Overview and Usage of Binary Analysis Frameworks

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whoami

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Who we are

- Germany-based ERNW GmbH
  - Independent
  - Deep technical knowledge
  - Structured (assessment) approach
  - Business reasonable recommendations
  - We understand corporate
- Blog: *www.insinuator.net*
- Conference: *www.troopers.de*

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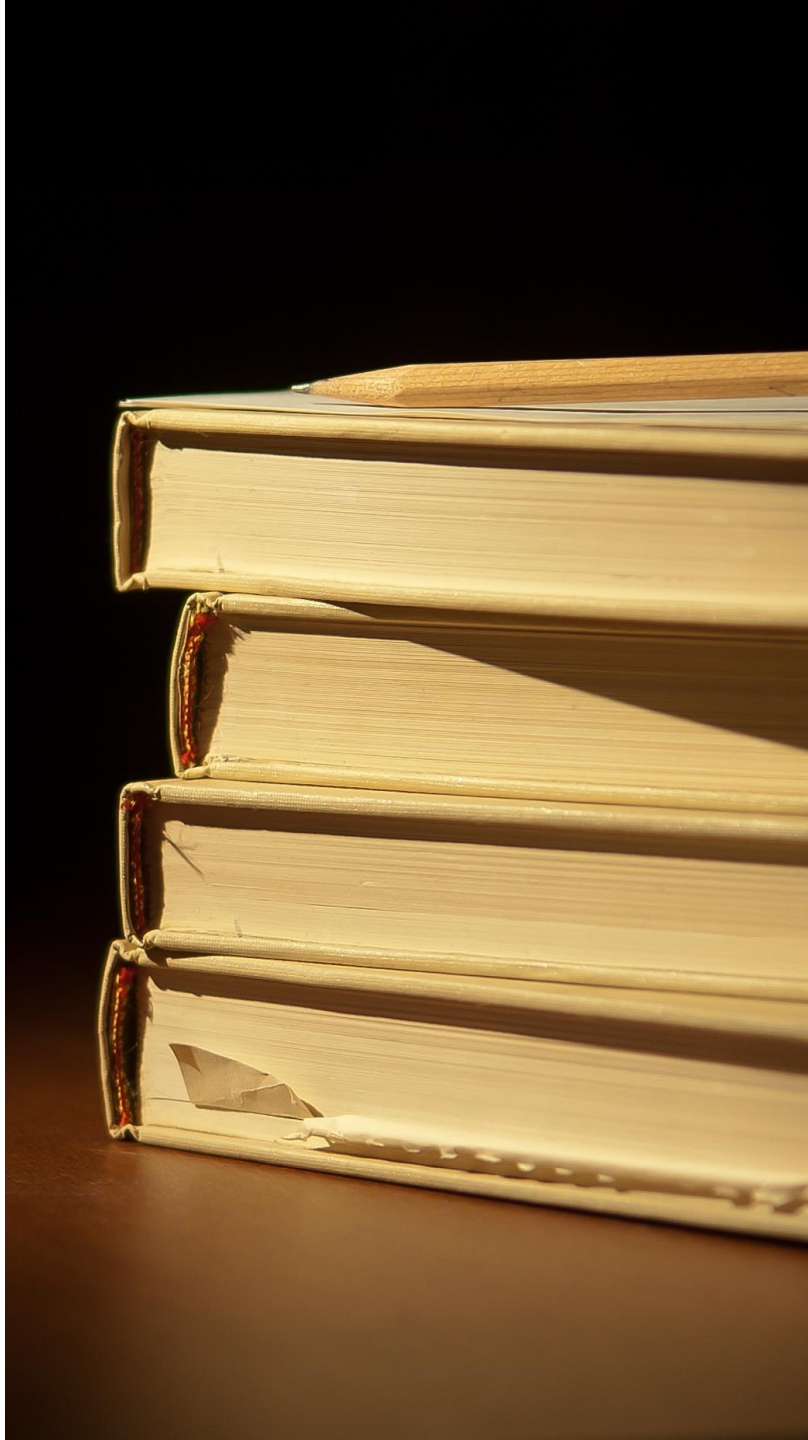
Agenda

What actually is automated analysis?

How does it work?

What else are some of the frameworks capable of? (In this case angr)



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What is Automated Binary Analysis?

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What is Automated Binary Analysis?

-> Binary Analysis performed by algorithms

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Wait, isn't that impossible?

- It's impossible to generally tell if a program halts for a given input (Halting Problem)
- Also Rice's Theorem
- Also, what exactly are we even looking for?
  - Crashes?
  - Memory Corruptions?
  - Logic Errors?

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Bit of History

- The ideas themselves are 40 years old
  - Robert S. Boyer and Bernard Elspas and Karl N. Levitt, SELECT--a formal system for testing and debugging programs by symbolic execution, 1975
- Analysis is resource intensive
  - Cray-1 supercomputer from 1975 had 80MFLOPS (8MB of RAM)
  - iPhone 5s from 2013 produces about 76.8 GFLOPS (1GB of RAM)

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DARPA CGC

- Task: Develop a “Cyber Reasoning System”
- Big push in moving the ideas from academia to practicability
- Qualification Prize: $750,000
- Final Prizes:
  1. $2,000,000
  2. $1,000,000
  3. $750,000

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DARPA CGC

- CRS needs to:
  - Find vulnerabilities
  - Patch them
- Ran on 64 Nodes, each:
  - 2x Intel Xeon Processor E5-2670 v2 (25M cache, 2.50GHz) (20 physical cores per machine)
  - 256GB Memory
- 7 finalists, winner competed at DEFCON CTF
- It was better than some of the human teams some of the time

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How do they work?

Overview of the basic concepts

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Intermediate Representations

- What do we actually analyze?
- Every architecture is different
  - ➡ Common Representation
- Typical case of too may standards
  - VEX IR (used by Valgrind and angr)
  - Binary Ninja IR
  - LLVM IR
  - So many more

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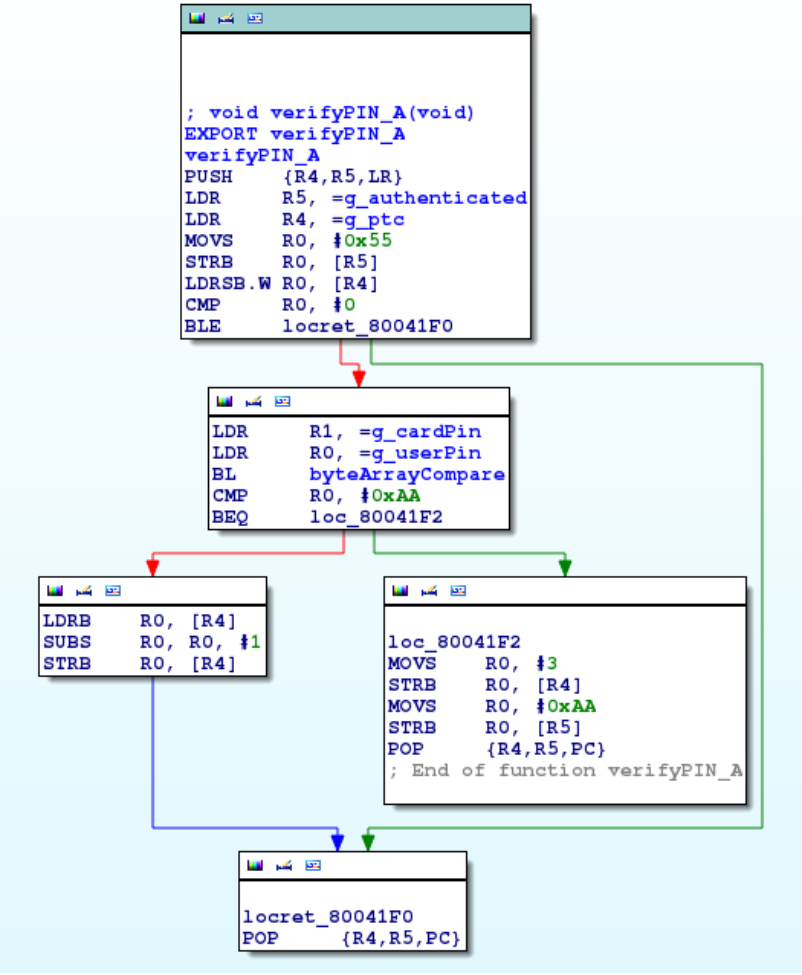
CFG Recovery

- Recursively build a graph with jumps as edges and basic blocks as nodes
- Easy with calls and direct jumps
- But what about "jmp eax"?
  - Jump table
  - Callbacks/Higher Order Functions
  - Functions of Objects in OOP
- "Graph-based vulnerability discovery"



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Value-Set Analysis

- Approximate program states
- Values in memory or registers
- Reconstruct buffers
- Can be enough to detect buffer overflows
- Research paper is in the last slide (18 Pages)

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Data-Flow Analysis/Taint Analysis

- Track where data ends up
- Data dependencies
- Discover functions that handle user input
- Different granularity:
  - Bits
  - Bytes

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Constraint Solving

- A LOT of Math involved
- Highly simplified:
  - a = 5
  - b = 15
  - x < b && x > a
  - x = ?

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Z3 Theorem Prover

- Developed by Microsoft Research
- Microsoft uses it to formally verify some parts of their products
  - Windows Kernel
  - Hyper-V
- MIT License
- Provides a SMT Solver

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Z3/Claripy Example

- Claripy is the abstraction layer for constraint solvers like Z3 used by angr
- Only exposes needed functionality for binary analysis

DEMO

Symbolic Execution

- Symbolic instead of concrete variables
- Following example shamelessly stolen from the angr presentations


```
x = int(input())
if x >= 10:
    if x < 100:
        print "You win!"
    else:
        print "You lose!"
else:
    print "You lose!"
```

State A
Variables x = ???
Constraints ------

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```
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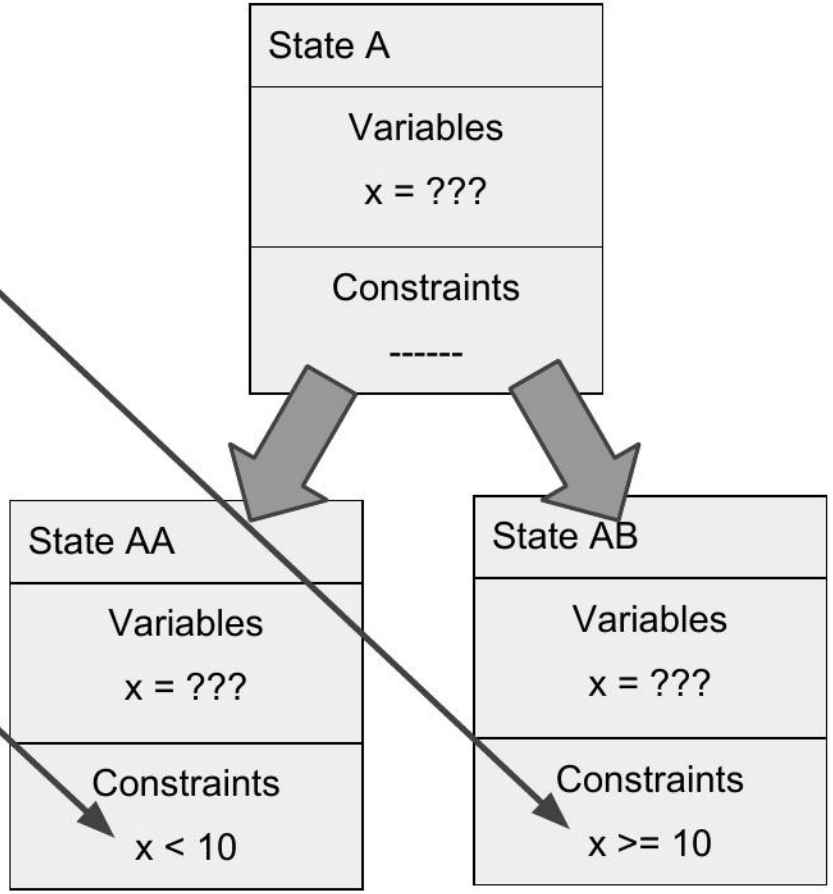

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x = int(input())
if x >= 10:
    if x < 100:
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    else:
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else:
    print "You lose!"
```

State AA
Variables x = ???
Constraints x < 10

State AB
Variables x = ???
Constraints x >= 10

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```
x = int(input())
if x >= 10:
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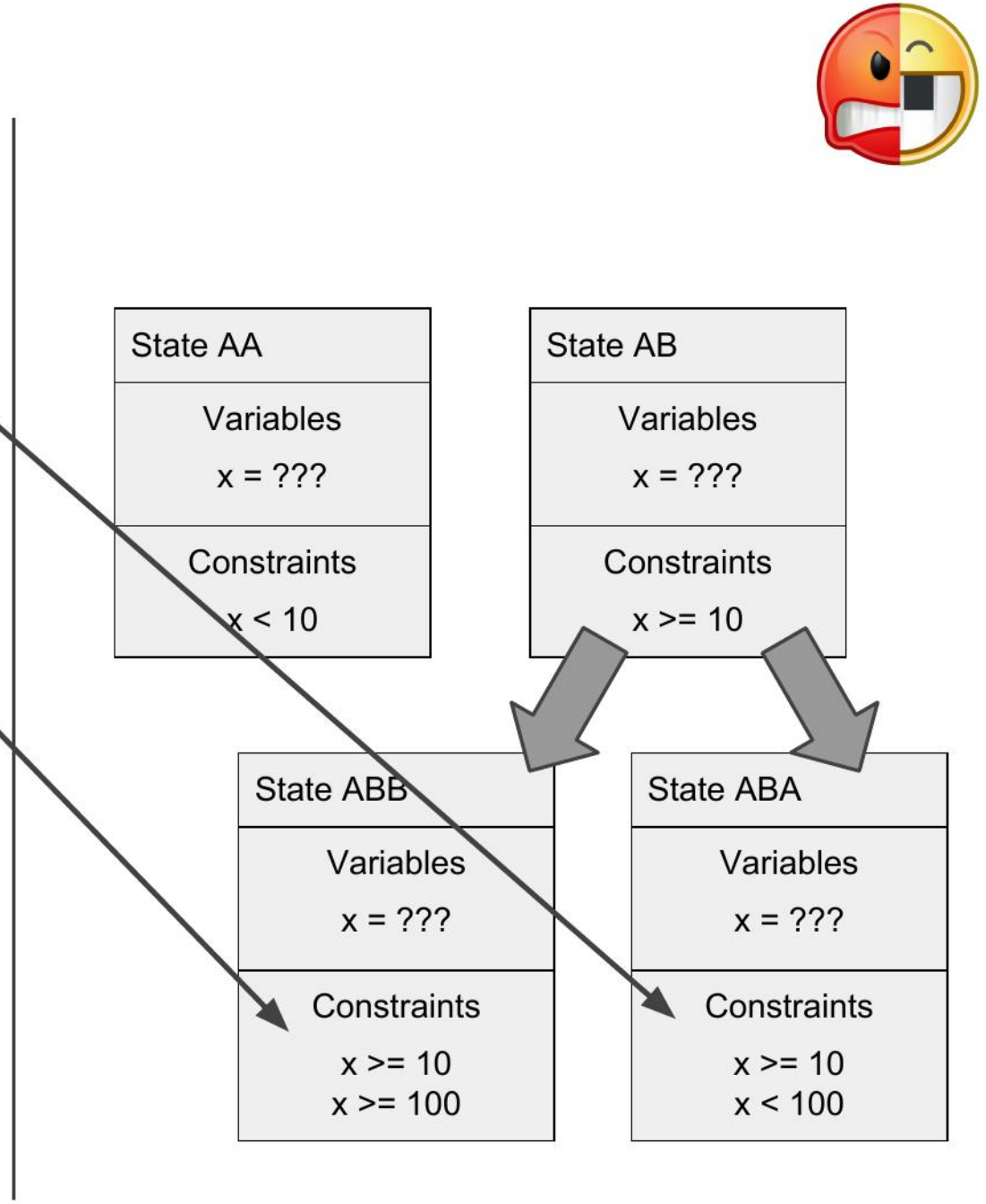

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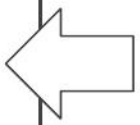

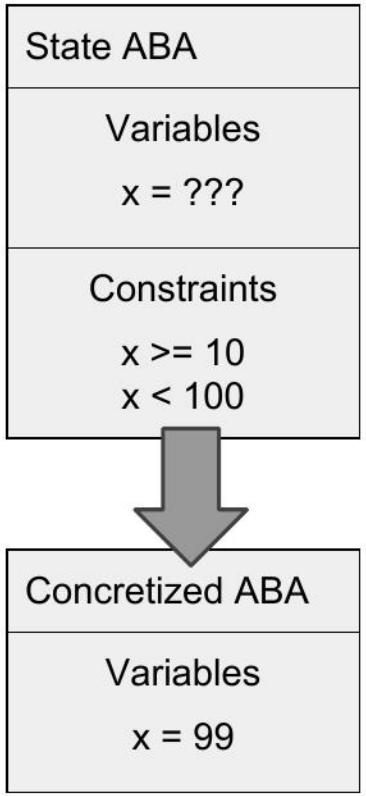

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AST

- Abstract Syntax Tree
- Basically a representation for the constraints from the previous slide

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Side Note: LLVM Compiler Infrastructure

- Own IR (LLVM IR)
- Own symbolic execution engine (KLEE)
- Own constraint solver (Kleaver)

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What to do with all this?

- These techniques don't scale
  - State Explosion
  - Constraint solving is generally NP-Complete
- Combine with something really smart but slow: a human
- Combine with something really dumb but fast: a fuzzer

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Augmented Fuzzing

- Taint Analysis to discover what branch depends on what input
- Symbolic Execution with constraint solver to build input to take that branch

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angr

- Most beginner friendly of all tools
- Written in Python
- Good Documentation
- Plenty of available research
- Used by Mechaphish (3rd at Darpa's CGC)
- Developed at University of California, Santa Barbara
- Even the CIA uses angr!

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Triton

- x86 and x86_64 only
- Designed as a library (LibTriton.so)
  - Should be easier to integrate into C Projects
- Has python bindings
- Not focused on automating but assisting
- Sponsored by Quarkslab

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Others

- Bitblaze
  - University of California, Berkeley
- bap: Binary Analysis Platform
  - Carnegie Mellon University/ForAllSecure
  - Written in OCaml
  - Used by Mayhem (1st Place at Darpa's CGC)
- Miasm

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Comparison with other projects

Items	angr	KLEE	BAP	BitBlaze	S2E	Triton	Microsoft SAGE	Mayhem
Work on binaries w/o src								
Online symbolic execution								
Offline symbolic execution		?		?			?	
Cross-platform analysis								
Static analysis								
Multi-platform/arch support								
Open source								
Actively maintained					?			
Free license								

Overview of Frameworks and Projects

Source: Angr Tutorial (so obviously biased)

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Installing Angr

- My setup: Vagrant Box ~~with Archstrike Repositories~~ (turns out that's outdated)
  - pacman –S angr
- Alternatives:
  - Official Docker Image
  - pip2 install angr

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Foreign Function Interface

- Automagically import binary functions
  - angr detects calling convention
  - Maps python types to binary representation
- Call them from python
  - With concrete values
  - With symbolic value

```
>>> import angr
>>>b=angr.Project('/path/binary')
>>>f = b.factory.callable(address)
>>>f?
Type: Callable
[...]
Callable is a representation of a function in the binary that can be
interacted with like a native python function.
[...]
```

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Inversing Functions

- Get an input so that a function returns a certain value
- Function can be from Python or from binary(see FFI)
- f(x,y) -> (x*3 >> 1) * y
- f(?,0x42) - > 0x76E24

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Inversing Functions

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Inversing Functions

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- f(x,y) -> (x*3 >> 1) * y
- f(?,0x42) - > 0x76E24

- We got two possible solutions
  - 0x1337 (intended)
  - 0x55555555555688c which returns 0x21000000000076e24
    -> Integer Overflow

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Automagic Solving of Crackmes

- Binary that takes some user input
  - stdin
  - argv
  - Some file
- Checks it against constraints
- Determines if it's valid

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Automagic Solving of Crackmes

- Binary that takes some user input
  - stdin
  - argv
  - Some file
- Checks it against constraints
- Determines if it's valid

- We just declare that input as symbolic
- Choose a starting point and explore the possible paths from there
- Solve for an input that brings us down the wanted path ➡ that's the solution

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Debugging capabilities

- Breakpoints with callbacks before or after:
  - Instructions or address
  - Memory read/write
  - Register read/write
  - Many others
- Hooks
  - Optimized libc functions
  - Own Python Code

```
>>> import angr, simuvex
>>>b=angr.Project('/path/binary')
>>> s = b.factory.entry_state()
>>> def debug_func(state):
...         print 'Read',
state.inspect.mem_read_expr, 'from',
state.inspect.mem_read_address
>>> s.inspect.b('mem_write',
when=simuvex.BP_AFTER, action=debug_func)
```

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Anti-Anti-Debugging

- angr is not a debugger
  - Most tricks wont work
  - Might accidentally break angr in other ways
- Simuvex or Unicorn can be used as an emulator
  - Breakpoints without the program noticing
  - Invisible Hooks
- Overall it needs a different approach

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Angr Cheat Sheet

- Currently developing an angr cheat sheet
  - Common Commands to look up
  - Features that are hidden somewhere in the docs
- Release $soon
  - Probably as part of the angr/angr-doc repo

Other Tools to know

- Unicorn Emulator
  - Emulate all the architectures!
- Capstone
  - Disassemble all the architectures!

- Interesting Mechaphish Components
  - angrop (generates ROP Chains)
  - Driller (Augmented Fuzzing)
  - Everything in https://github.com/mechaphish

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Thank you for your attention

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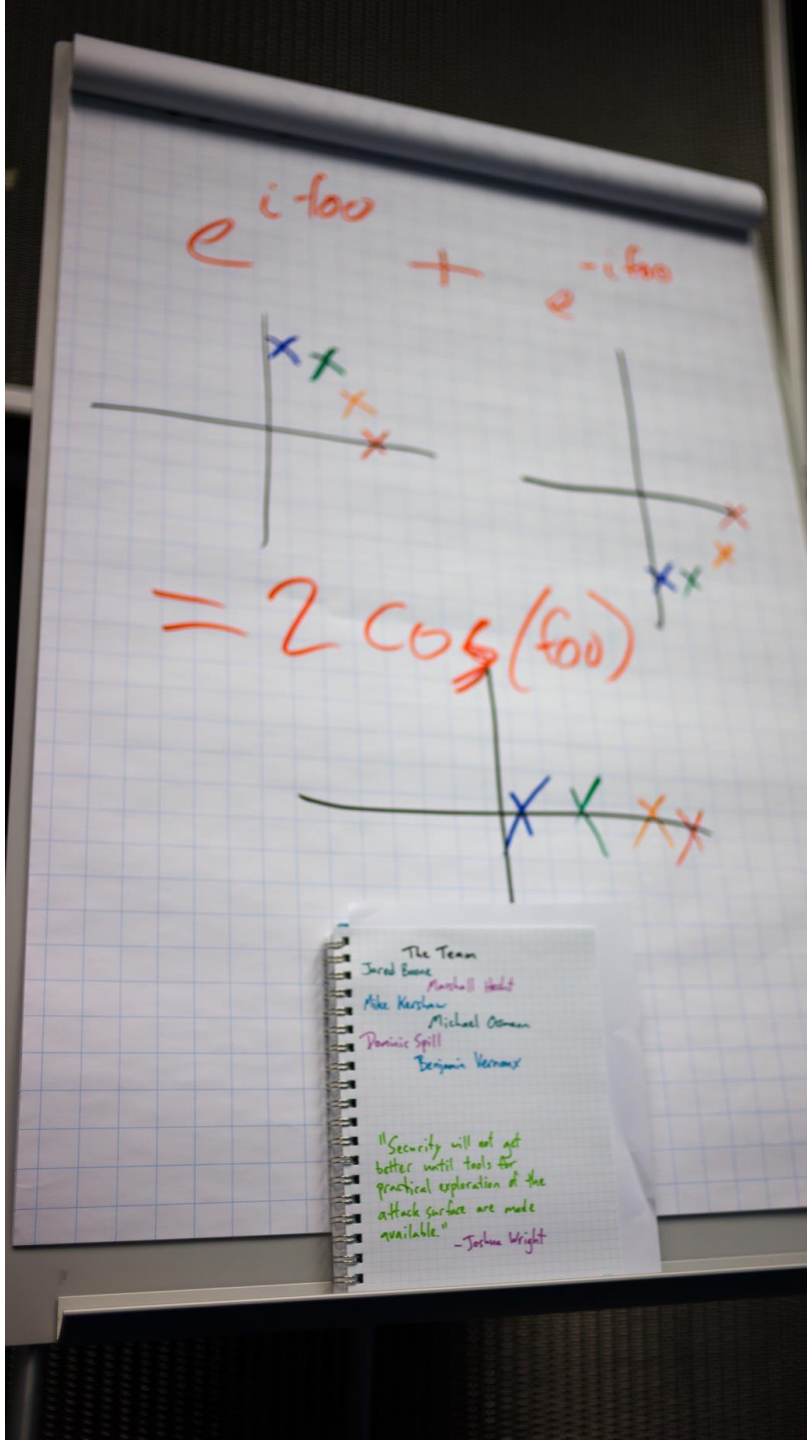

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References & Literature

- “SoK: (State of) The Art of War: Offensive Techniques in Binary Analysis”
- https://docs.angr.io/
- VSA:

  Analyzing Memory Accesses in x86 Executables

  Gogul Balakrishnan and Thomas Reps

  Comp. Sci. Dept., University of Wisconsin; {bgogul,reps }@cs.wisc.edu