Obfuscation

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Course: *Introduction into modern Cryptography*
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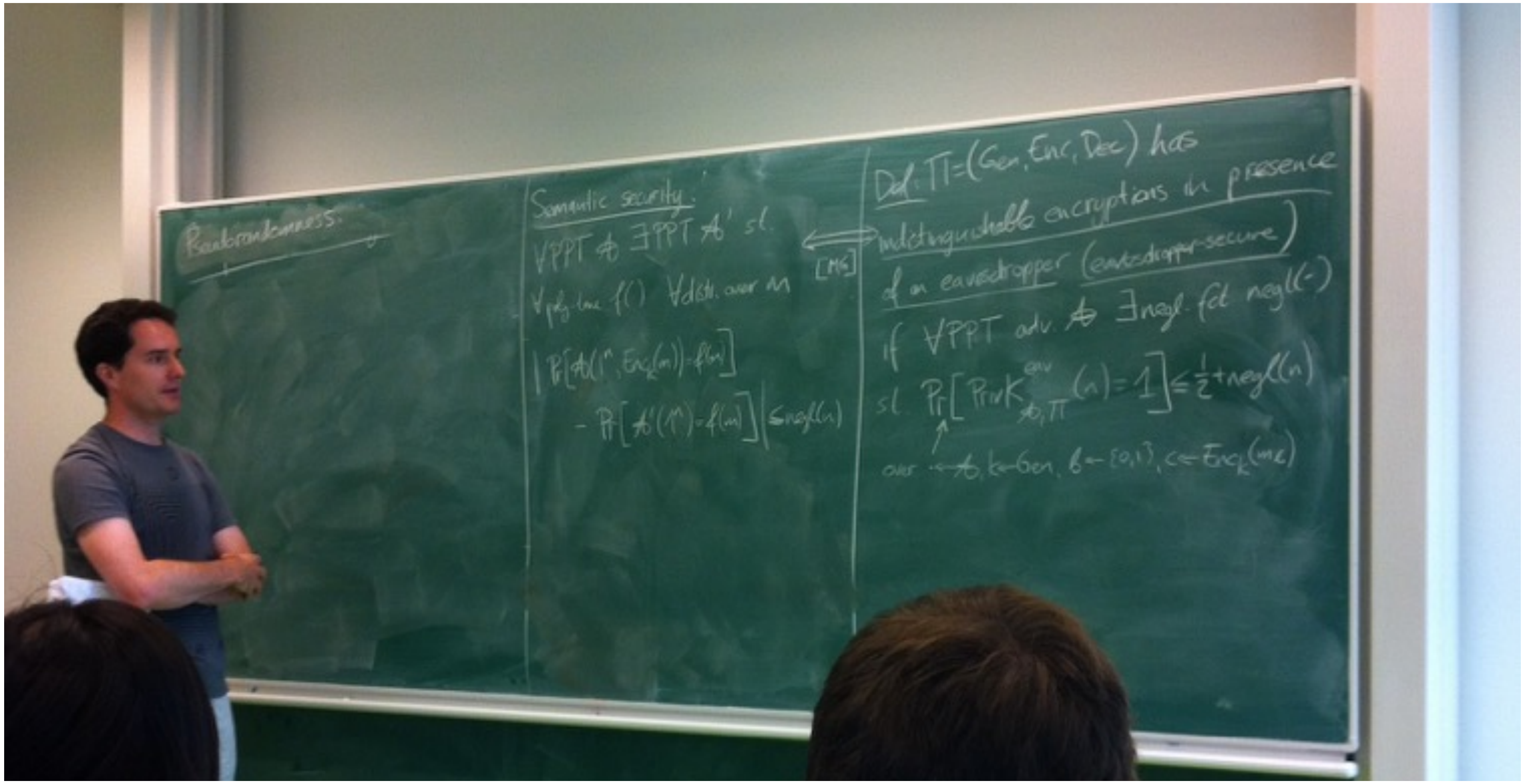
Cryptography

- Theoretical cryptography provided theoretic foundations for most classical problems
    - *encryption, authentication, protocols*
- Still cryptography challenges little theory
- One such problem program obfuscation

Cryptography



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What is obfuscation?

Obfuscation

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Obfuscation

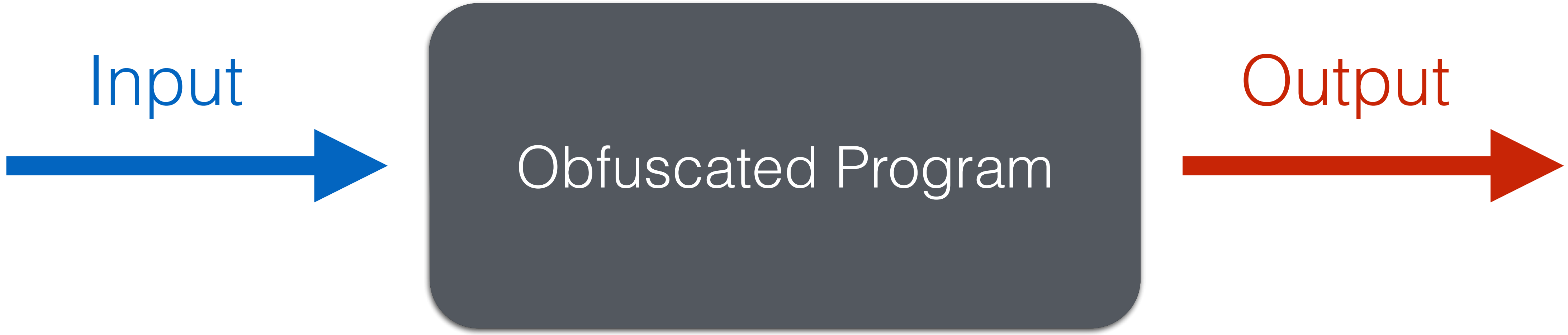
- Goal program obfuscation: make a program unintelligible while preserving functionality
- Ideally a virtual black box: anything one can compute from it also computed from input-output behaviour

Situation 1

Alice

Situation 2

Bob



Obfuscation

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    2. Anything that can be efficiently computed from O(P) can be efficiently computed given oracle access to P

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Why obfuscation?

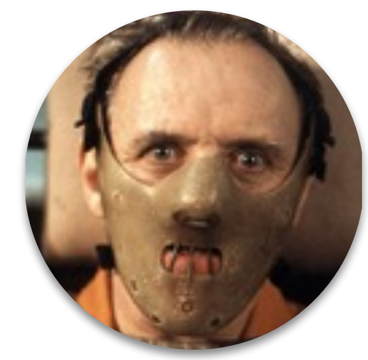
Windows Security Update

Microsoft

Windows Security Update

Microsoft

Mallory



Windows Security Update

Microsoft

Mallory

Windows Security Update

Mallory

Windows Security Update

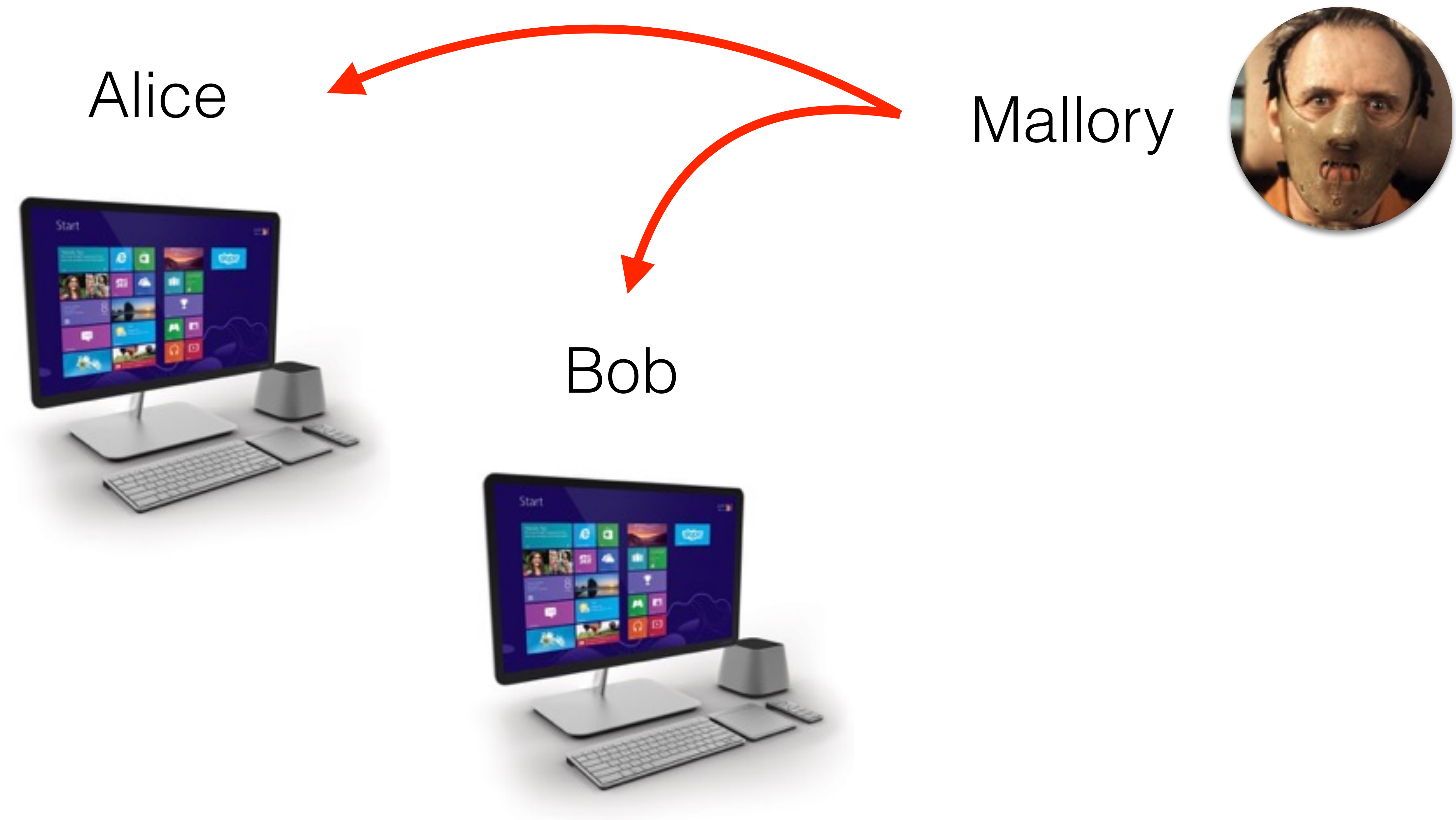
Reverse engineering patches

Mallory

Windows Security Update

Mallory

Windows Security Update



Windows Security Update

Should we be worried?

Windows Security Update

- Less than 30 minutes, flaw fixed by a Microsoft update to the Secure Sockets Layer (SSL)
- A reliable exploit for the flaw was created in less than 10 hours
- Less than three hours, Microsoft corrected vulnerability in the Internet Security and Acceleration (ISA) Server, missed same vulnerability other parts of the system

Windows Security Update

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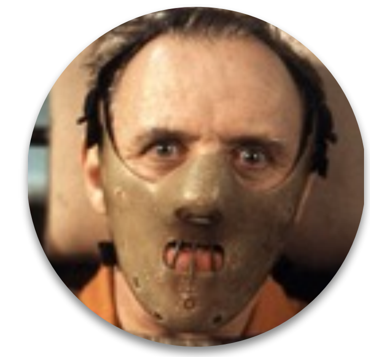
Mallory



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Obfuscated

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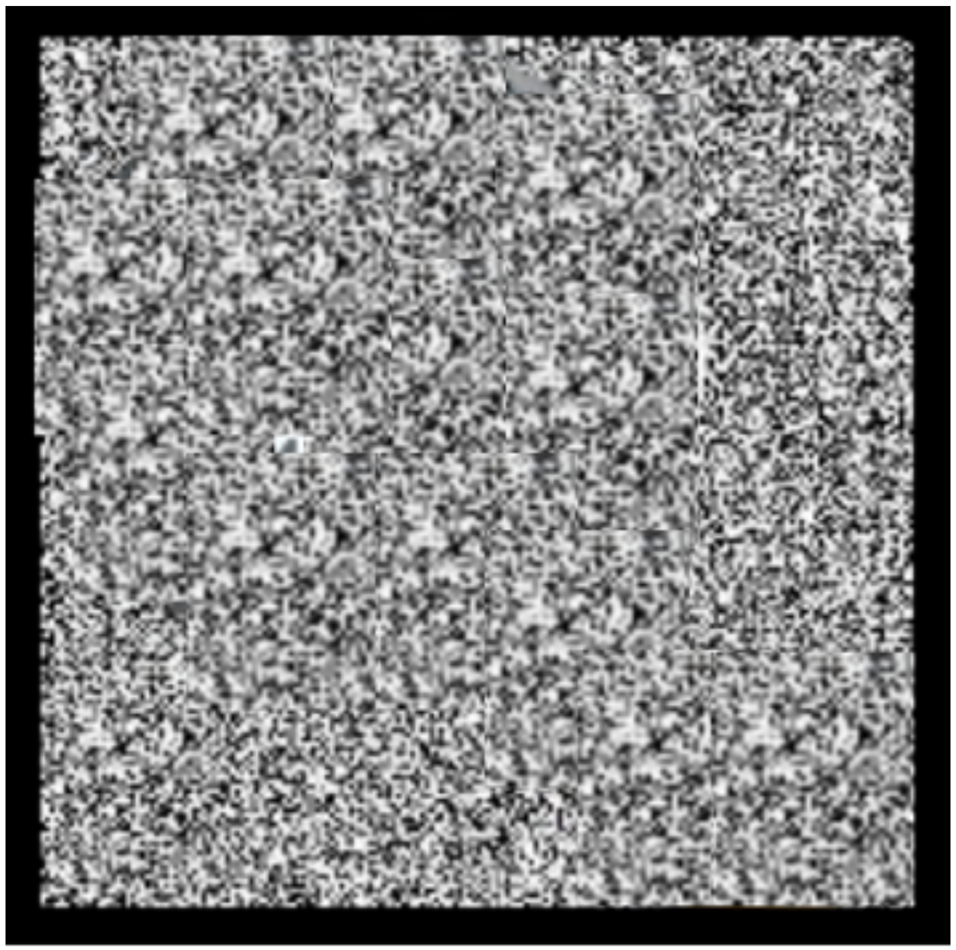
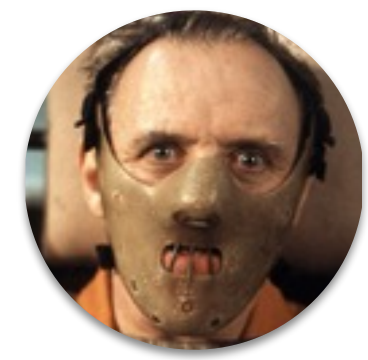


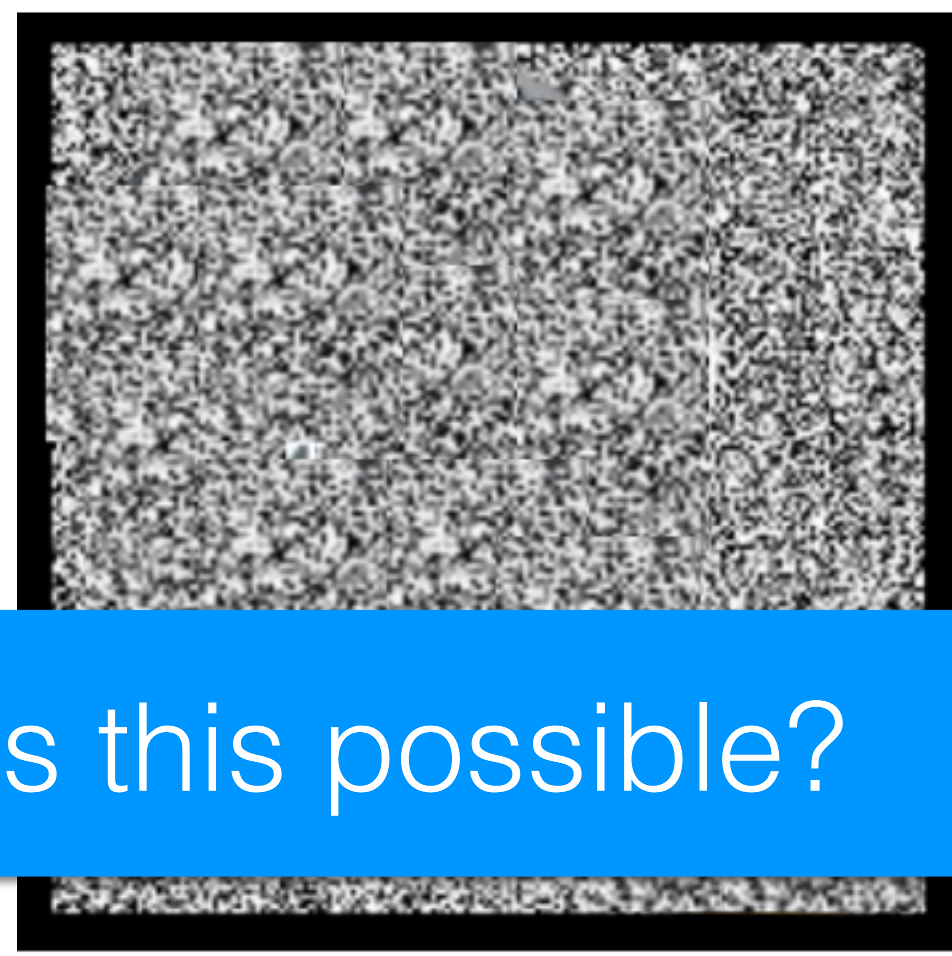
Windows Security Update

Microsoft

Obfuscated

Mallory





Is this possible?

In Practice

- This is done a lot
- Not standard
- Relies on human ingenuity, security-via-obscurity
- “At best, obfuscation merely makes it time-consuming, but not impossible, to reverse engineer a program”

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Can we formalise it?

Barak

On the (Im)possibility of Obfuscating Programs

- Intuition: can't be, it's too strong
- Black Box Paradigm: any function $f(\cdot)$ should be obfuscated $O(f(\cdot))$
- Barak constructed functions that are unobfuscatable

Barak

On the (Im)possibility of Obfuscating Programs

- Virtual' black box paradigm, even weak formalisations, impossible
- Families of efficient programs $\mathcal{P}$ unobfuscatable
- Given any efficient program P' computing same function as $P \in \mathcal{P}$, the "source code" of P can be efficiently reconstructed
- Only oracle access to $P \in \mathcal{P}$, no efficient algorithm reconstruct P, except negligible probability

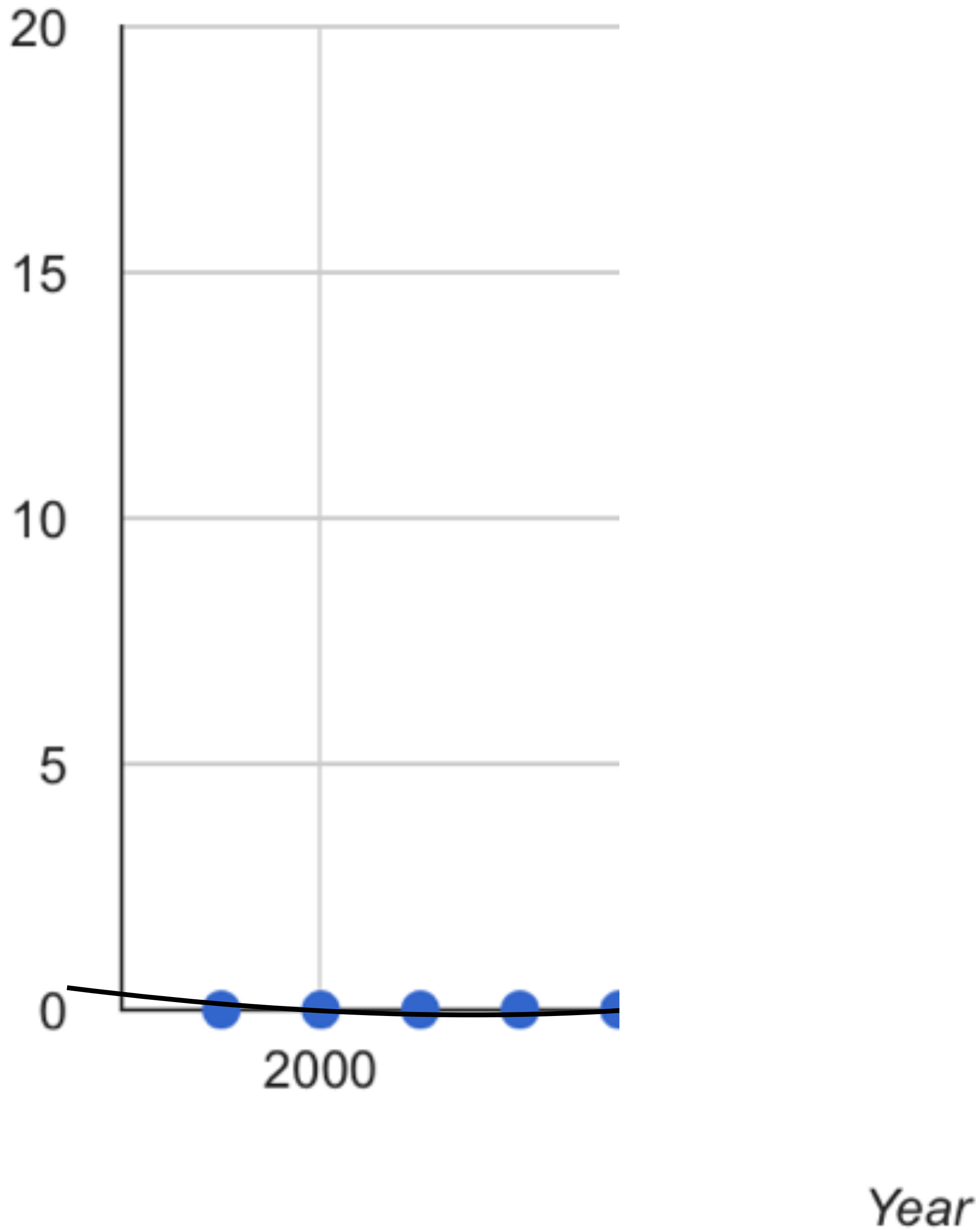
Barak

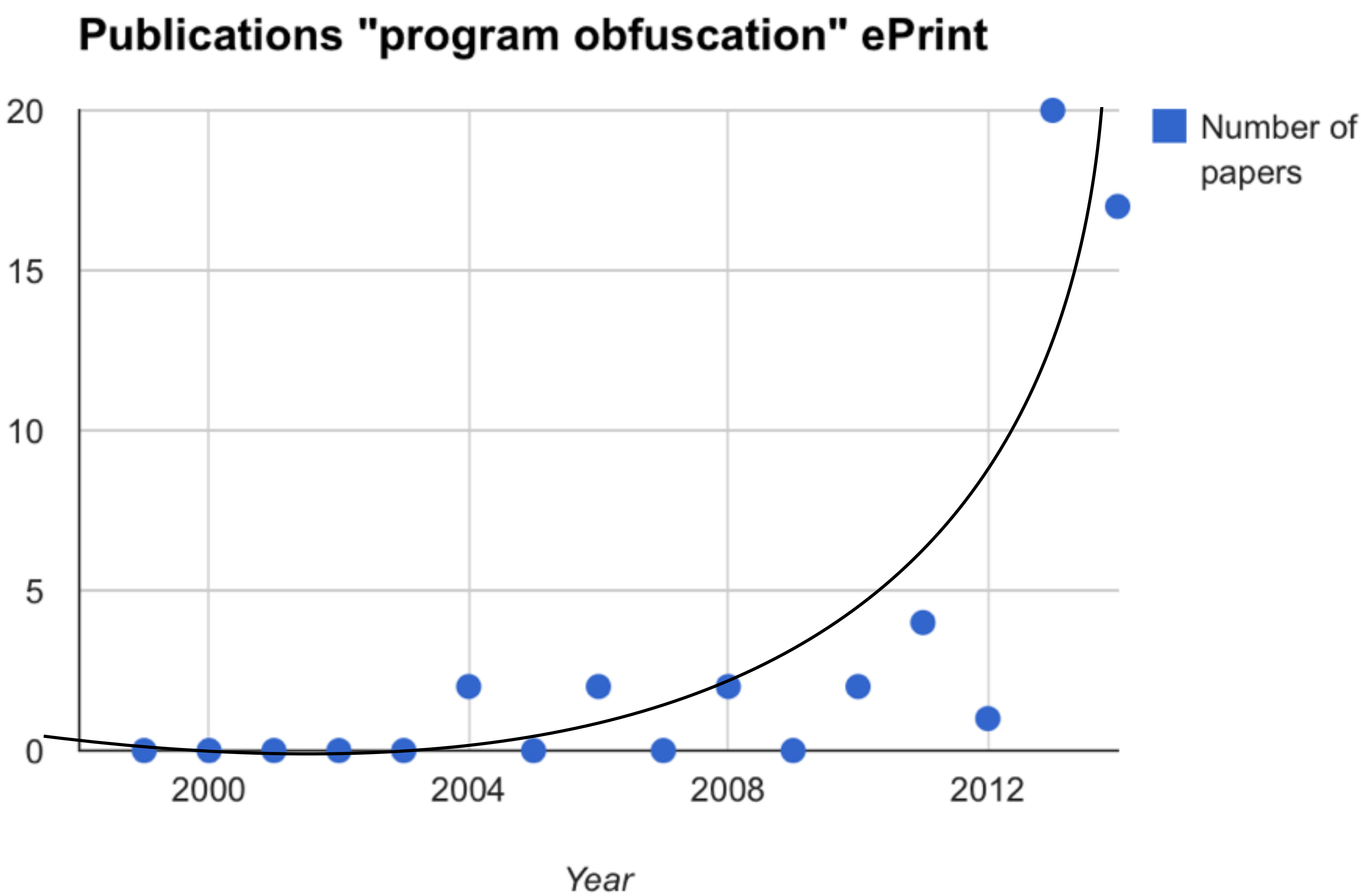
On the (Im)possibility of Obfuscating Programs

- Remained impossible even when including obfuscators that

    1. Are not necessarily computable in polynomial time
    2. Only approximately preserve the functionality
    3. Only need to work for very restricted models of computation.

Publications "program obfuscation" ePrint




Publications "program obfuscation" ePrint
20
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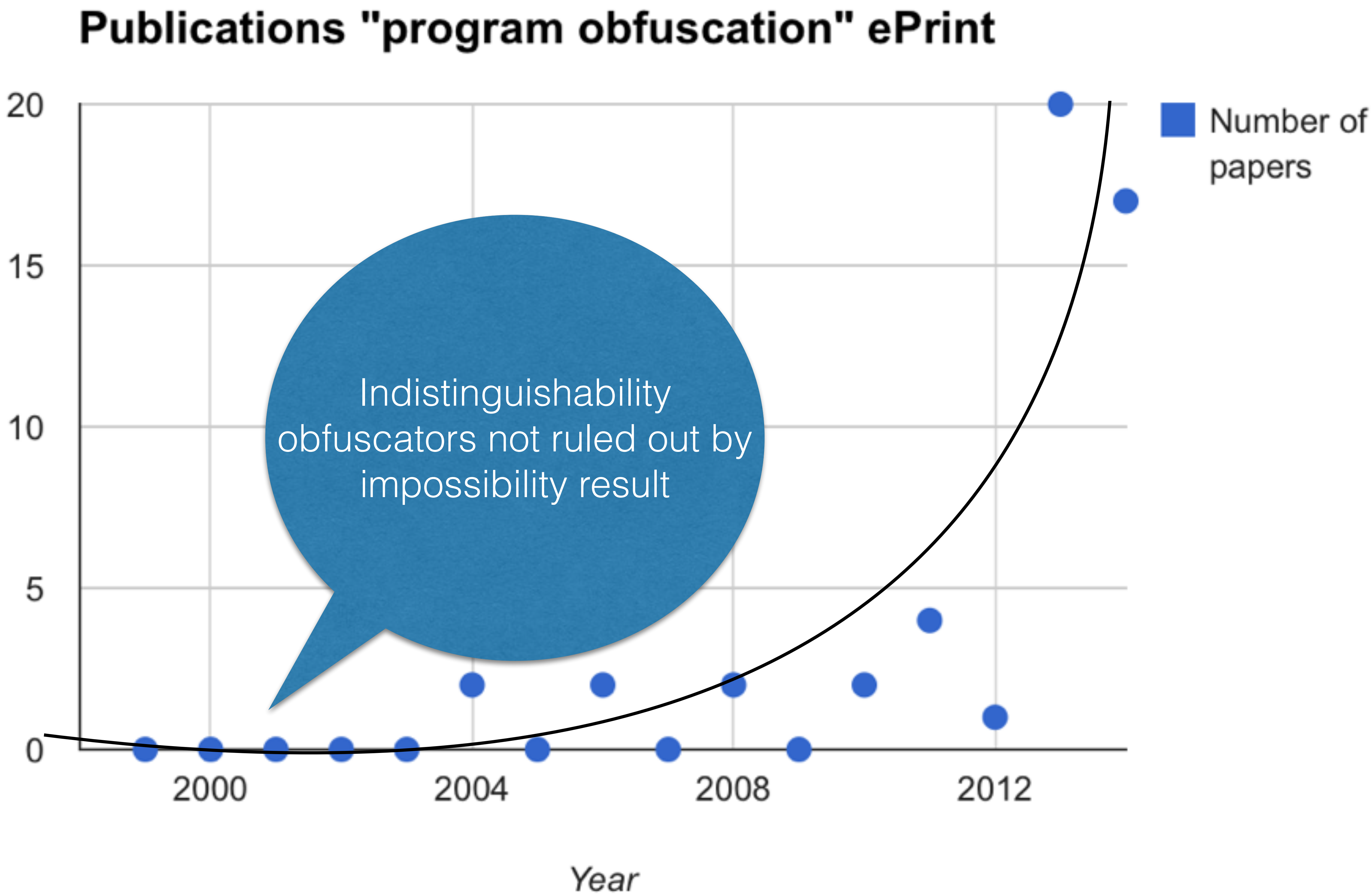
2004
2008
2012
Year
Number of papers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Indistinguishability obfuscators not ruled out by impossibility result

Garg

Candidate Indistinguishability Obfuscation and Functional Encryption for all circuits

- Indistinguishable obfuscation
  - Barak showed this is best possible obfuscation
  - Suffices for many applications

Indistinguishable obfuscation

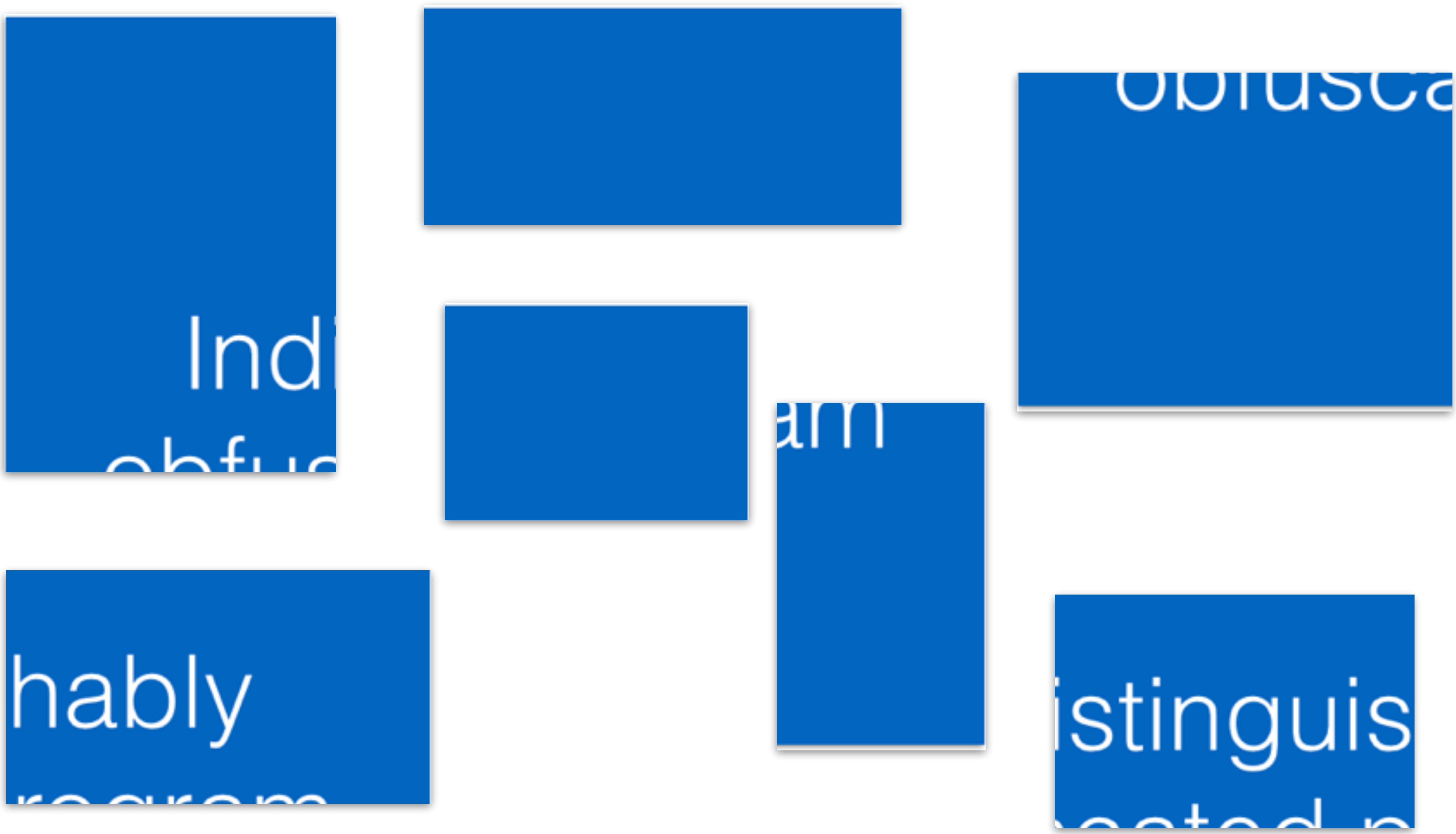
- An indistinguishability obfuscator iO for a class of circuits C

- Equivalent circuits C_1 and C_2 from same class, compute same function and $|C_1| = |C_2|$

- Distribution of obfuscations $iO(C_1)$ and $iO(C_2)$ be computationally indistinguishable

Multilinear Jigsaw Puzzle

Multilinear Jigsaw Puzzle



Multilinear Jigsaw Puzzle

Indistinguishably obfuscated program

Multilinear Jigsaw Puzzle

- Variant of multilinear maps
- Offers only a strict subset of functionality
- Similar to encoding scheme (GGH) from 1997

Multilinear Jigsaw Puzzle

- Jigsaw generator
- Jigsaw verifier $e : G_1 \times G_2 \times \cdots \times G_k \to G_T$
- Perform group and multilinear operations
- Valid multilinear form anything can be computed using group operation in separate groups and multilinear map

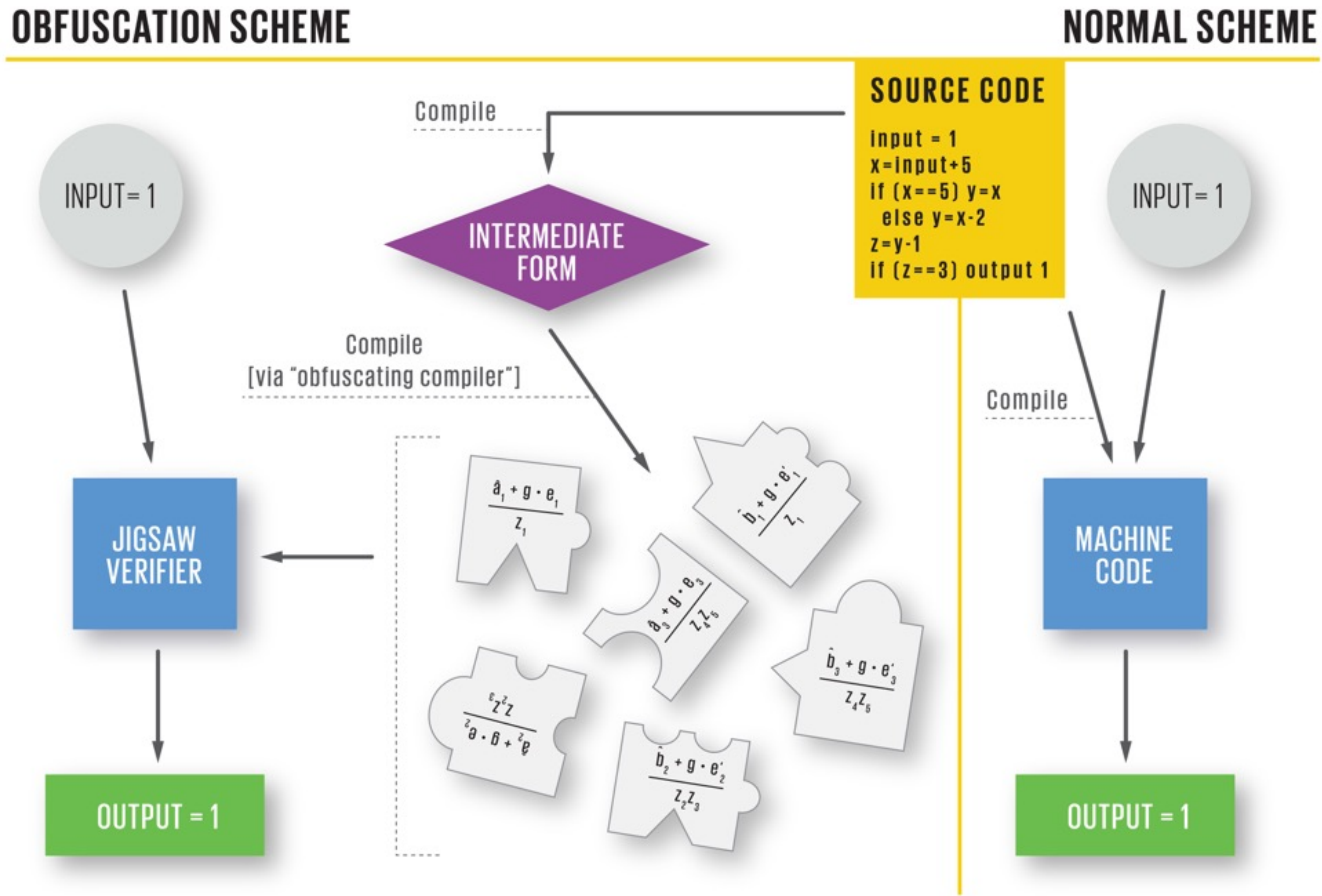
Multilinear Jigsaw Puzzle

- Jigsaw generator outputs some system parameters prms and k+1 nonempty sets of elements $S_i = \{x_1^{(i)},\ldots,x_{n_i}^{(i)}\} \subset G_i$ for i = 1,…,k,T

- The Jigsaw verifier takes as input:

$$(prms, S_1, \ldots, S_k, S_T, \Pi)$$

- Where ∏ and is a valid multilinear form in these elements
  - "yes" if ∏ evaluates to the unit element in G_T on the given elements
  - "no" otherwise


OBFUSCATION SCHEME
NORMAL SCHEME
SOURCE CODE
input = 1
x=input+5
if (x==5) y=x
else y=x-2
z=y-1
if (z==3) output 1
Compile
INPUT= 1
INTERMEDIATE FORM
Compile [via "obfuscating compiler"]
JIGSAW VERIFIER
OUTPUT = 1
Compile
INPUT= 1
MACHINE CODE
OUTPUT = 1

Shai Halevi

- We are in the midst of (yet another) “quantum leap” in our cryptographic capabilities
- Things that were science fiction just two years ago are now plausible
- Fuelled by new powerful building blocks
  - Combination of Homomorphic Encryption (HE)
  - Cryptographic Multilinear Maps (MMAPs)

Shai Halevi

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  - Cryptogr

Are we done?

Future research

- "... far from ready for commercial applications. The technique turns short, simple programs into giant, unwieldy albatrosses."

Future research

- Better underlying hardness assumptions
- Faster constructions (horrendous complexity)
- Better notions
  - Not capture intuition of what obfuscator is

Take Home Message

- Obfuscation of general programs in ‘virtual black box’ paradigm is impossible
- The weaker notion of indistinguishable obfuscation can be achieved for polynomial sized circuits

Sources

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- Barak, Boaz, et al. "Protecting obfuscation against algebraic attacks." *Advances in Cryptology–EUROCRYPT 2014*. Springer Berlin Heidelberg, 2014. 221-238.

- Damien Stehlé and Ron Steinfeld. *Making ntru as secure as worst-case problems over ideal lattices*. p. 27–47, 2011.

- Shai Halevi – IBM Research, Multilinear Maps and Obfuscation

Thanks for your attention!

- Questions
- Discussion
- Appendix

Discussion

- What challenges remain in cryptography?

Discussion

- How is it possible that one can reverse engineer two unobfuscatable programs, but not distinguish between the two?

Functional encryption

- Send encrypted function instead of message
- Revealed information depends on receiver

Functional encryption

- Hospital treatment information
    - Share anonymised with researchers
    - Share with GP
    - Share with insurance

Software Protection

- By definition, obfuscating a program protects it against reverse engineering.
- For example, if one party, Alice, discovers a more efficient algorithm for factoring integers, she may wish to sell another party, Bob, a program for apparently weaker tasks (such as breaking RSA) that use the factoring algorithm as a subroutine without actually giving Bob a factoring algorithm. Alice could hope to achieve this by obfuscating the program she gives to Bob.
- Obfuscators would also be useful in watermarking software. A software vendor could modify a program's behaviour in a way that uniquely identifies the person to whom it is sold, and then obfuscate the program to guarantee that this "watermark" is difficult to remove.

Software Patching

- If a new malware vulnerability is found in software, there is a risk that releasing a software patch will allow attackers to become aware of a vulnerability before the patch has a chance to fully circulate among users. Obfuscation offers a solution concept: an initial patch can be released in obfuscated form, and then transitioned to a more efficient un-obfuscated patch once large-scale adoption has occurred for the initial patch. Here, the assumption would be that the obfuscated patch would hide where the vulnerability in the software was (at least as well as the original vulnerable software did).

Private to Public

- Obfuscation can also be used to create new public-key encryption schemes by obfuscating a private-key encryption scheme. Given a secret key K of a private-key encryption scheme, one can publish an obfuscation of the encryption algorithm EncK. This allows everyone to encrypt, yet only one possessing the secret key K should be able to decrypt.

- Interestingly, in the original paper of Diffie and Hellman [DH], the above was the reason given to believe that public-key cryptosystems might exist even though there were no candidates known yet. That is, they suggested that it might be possible to obfuscate a private-key encryption scheme

Homomorphic Encryption

- A long-standing open problem in cryptography is whether homomorphic encryption schemes exist (cf., [RAD, FM, DDN, BL, SYY]). That is, we seek a secure public-key cryptosystem for which, given encryptions of two bits (and the public key), one can compute an encryption of any binary Boolean operation of those bits.

- Obfuscators would allow one to convert any public-key cryptosystem into a homomorphic one, by using ideas as in the previous paragraph. Specifically, use the secret key to construct an algorithm that performs the required computations (by decrypting, applying the Boolean operation, and encrypting the result), and publish an obfuscation of this algorithm along with the public key.

Boolean Circuit

- Jigsaw is a mathematical construction
- Garg now only allows for AND, OR, NOT gates
- Not functioning as a Turing machine