op1_register(),
);
let new_len = encoder
    .encode(&new_instruction, offset as u64)
    .map_err(|s| anyhow!(s))?;

// ... snip ...

text_copy
    .data
    .splice(
      offset..(offset + new_len), encoder.take_buffer());
```

steg86: results

binary diff:




```
$ cargo install steg86

$ echo "hello!" > message.txt

$ steg86 embed \
  /bin/bash test.steg \
  < message.txt

$ steg86 extract test.steg
hello!
```

steg86: next steps

- other tricks
  - `test reg1, reg2` is the same as `test reg2, reg1`
  - same with `xchg`
  - multi-byte `nops`
- deficiencies
  - code/data disambiguation is impossible in the general case
    - many open problems in program analysis reduce to this
    - partial workarounds: CFG recovery, jump table identification
  - very easy to detect (real compilers stick to one encoding)

thank you!

slides: yossarian.net/publications#munich-rust-2020

github: woodruffw/steg86

blog post: hiding messages in x86 binaries using semantic duals

contact: william@yossarian.net / @8x5cIPW2

links and prior work

- A86 assembler (1980s!)
- HYDAN (2004)
- ARMaHYDAN (2019, PoC||GTFO)