Malware Devirtualization with Predicate Synthesis

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A False History of Binary Obfuscation

Reverse Engineering		Obfuscation
Static analysis	→	Packing
Dynamic analysis	←	Evasion
Concolic analysis	→	Virtualization
Devirtualization	←	Opaque predicates
Predicate synthesis	→	…

→ = ¨severely hindered by¨

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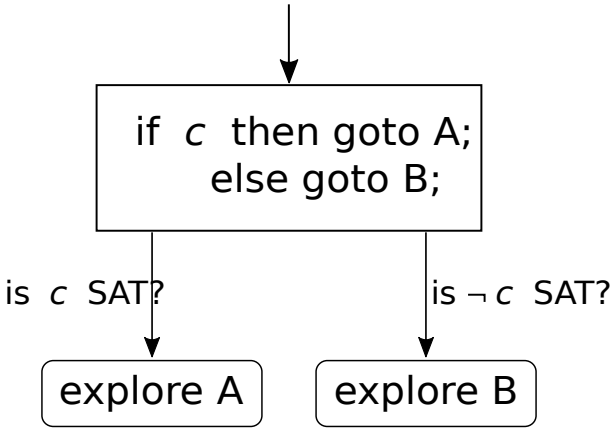
Concolic (CONCrete-symbOLIC) Analysis

- Static symbolic analysis
- To increase code coverage:
  - SMT solver to determine conditional satisfiability
  - Concretize traces as necessary (less static)



- Angr: Concolic Binary Analysis Engine

http://angr.io/

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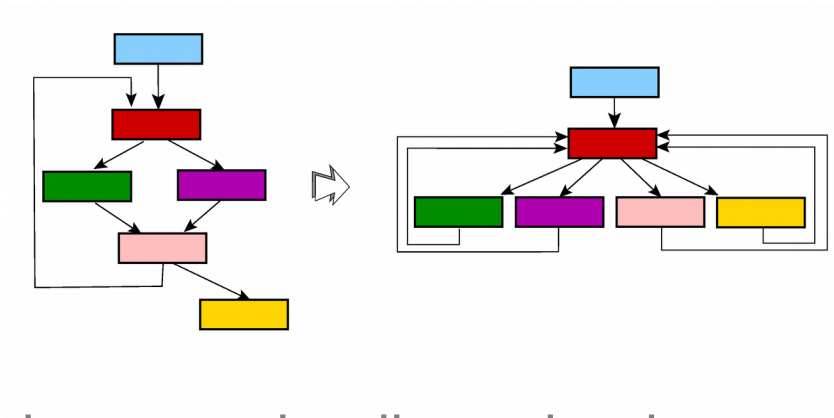
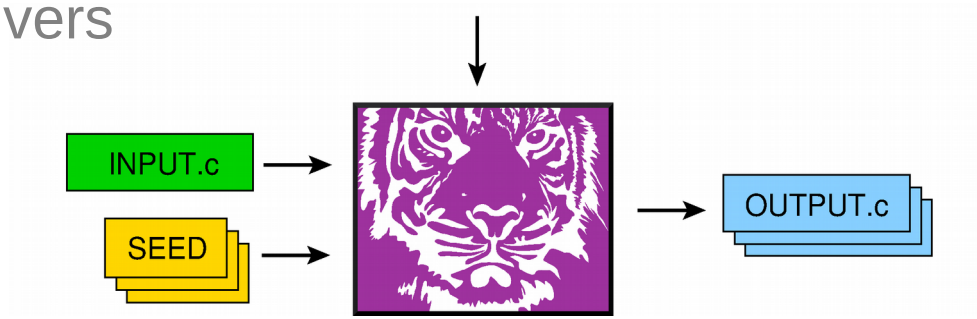
Virtualization

- Control Flow Flattening
- Embeds an intepreter in the code and uses it as dispatcher



- Hinders concolic analysis because the dispatcher is too complex for SMT solvers

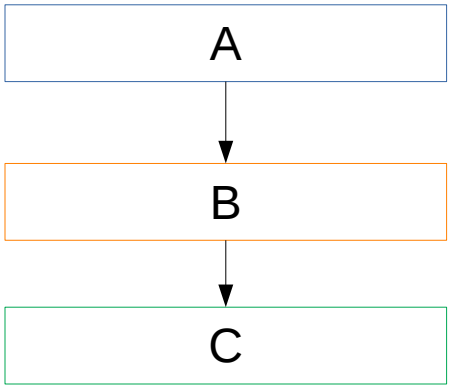


- Tigress: source-to-source virtualizer

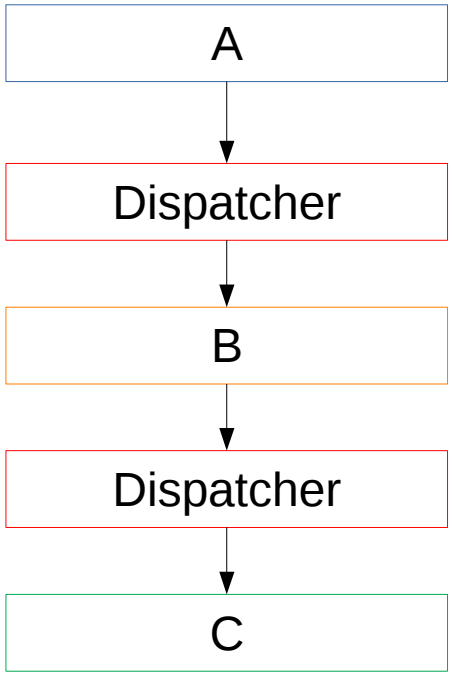
http://tigress.cs.arizona.edu/

Virtualization

Original trace



Virtualized trace



The dispatcher:

- computes the next operation's address
- Is too complex to be analyzed symbolically

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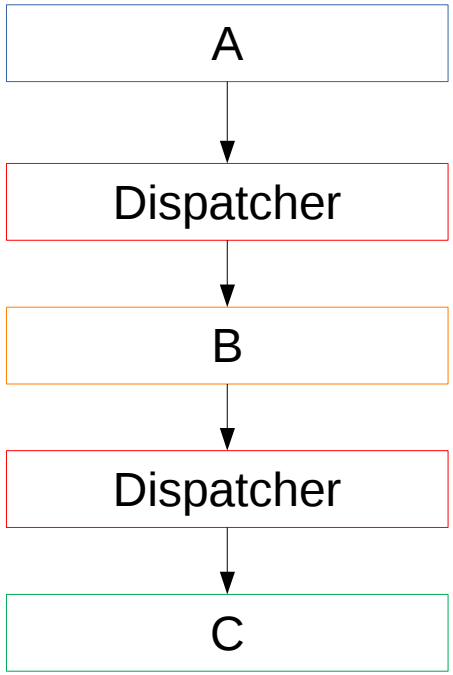
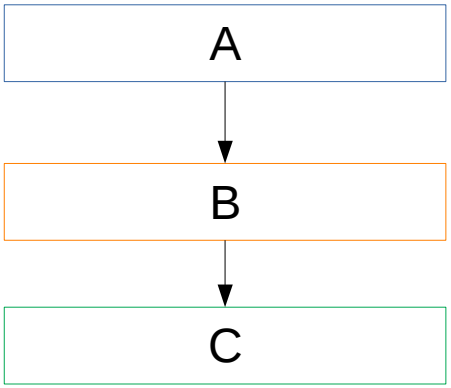
Devirtualization

Virtualized trace



Reconstructed trace



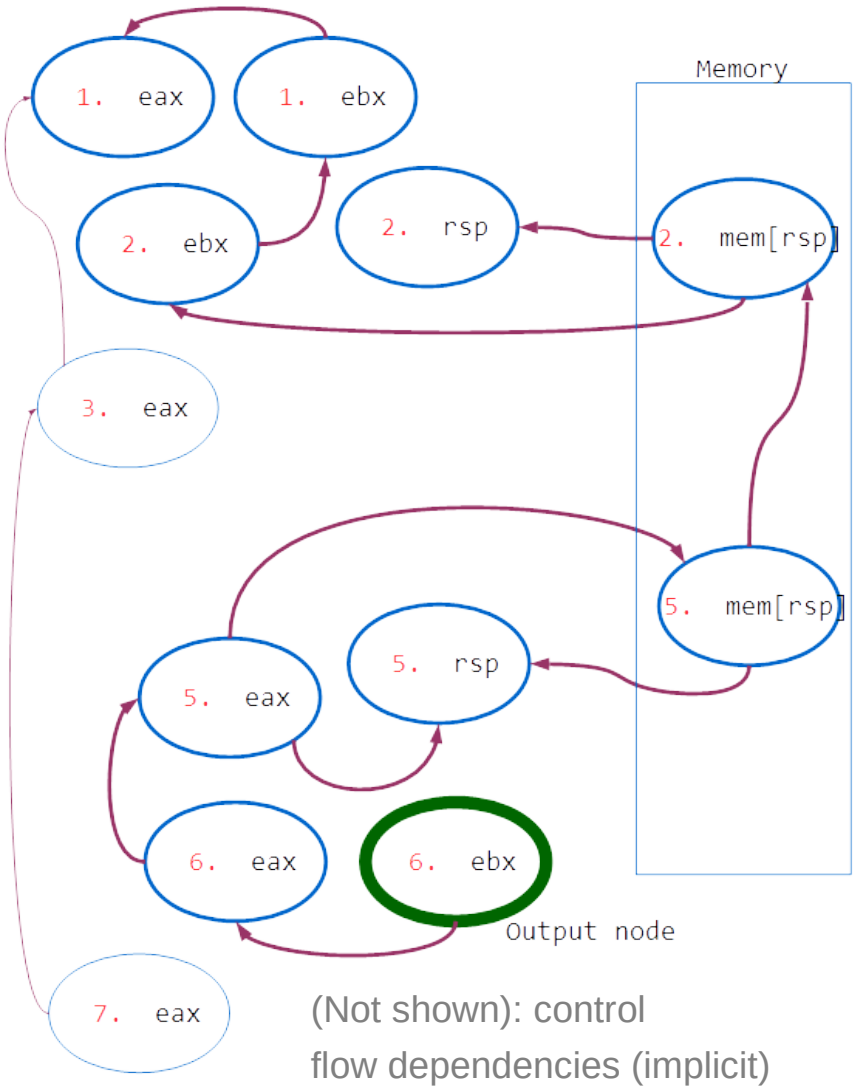
Goal: identify and remove dispatcher

Devirtualization: Data Dependency Graph

Example code:

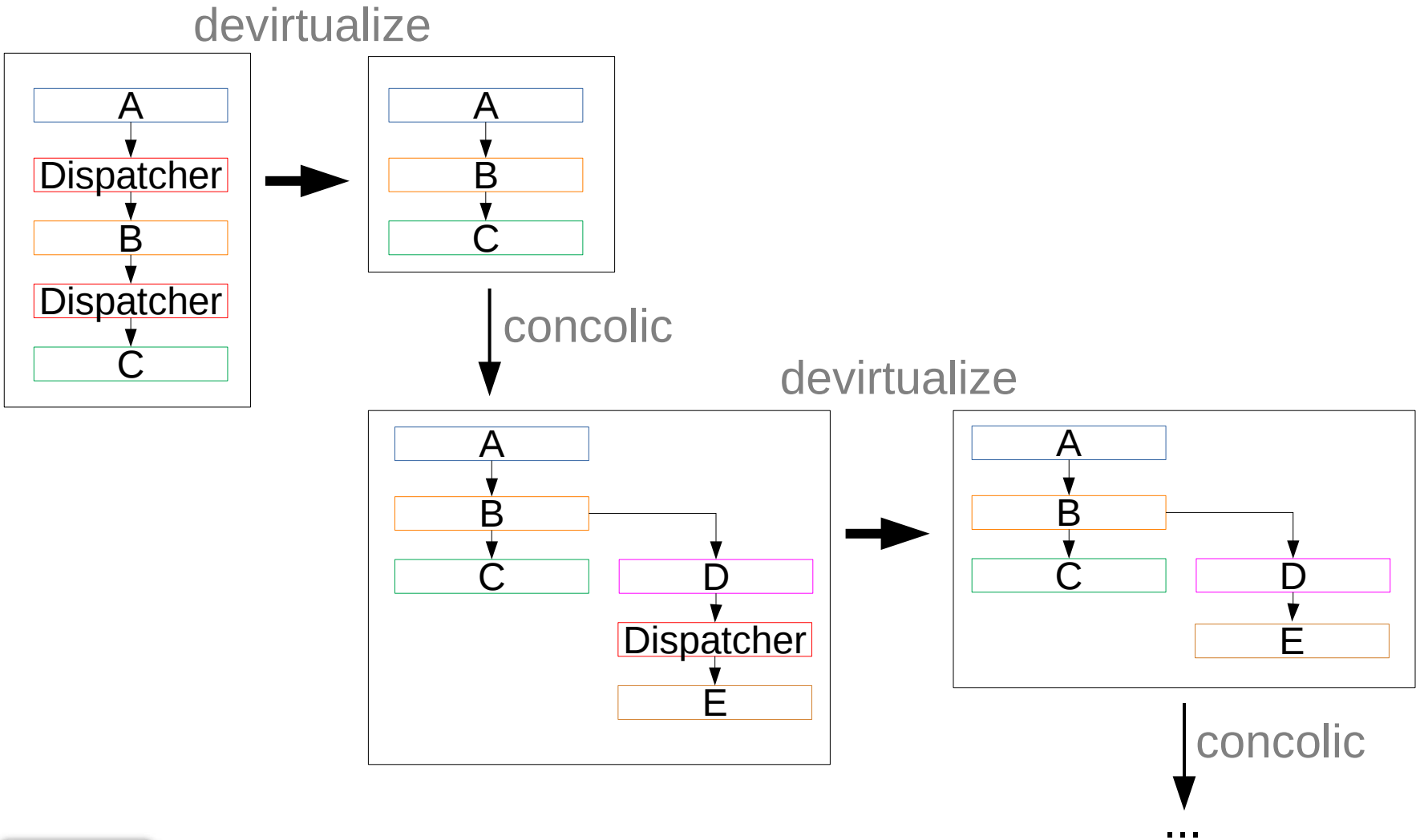
1. addl eax, ebx // ebx = ebx + eax
2. pushl ebx // mem[rsp] = ebx
3. subl 8, eax // eax = eax - 8
4. jmp _fun // jump to _fun
_back:
5. popl eax // eax = mem[rsp]
6. addl eax, ebx // esi = esi + eax
_fun:
7. movl 1, eax // eax = 1
8. jmp _back // jump back to _back

Bolded instructions/nodes/arrows:
Keep in simplified program
Underlined instructions:
Implicit dependencies, also kept



(Not shown): control flow dependencies (implicit)

Devirtualization: Traces to Programs



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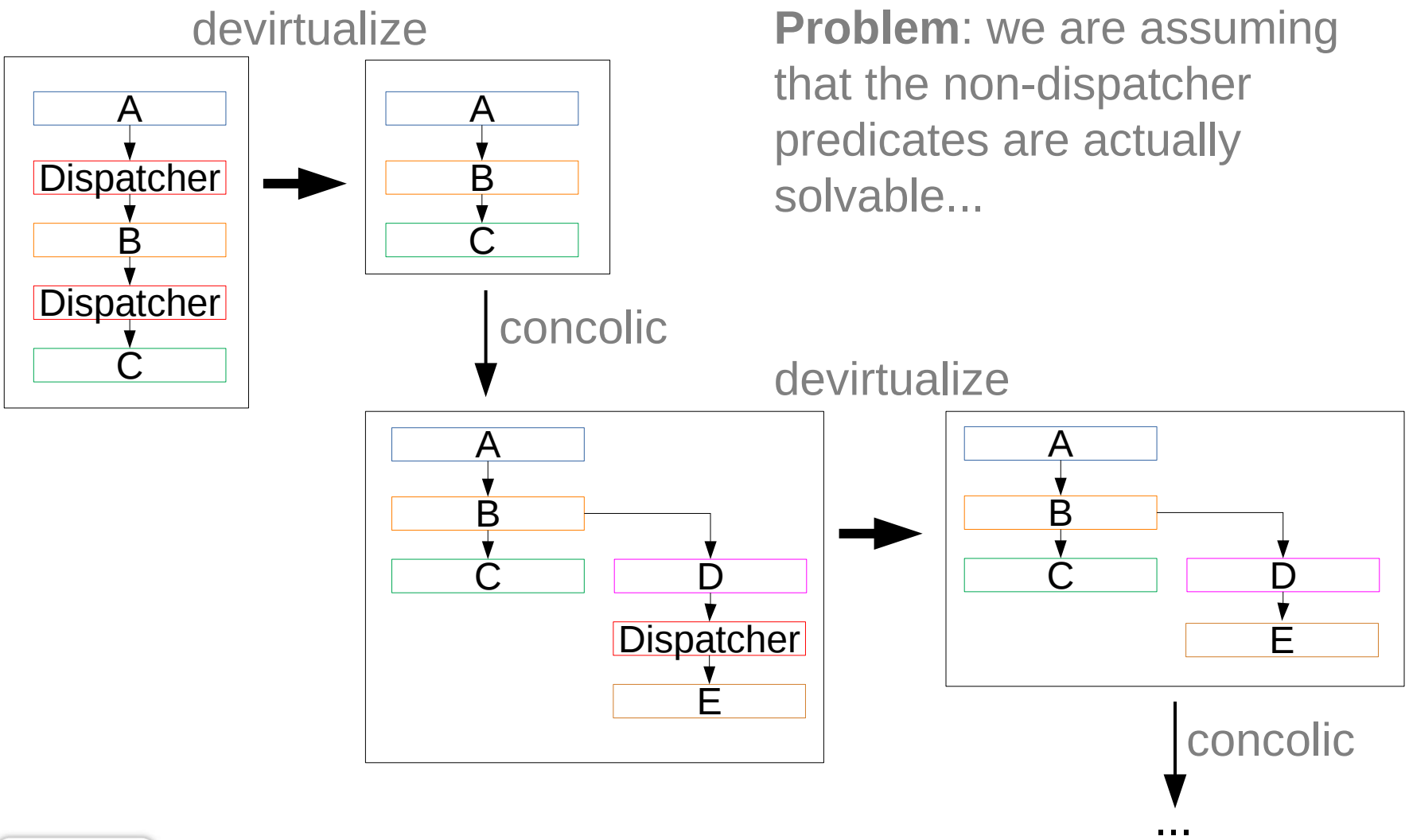

Problem: we are assuming that the non-dispatcher predicates are actually solvable...

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Opaque Predicates

These predicates are equivalent:

- `if (x==4)…`
- `if (x^3 – 4x^2 + 6x – 24 = 0)…`
- `if(sha3(x)==37f558134baa535903c6a88931c8122e334368bf951f2cada569b11774ef9795ef6d2ac961d13ee44a0c837db3817bb9db68ac3bdfb8b19a1308618484a9da8f)…`

Note that they are **point functions**:

- true for *one* input, false for *any other*
- SMT solvers often report point functions as constant false

Mixed Boolean Arithmetic Obfuscation

1) Wrap conditional *c* in polynomial function *F* <u>of degree *d*</u>
2) Add linear identities $e_1 \ldots e_n$ multiplied by $a_1 \ldots a_n$
3) Wrap all in F^{-1}

original obfuscated

$$c = F^{-1}\left(\sum_i a_i e_i + F(c) \right)$$

Y. Zhou, A. Main, Y. X. Gu, H. Johnson, *Information hiding in software with mixed Boolean-arithmetic transforms*, WISA'07

Mixed Boolean Arithmetic Obfuscation

original

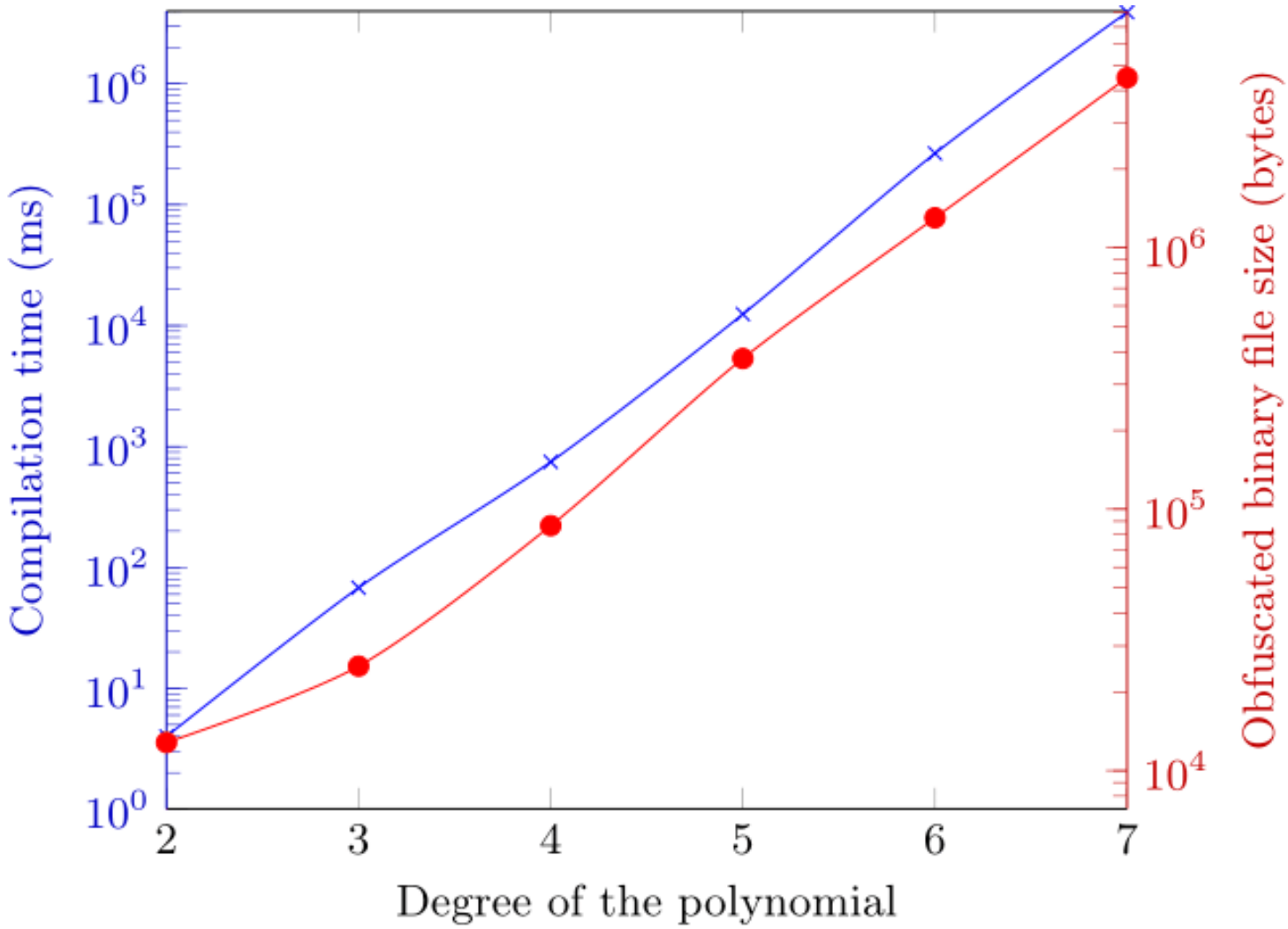
```
if (IN == 0x87654321)
..
else
..
```

obfuscated (d = 2)

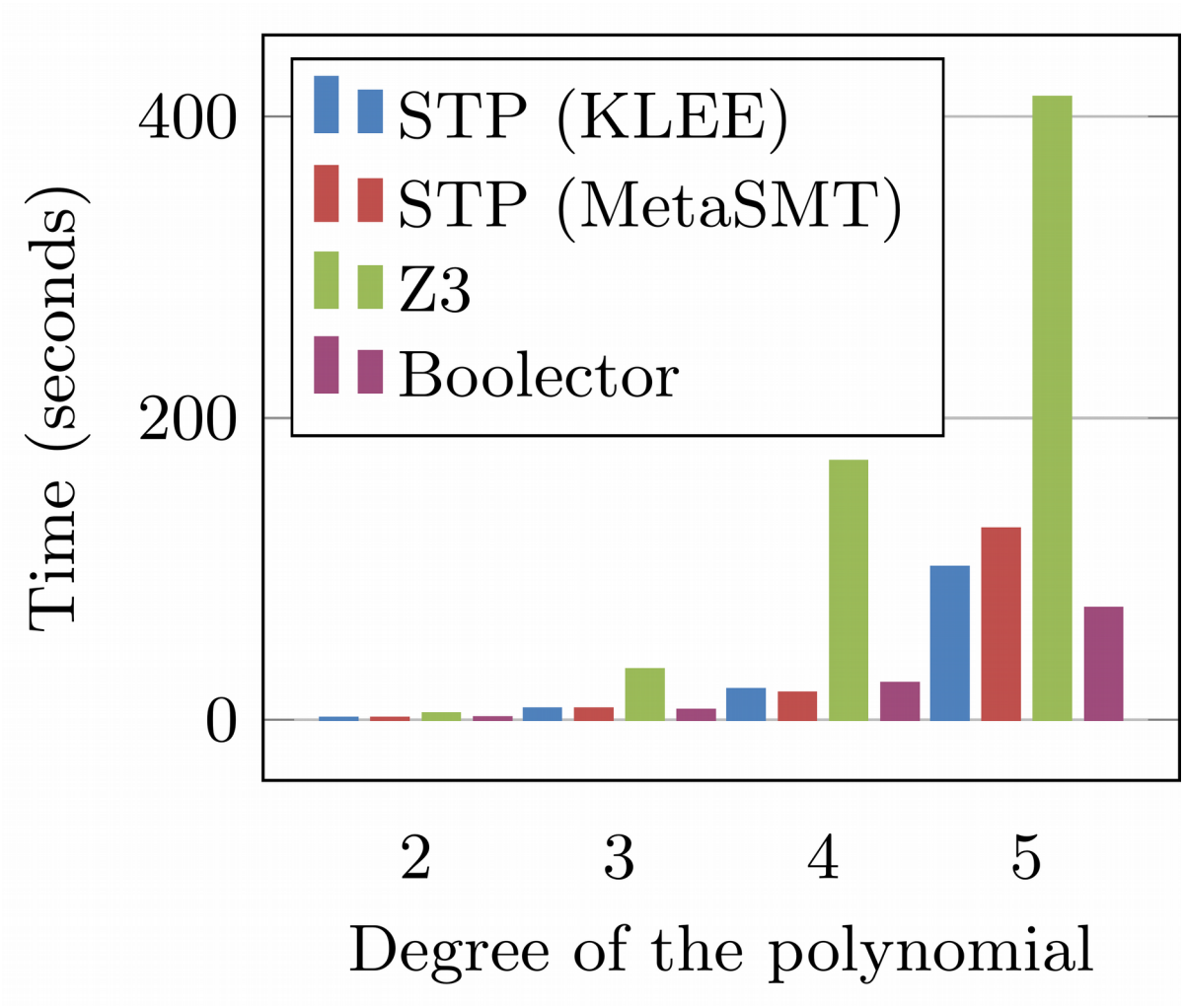
```
a = x * (x1 | 3749240069);
b = x * ((-2*x1 - 1) | 3203512843);
d = ((235810187 * x + 281909696 - x2)
      ^ (2424056794 + x2));
e = ((3823346922 * x + 3731147903 + 2 * x2)
      | (3741821003 + 4294967294 * x2));

f = 2284837645 + 272908530*a + 136454265*b
      + 409362795*x + 135832444*d
      + 4159134852*e + 415760384*a*a
      + 415760384*a*b + 1247281152*a*x
      + 2816475136*a*d + 1478492160*a*e
      + 3325165568*b*b + 2771124224*b*x
      + 1408237568*b*d + 2886729728*b*e
      + 4156686336*x*x + 4224712704*x*d
      + 70254592*x*e + 1428160512*d*d
      + 1438646272*d*e + 1428160512*e*e;
if (IN == f )
..
else
..
```

Y. Zhou, A. Main, Y. X. Gu, H. Johnson, *Information hiding in software with mixed Boolean-arithmetic transforms*, WISA'07

Cost of MBA Obfuscation



Attacking MBA Obfuscation with SMT Solvers



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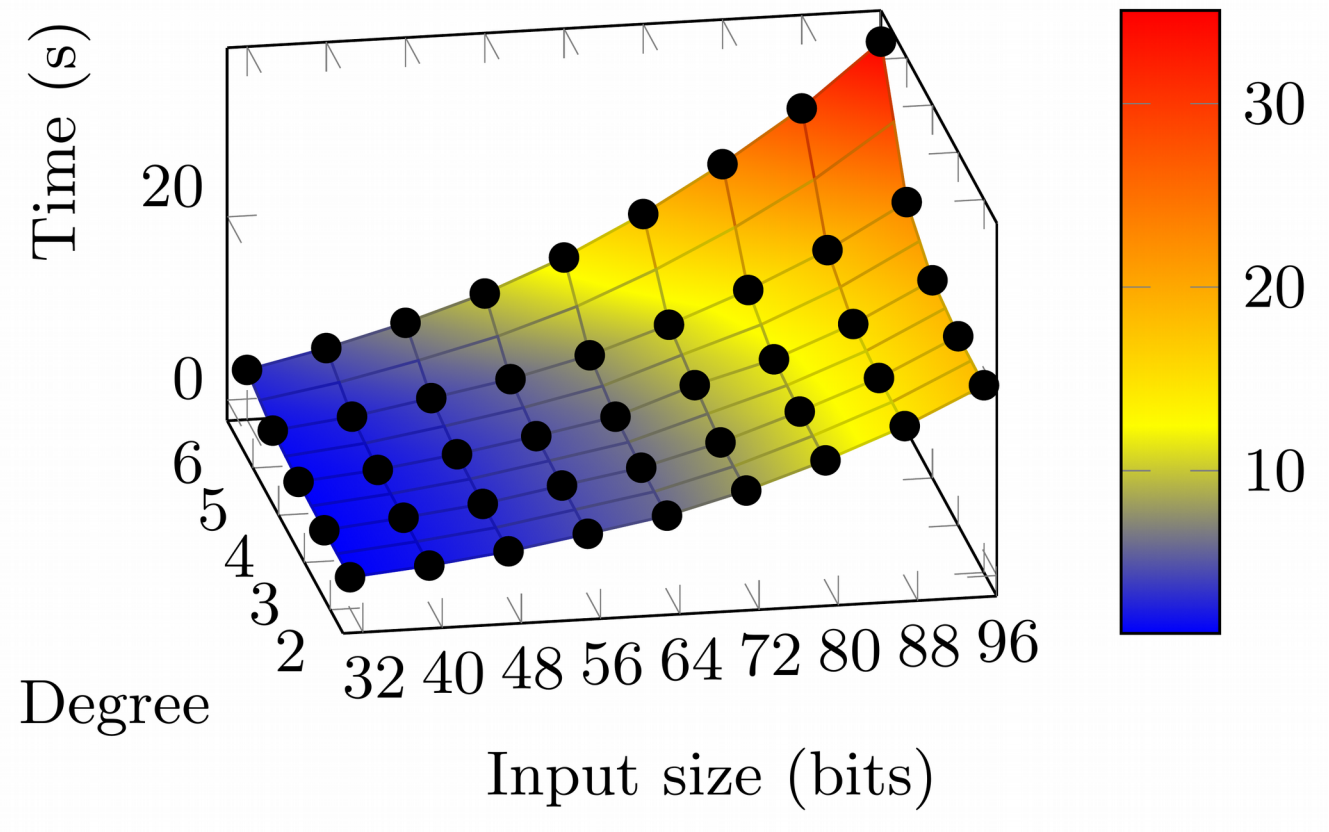
Predicate Synthesis

- Synthesis method: drill-and-join (efficient Reed-Muller)
- Obfuscated conditional interrogated as **black-box** oracle
- Conditional function reconstructed
  - Not only satisfiability
  - Smaller constraints
  - Can be reinjected in the code
- Depends on input size

R. Balaniuk, *Drill and join: A method for exact inductive program synthesis*, LOPSTR'14

Attacking MBA Obfuscation with Synthesis



Insight Gained from Predicate Synthesis

- Synthesis is more expensive than satisfiability
- … so why is synthesis faster in this case?
  - based on a ¨smart brute force approach¨
  - black box: does not start by analyzing the actual formula
  - better for simple formulas written in a complex manner?
- Probably not better than SMT in general
- Seems **SMT with targeted brute forcing** could improve concolic analysis

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Conclusions

- Virtualization can be countered by cycles of data dependency analysis and concolic analysis
  - Note: the dispatcher is too complex to hope to solve/simplify/synthesize it directly
- Opaque predicates can be synthesized to analyze multiple traces
  - Synthesis provides simplified predicate, can be reinjected
  - Effectiveness of synthesis suggests that SMT solving equipped with brute force would be more effective

Thank you for your attention!