Theory of Obfuscation and its practical applications

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What is Obfuscation? (Intuitively)

- A compiler; output is `obfuscated' program
  - Obfuscated program has same functionality as original, and similar performance
- Intuitive Security Goals:
  - Hide program
  - Hide secrets inside a program
  - Prevent modification of program
- Used to protect program running in untrusted PC:
  - DRM, eVoting, `trusted' TCP, policy enforcement, …

Obfuscation: Theory vs. Practice

- Practice
  - Obfuscation widely used
  - Lots of skepticism: security, impossibility alike
- Theory
  - Precise definitions (several variants)
  - Impossibility results
  - Positive (possibility) results
  - Related tools
- This talk: review of theory and its applications

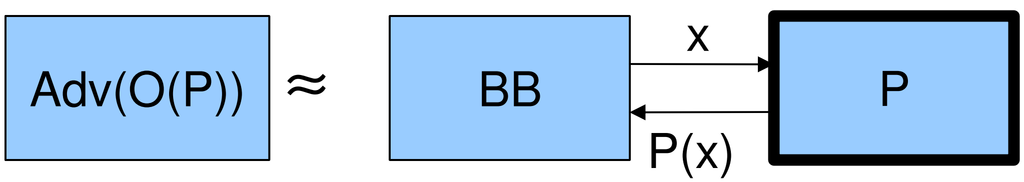
Theory of Obfuscation: Outline

- Introduction
- Definition: Virtual Black-Box Obfuscation
- Impossibility (negative) result
- Positive results and challenges
- Beyond black-box obfuscation
  - Non-malleability
  - Verifiable non-malleability
- Few related goals and tools
  - Public-key Obfuscation
  - WBRPE (White-Box Remote Program Execution)
- Conclusions and open questions

Definition: Virtual Black-Box Security

[Barak et al., 2001]

- An obfuscator $\mathcal{O}$ is an efficient compiler that on input *P* outputs $\mathcal{O}$(*P*), such that:
  - Functionality:
    - For every *P*, $\mathcal{O}$(*P*) computes the same function as *P*
    - Program $\mathcal{O}$(*P*) is slightly slower (and larger) than *P*
  - Virtual Black-Box:
    - Whatever Adv can compute with obfuscated code *O*(*P*)
    - A `black-box Adv` BB can compute by only <u>calling</u> *P*



Example: Obfuscating a Point Function

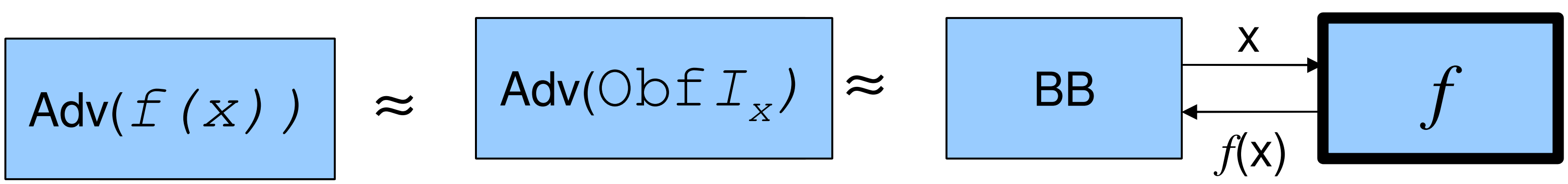
[Canetti97]

- Point function $I_x(w) = \{1 \text{ if } w=x, 0 \text{ otherwise}\}$
- Obfuscate I_x with perfectly one-way function f

  Let $y=f(x)$

```
Program ObfIx (w):
  { if y=f(w) return 1 else return 0 }
```

- Intuitively: $y=f(x)$ reveals no more info than black-box access to I_x



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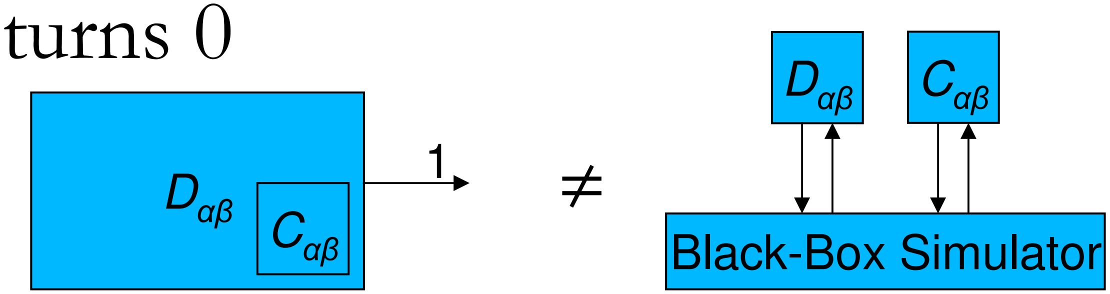
- Intuitively: $y=f(x)$ reveals no more info than black-box access to I_x
- But: this is a <u>very</u> specific obfuscator...
- Is there general obfuscator (for all programs)?

Barak's Unobfuscatable Program

- Is there a general obfuscator (for all programs)?
- [Barak et al, 01] No!
- They present a <u>program</u> P that cannot be obfuscated
  - Hence: no obfuscator for <u>all</u> programs!
- First, they present <u>two</u> programs C, D and then transform it into P
- Let *C*, *D* be two programs specified by two secret strings (α,β)
  - Upon input x, $C_{\alpha\beta}$ returns β if x=α and returns 0 (of same length as β) otherwise
  - Upon input a program, D runs it with input α, and if the result is β, returns 1 otherwise 0

No Virtual Black-Box Compiler for Every Program

- Obfuscate C and D, to obtain $O(C_{\alpha\beta})$ on $O(D_{\alpha\beta})$
- Evaluating $O(C_{\alpha\beta})$ on $O(D_{\alpha\beta})$, always results in 1
- Black-box access to C and D is similar to black-box access to D and some program that always returns 0



- To extend the impossibility to single program, define $P=D(C)$

No Virtual Black-Box Compiler for Every Program

- So: some programs that cannot be obfuscated according to virtual black box definition
- So what? Practical implication? Options:
  - Ignore…?
  - Consider alternative, e.g., weaker definitions
    - None so far?
  - Consider obfuscation of specific programs
    - Which? Few `positive results`...
      - E.g., point function obfuscation, re-encryption

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- Related goals and tools
  - Public-key Obfuscation
  - Secure function evaluation (SFE) and Garbled Circuits
  - Cryptocomputing and homomorphic encryption
- Conclusions and open questions

Obfuscator for Shared-Key Encryption

- Let (E_K, D_K) be shared key encryption
- [Hofheinz, Malone-Lee, Stam07]: there exists obfuscatable encryption schemes
  - $O(E_K)$ gives <u>public</u> key encryption!
- How? Let (E',D') be <u>public</u> key encryption
- Define shared key (E,D) scheme with key $(e.d)$. (both keys of public key scheme)
- Then $O(E_{e,d})=E'_e$ is obfuscation of (E,D)...
  - But again, is this `real' obfuscator??

Challenge: Obfuscatable Program

- All `positive results` use trivial obfuscators
  - Based on properties of program
- Challenge: find programs P={P_K} s.t.:
  - Impossibility does <u>not</u> (seem to) hold for P
  - Yet, no `trivial' obfuscator for P
    - Preferably, non-trivial obfuscator – e.g. one that may work for some other programs too...

Non-Malleable Obfuscation

- Ensure non-malleability of obfuscated program
  - Alice obfuscates a decryption algorithm which outputs the encrypted message only if certain conditions hold
  - Eve modifies the program to always output the result of decryption
- Goal: prevent modifications of the obfuscated programs

Verifiable Non-Malleable Obfuscation

- Obfuscation is verifiably non-malleable if the only programs attacker can create that pass verification are those it could create given black-box access to obfuscated code
- Allows to detect attacks that were not prevented
  - e.g., digitally sign obfuscated program, then verification procedure will check that the signature attached to the obfuscated program is correct
    - According to unforgebility property it is impossible to modify the program
    - How does the verification procedure obtains the verification key?
      - May not be practical

Public-Key Obfuscation

- Public-Key obfuscator is a pair of algorithms (Compile,D)
  - Use **Compile** to obfuscate secret program P, obtain O(P),K
  - The output is encryption of original program's output
  - Use **D** with K to recover result of O(P)(x) on some input x
  - Correctness: for any input x, D(C(x))=P(x)

Fin