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sense and simplicity

White-Box Cryptography

State of the Art

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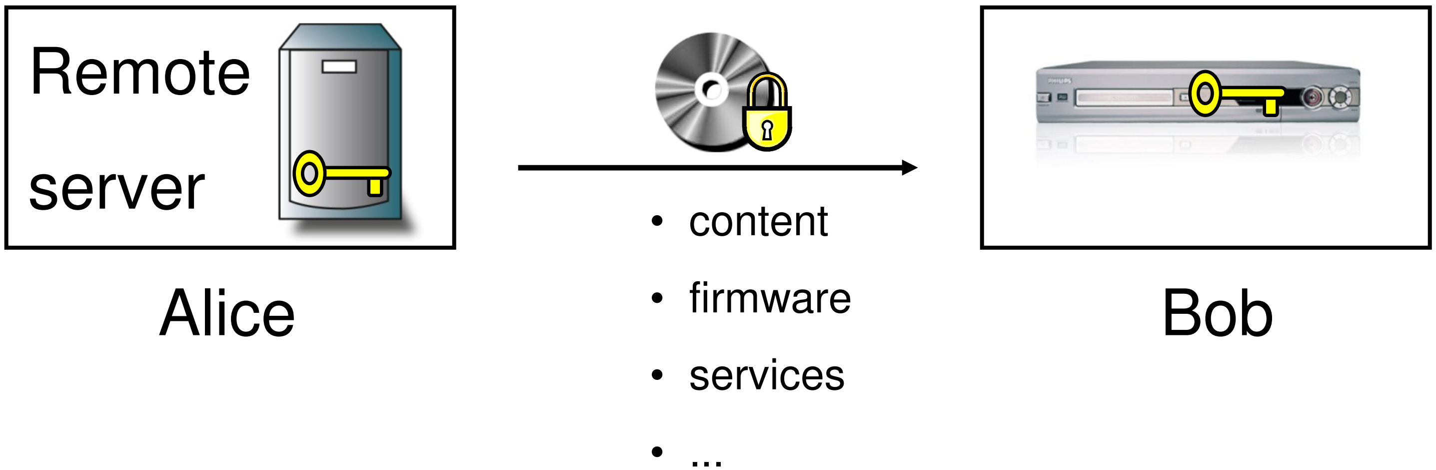
Outline

- Introduction
  - Attack models
- White-box cryptography
  - How it is done
  - Interesting properties
  - State of the art
- Conclusion

Introduction



- One generally encrypts data to protect it from malicious use.
- To get the key, the device will be attacked instead of the link.
- Problem to be solved: How to protect a key on a device.
- Solution depends on attack model:

  to how much information does an attacker have access.

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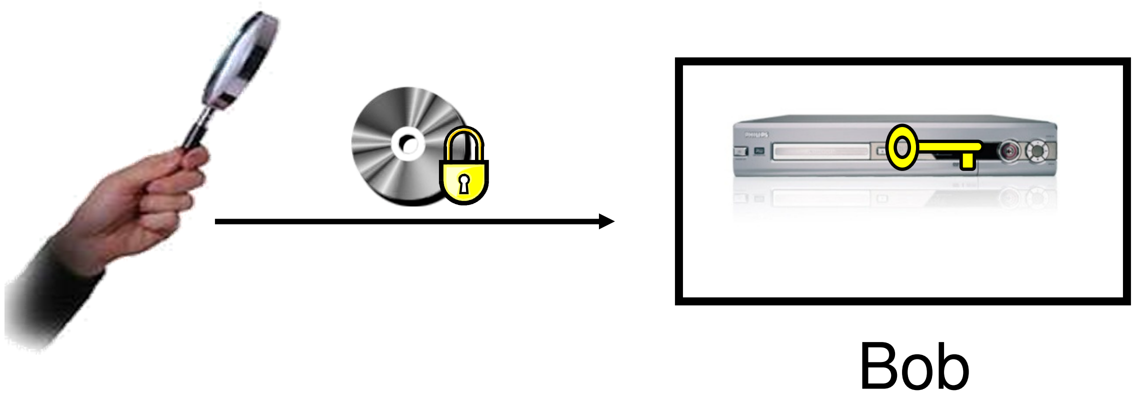
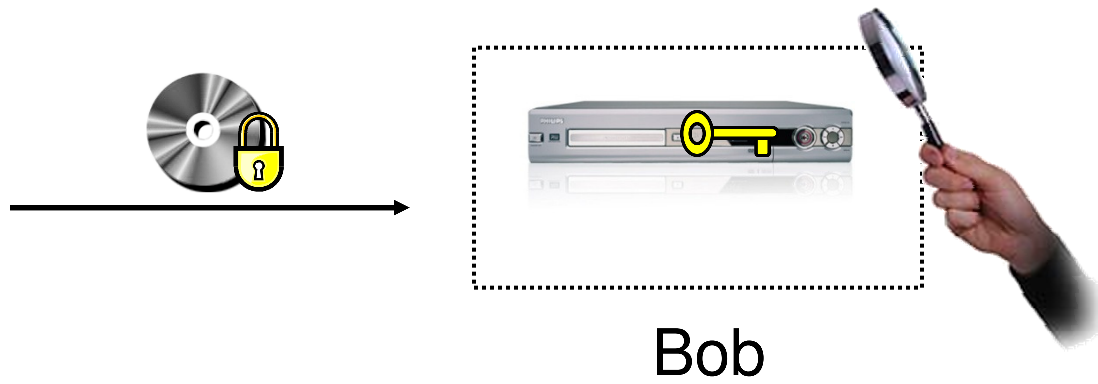
Black-box attack model



- Computation cannot be observed (device is a black box)
- Only the communication link is observable

- Assumptions may be too strong if communicating parties are not trusted.

Grey-box attack model

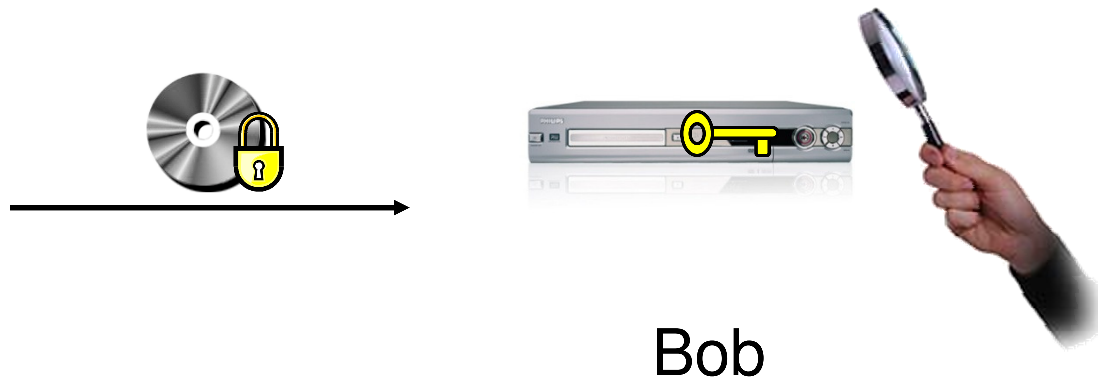


Performance characteristics of computation can be observed

- timing information
- power consumption
- sound

Problem: new types of side-channel attacks are found and published every few months.

White-box attack model



- Computation can be fully observed

  full access to and full control over the device

- Observation:

  if we have a secure implementation in this model, we are automatically secure against all possible side-channel attacks.

White-box cryptography

- Prevent an attacker from extracting the key from a software program that implements a cryptographic algorithm.
  - The key cannot be extracted by analyzing the code
  - The key cannot be extracted by analyzing the intermediate results during execution.

- while the attacker is assumed to have full access to the software implementation and full control over the execution environment (white-box attack model).

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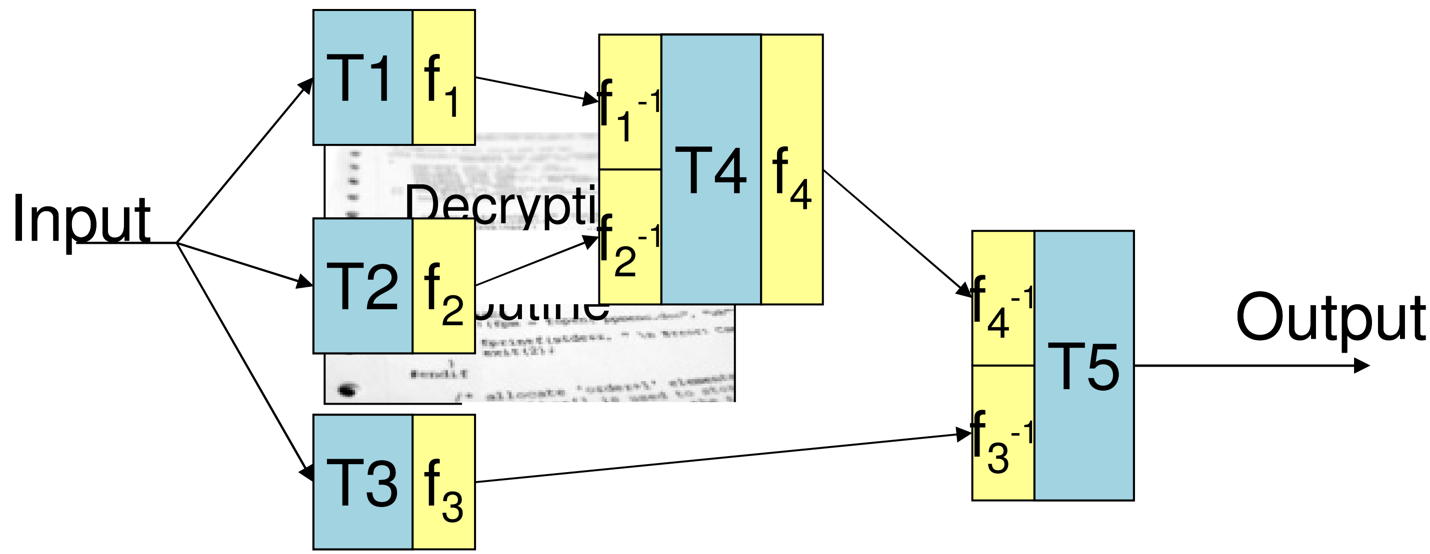
White-Box Cryptography – How it is done

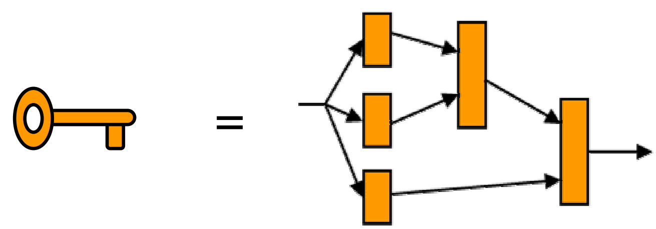


- A recipe for a white-box implementation of a symmetric block cipher
  - Convert the cipher to a lookup table implementation

    Key and algorithm are merged in lookup tables
  - Obscure the network of tables
  - Obfuscate inputs and outputs of each table

White-Box Cryptography – White-Box Key

- Usually white-boxing is achieved by hiding the secret key ("classic key") in a larger bit-string ("white-box key")



  - Symmetric ciphers: key is hidden in implementation of the algorithm
  - Asymmetric ciphers: key is replaced by a larger, equivalent key

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Interesting property 1: side channel attacks

- White box implementations can increase the resistance against side-channel attacks (differential power analysis, timing analysis) if the execution is sufficiently randomized.
  - White-box implementations offer many opportunities for randomizing the execution

- White-box implementations can increase the resistance against the exploitation of software bugs and fault injection attacks if the white-box key is much larger than the classic key
  - Typically, one bug or fault will recover only a small part of the key, and it becomes increasingly difficult to find enough bugs to exploit, or different faults to inject, when the size of the key increases.

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Interesting property 2: asymmetry

- When implementing symmetric ciphers in a traditional way the difference between encryption and decryption is in the algorithm
  - Encryption and decryption key are identical
  - If you know the encryption key, you can also decrypt (and vice versa)
- In white-box implementations the encryption key is different from the decryption key
  - A system that performs encryption cannot be used for decryption (or vice versa)

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Interesting property 3: information binding

- Any arbitrary string of bits can be included in the white-box key
  - string length can be thousands of bits (size has practical limits, no theoretical limit)
  - a modification of the string will destroy the white-box implementation
- Examples of an included bit-string:
  - White-box key can be “locked” to hardware
    - By including hardware characteristics in the white-box key
  - Visible string can be included in the white-box key
    - e.g. “(C) Royal Philips Electronics”, or the name of the customer

```
"A43RS (C)Philips 96GDB" => "A43RS (C)Pirates 96GDB"
"A43RS (C)Philips 96GDB" => "GF45DJ326254UT53BVSA20"
```

  - Hidden (forensic) trace-mark can be put in the white-box key
    - Makes it possible to find the source of a leak (“traitor tracing”)

Forensic key watermarking

- All white-box implementations have the same cryptographic functionality.
- Include a user identifier in the white-box implementation.
- Each user gets a traceable white-box implementation.

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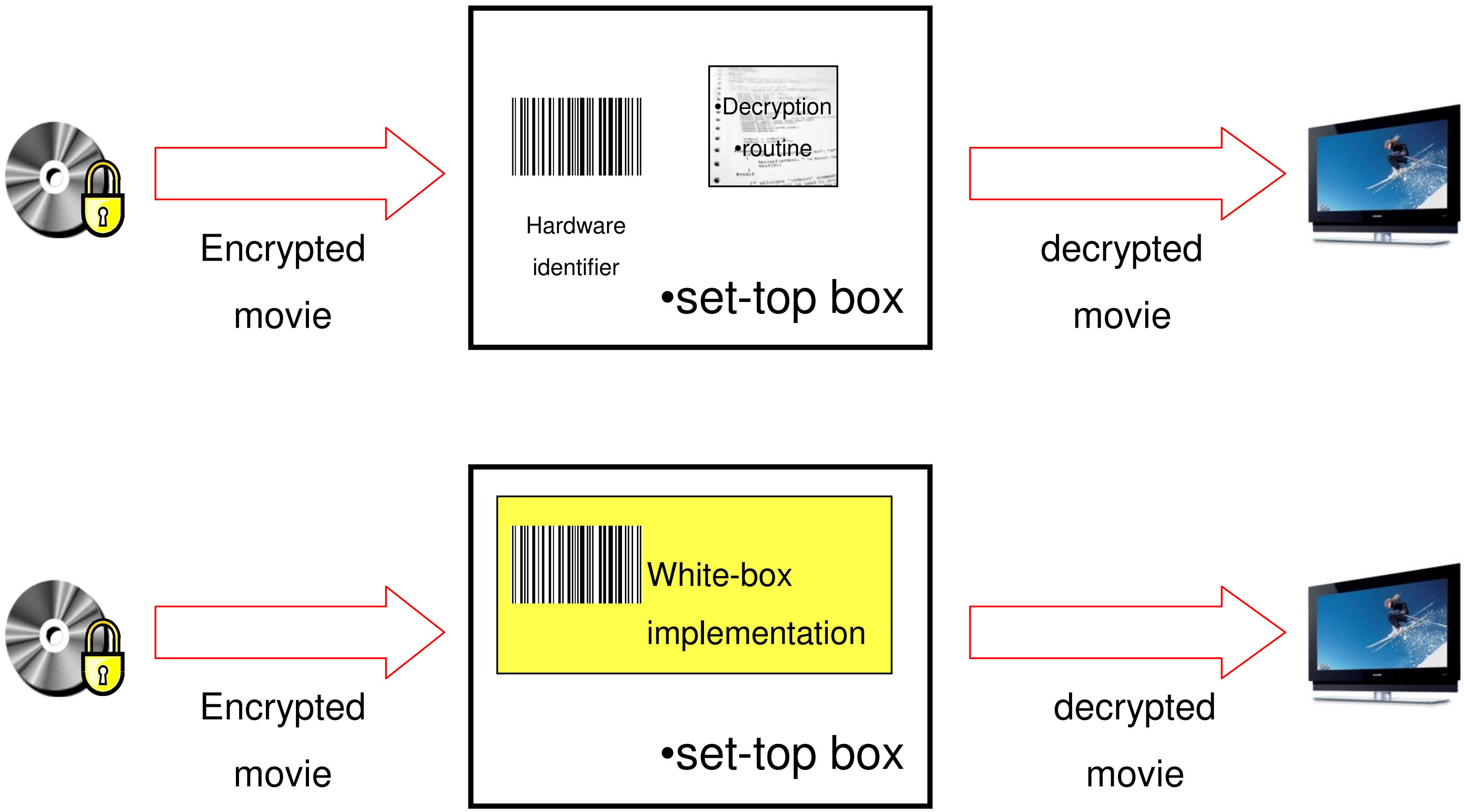
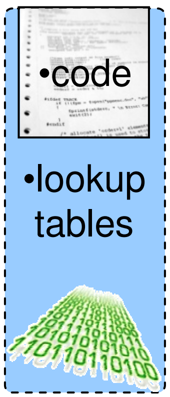
Node locking

- Include a hardware identifier in the white-box implementation.
- Give a user a white-box implementation in which the hardware identifier is omitted.
- The white-box implementation only works on a system with the correct hardware identifier.

Node locking



Software tamper resistance



- Include a binary software image in the white-box implementation.
- Software gets a dual interpretation.
- Changing the code

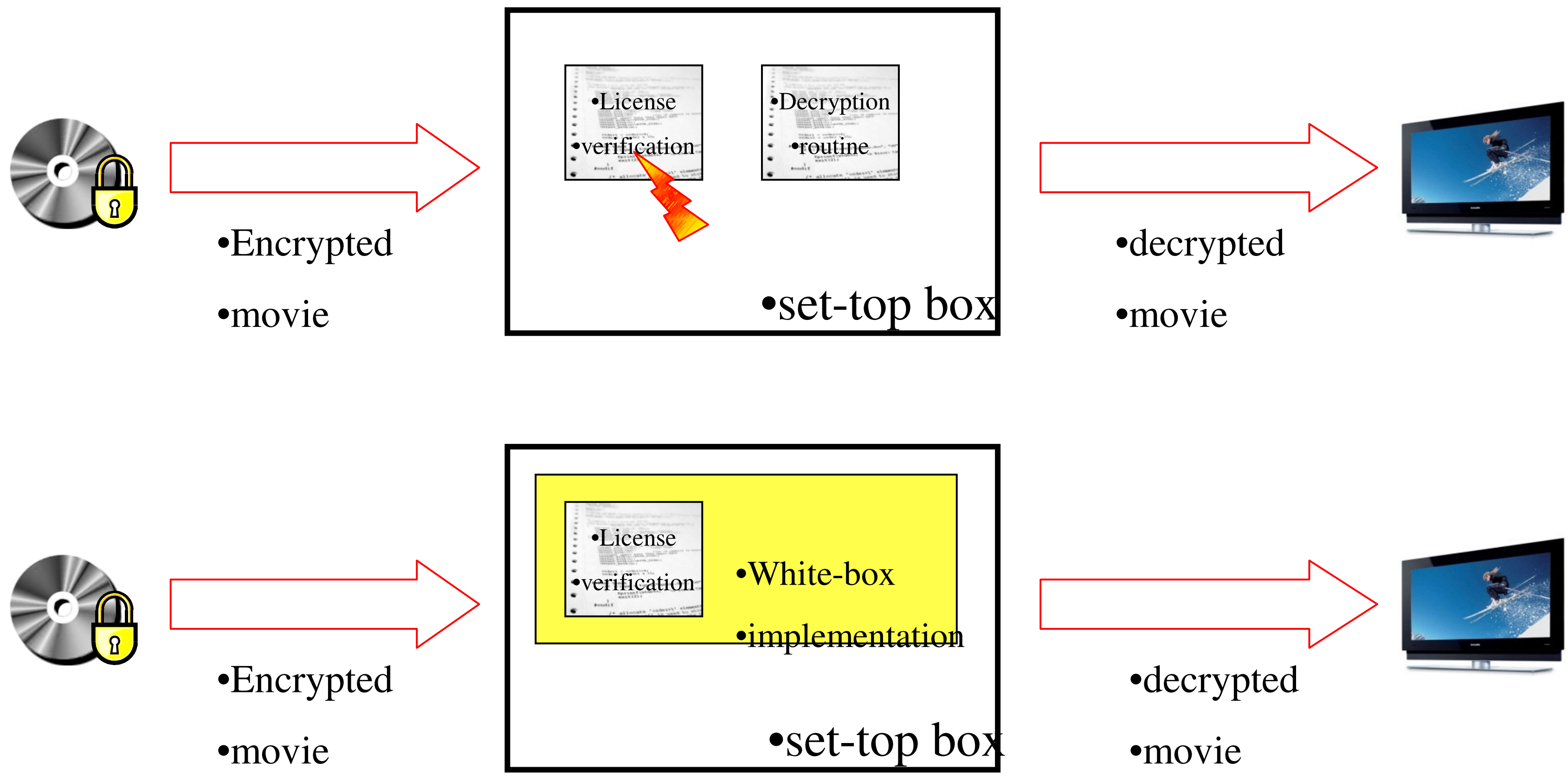
  ⇒

  changing the white-box implementation (key)

  ⇒

  cryptographic operation disabled

Software tamper resistance



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State of the art (1) – known white-box methods

- We do not know any publication describing white-box implementations of RSA or ECC
- Several companies offer white-box implementations of RSA and ECC:
  - Cloakware http://www.cloakware.com/
  - Arxan http://www.arxan.com
  - Syncrosoft http://www.syncrosoft.com

State of the art (2) – known white-box methods

- White-box implementations for DES[1] and AES[2] have been published.
- Several companies offer white-box implementations of AES and DES
  - Cloakware http://www.cloakware.com/
  - Syncrosoft http://www.syncrosoft.com

1) Chow, S., Eisen, P., Johnson, H., van Oorschot, P.C.: A White-Box DES Implementation for DRM Applications. Proceedings of the 2nd ACM Workshop on Digital Rights Management, 1-15, 2002.
2) Chow, S., Eisen, P., Johnson, H., van Oorschot, P.C.: White-Box Cryptography and an AES Implementation. Proceedings of the 9th Annual Workshop on Selected Areas in Cryptography, 250-270, 2002.

State of the art (3) - attacks on white-box crypto

- The published white-box implementations of AES and DES have been broken
  - The classic key can be found in 2^{30} time for AES[1] and in 2^{14} for DES[2]
- Philips has shown that standard methods of symmetric cipher construction have fundamental weaknesses for a strong white-box implementation[3]
  - AES and DES are not suitable for applications that need secure white-box implementations
  - New ciphers, or new white-box techniques, are needed to allow secure white-box implementations

1) Billet, O., Gilbert, H., Ech-Chatbi, C.: Cryptanalysis of a White-Box AES Implementation. Proceedings of the 11th Annual Workshop on Selected Areas in Cryptography, 227--240, 2004.

2) Wyseur, B., Michiels, W., Gorissen, P., Preneel, B.: Cryptanalysis of White-Box DES Implementations with Arbitrary External Encodings. Proceedings of the 14th Annual Workshop on Selected Areas in Cryptography, 264--277, 2007.

3) Michiels, W., Gorissen, P., and Hollmann, H.D.L.: Cryptanalysis of a Generic Class of White-Box Implementations, Proceedings of the 15th Annual Workshop on Selected Areas in Cryptography (SAC 2008), 392-406, 2008

State of the art (4) - beyond parlor tricks and obfuscation

- Is it impossible to achieve real security with white-box crypto?
  - It is quite clear that AES and DES cannot be securely white-boxed

- It is possible to construct symmetric ciphers that have the right characteristics to resist the known attacks on white-box methods:
  - Enlarge the key-dependent operations of the cipher by making the diffusion matrix and/or S-box variable and/or key-dependent

  - Use a diffusion operator other than matrix multiplication
    - MDS matrices, for example, should be avoided.

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Conclusions

White-box implementations can have useful properties, but beware…

different white-box methods have different security properties

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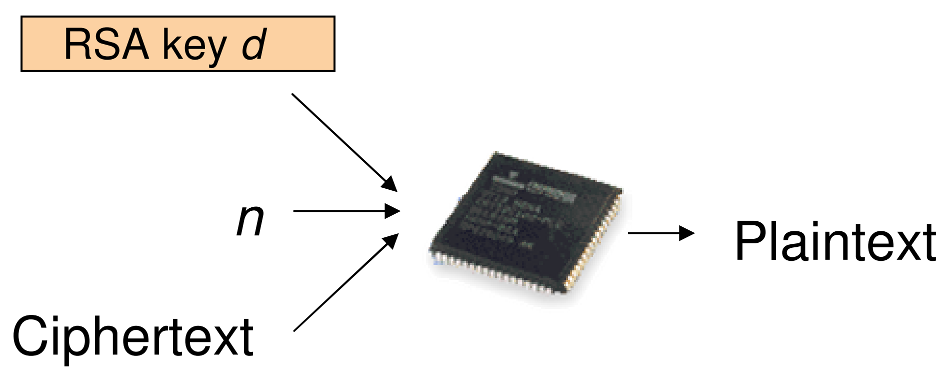
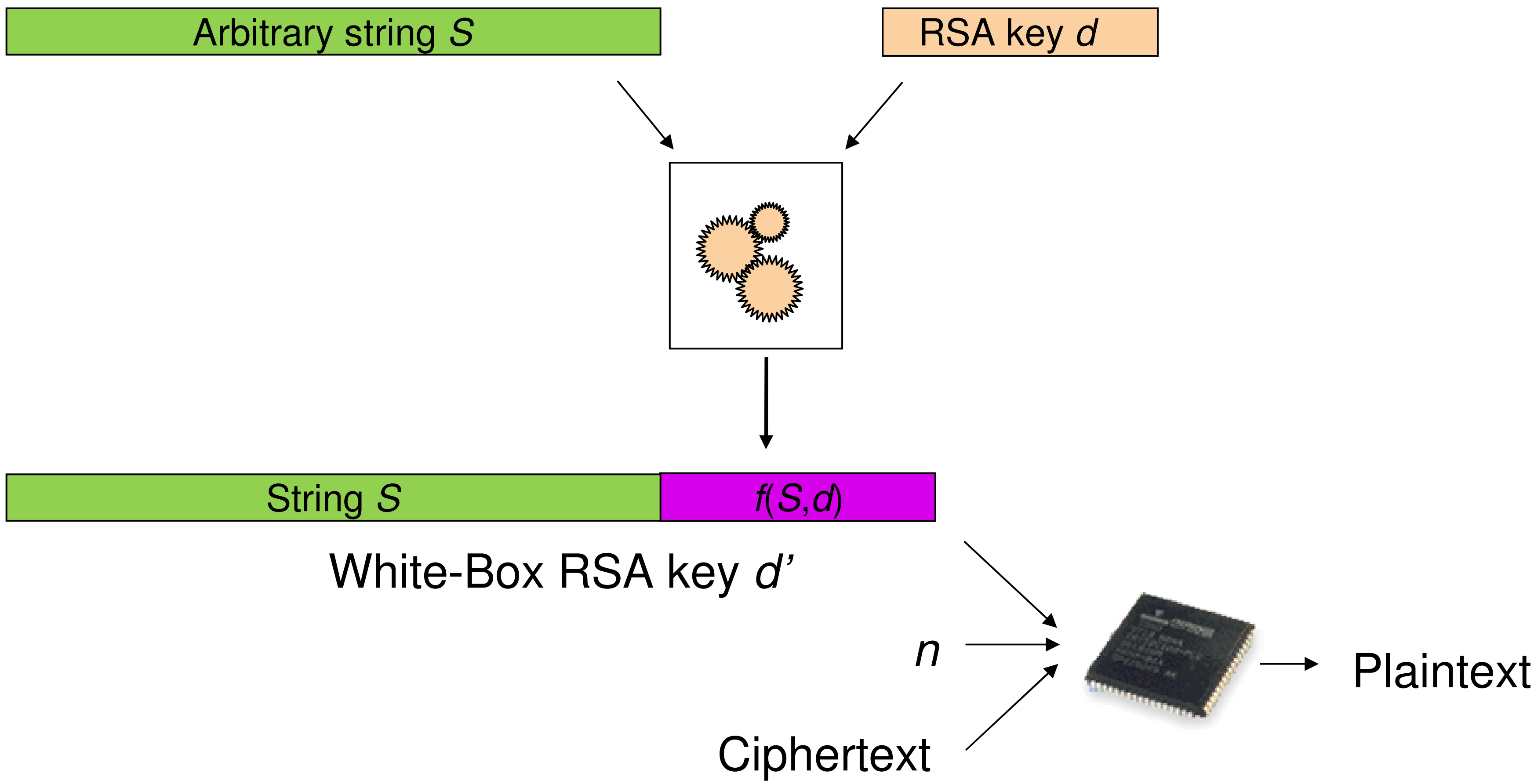
RSA Decryption



White-box RSA – Philips' method (1)



White-box RSA: Philips' method (2)

- RSA is a matter of exponents:
  - Choose prime p and q and create $n = p*q$
  - Choose public key e
  - Create private key d
  - Encrypt: ciphertext = $\text{message}^{e} \bmod n$
  - Decrypt: message = $\text{ciphertext}^{d} \bmod n$
- Expand the key d by creating an equivalent larger key
  - New key $d' = d + b * \phi$
    - $\phi = (p-1)*(q-1)$ is the Euler function
  - By a proper choice of b, we can include any bit string S in the binary representation of d'.

White-box RSA: Summary (1)

- RSA key size can be enlarged from k bits (typically 1024-2048 bits) to an arbitrary number of bits
- Linear processing speed reduction
  - Bit length = 10*1024; new speed = old speed/10
- Arbitrary bit strings can be included
  - Maximum size of included bit strings will be on the order of thousands of bits due to practical performance degradation limits