Advanced Software Protections

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CM0626 – Software Security

CM0631-2 – Software Security

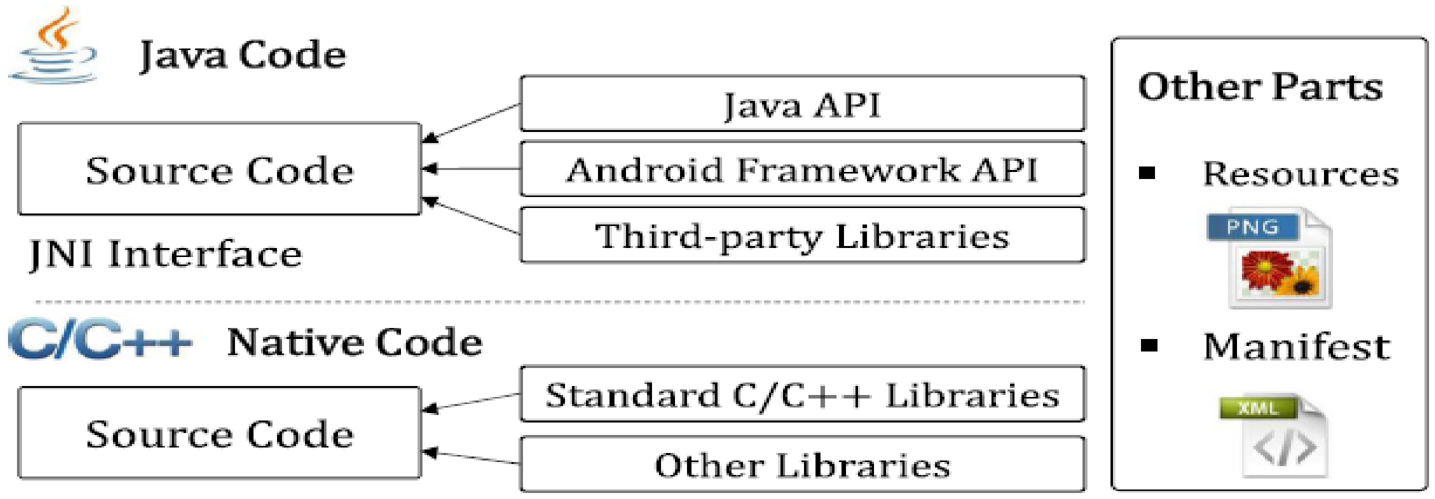
28 March 2025

Outline

- Obfuscation Intro
- Remote MATE Attacks
- Dynamic Security
- White Box Cryptography

Obfuscating Mobile Apps

- Android apps contain different components:
  - Java codes, native codes, third-party libraries, and other resources
  - Applying some obfuscations in an ad-hoc way can achieve limited obscurity
  - The remaining un-obfuscated information could jeopardize the obfuscated code



Android Obfuscators

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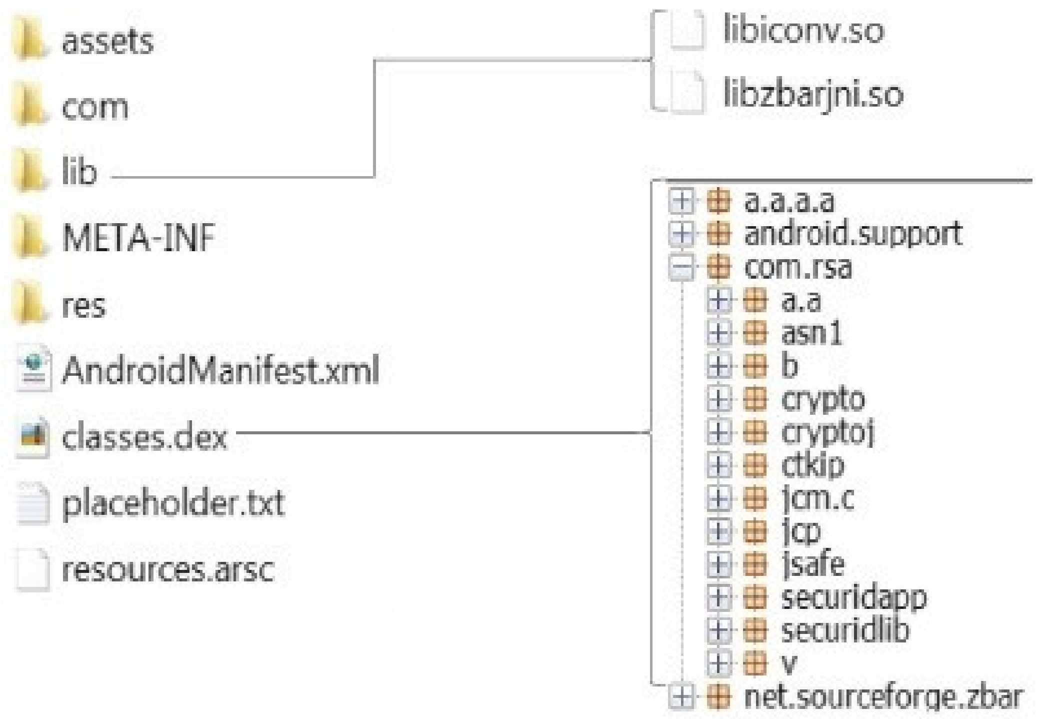
- Real-world obfuscation practice usually adopts one obfuscation technique or combines several techniques in an ad-hoc way
- ProGuard is the most popular obfuscation tool for Android apps
  - It is the default one embedded in Android Studio for free use
- ProGuard can only transforms identifiers to meaningless strings
  - Attackers can recover a significant portion of the original lexical information leveraging on the residual information in the obfuscated app (Bichsel et al.)
- DexGuard and DexProtector are more powerful
  - only less than 0.16% of real-world apps employ premium obfuscation tools

Android App Structure Example

- The components of an Android app installation package (e.g. RSA SecureID Software Token)
- All Java classes coded by developers are in the classes.dex component
  - It implements user interfaces (UI) based on the APIs of Android framework and JDK
  - Other UI-related materials (layout, images, and texts) are in the res folder
- The app also employs native codes in the lib folder
  - better than Java bytecodes for implementing some features (security, graphics, performance-critical code)
- There is a manifest file and other folders to store data, such as licenses and fonts.

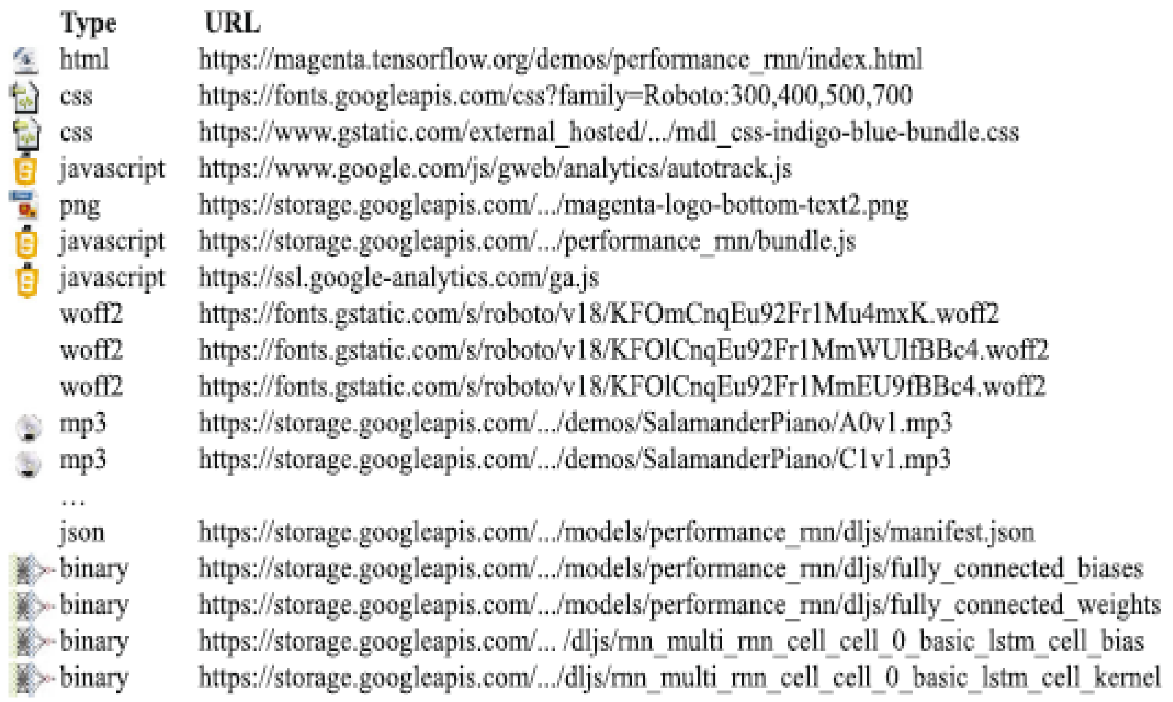


Android App Example

- Because the main feature of the app is to generate one-time passwords, the corresponding password generation codes and seeds should be most critical for protection.
- Current mainstream obfuscation techniques (e.g., lexical obfuscation and control-flow obfuscation) mainly focuses on Java or native codes
- DexProtector can also:
  - use Method Proxy to obfuscate native system calls (libc libraries)
  - encrypt the resource files of software packages and implement functions to decrypt them during runtime.

JavaScript Application Example

- Components of a Javascript application
  - Performance RNN – http://js.tensorflow.org
- Primary index.html file
- CSS file and pics defining appearance
- Bundle.js implements deep learning algorithm
- Binary files define RNN model
- Mp3 files for each note of a piano



Type	URL
html	https://magenta.tensorflow.org/demos/performance_rnn/index.html
css	https://fonts.googleapis.com/css?family=Roboto:300,400,500,700
css	https://www.gstatic.com/external_hosted/.../mdl_css-indigo-blue-bundle.css
javascript	https://www.google.com/js/gweb/analytics/autotrack.js
png	https://storage.googleapis.com/.../magenta-logo-bottom-text2.png
javascript	https://storage.googleapis.com/.../performance_rnn/bundle.js
javascript	https://ssl.google-analytics.com/ga.js
woff2	https://fonts.gstatic.com/s/roboto/v18/KFOmCnqEu92Fr1Mu4mxK.woff2
woff2	https://fonts.gstatic.com/s/roboto/v18/KFOlCnqEu92Fr1MmWUlfBBc4.woff2
woff2	https://fonts.gstatic.com/s/roboto/v18/KFOlCnqEu92Fr1MmEU9fBBc4.woff2
mp3	https://storage.googleapis.com/.../demos/SalamanderPiano/A0v1.mp3
mp3	https://storage.googleapis.com/.../demos/SalamanderPiano/C1v1.mp3
...	
json	https://storage.googleapis.com/.../models/performance_rnn/dljs/manifest.json
binary	https://storage.googleapis.com/.../models/performance_rnn/dljs/fully_connected_biases
binary	https://storage.googleapis.com/.../models/performance_rnn/dljs/fully_connected_weights
binary	https://storage.googleapis.com/... /dljs/rnn_multi_rnn_cell_cell_0_basic_lstm_cell_bias
binary	https://storage.googleapis.com/.../dljs/rnn_multi_rnn_cell_cell_0_basic_lstm_cell_kernel

Obfuscating JavaScript

- Key assets of the program should be in the RNN model and related algorithms
- Thus the binary files and the bundle.js must be obfuscated
- It may further randomize the names of the mp3 files to confuse reverse engineers
- Some tools for javascript:
  - http://stunnix.com/prod/jo/
  - http://jscrambler.com
  - https://www.javascriptobfuscator.com/
  - https://www.obfuscator.io/
  - https://javascript-obfuscator.org/

Obfuscating Neural Networks

- The structure of neural networks is a critical factor to improve the accuracy of deep learning models.
- The structural information of private machine learning models is a key intellectual property for such software
- To obfuscate deep learning models, Xu et al. proposed a simulation-based obfuscation method:
    - The method distils the knowledge of well-trained deep learning models and reloads such knowledge into less deep, shallow networks.
    - In this way, the shallow networks retain the same accuracy as the original models, but they have poor learning abilities.
    - Attackers can learn very few useful settings from the simulation networks

Obfuscation in DRM Systems

- A DRM system controls the access of users to multimedia files.
- The favourite solutions of DRM systems are based on content encryption.
- The critical challenge is to hide decryption keys, especially when attackers can have full access to the decryption software and the computing environment.
- *White-box encryption* is an obfuscation approach which can resist to key extraction attacks (Chow et al)

Other Protection Tools

- DexGuard
- DexProtector
- Themida
- Rewolf-x86-Virtualizer (open source)
- VMProtect
- Code Virtualizer
- Zelix

Diablo

- Diablo is a retargetable link-time binary rewriting framework.
- It can be used for compiler optimization
- It can be used for binary code protections on various platforms

https://diablo.elis.ugent.be/

Performance

Metric	Program	Slowdown
absolute time	application	<1s
relative	application	1.5x
relative	security kernel	100x-1000x

Code virtualizer	ExeCryptor	VMProtect	Themida
100x	700x	500x	1200x

Liem, Gu, Johnson: A compiler-based infrastructure for software-protection, PLAS'08

Time-to-Crack Matters

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Program	Adversary	Time
hw+sw		many years
well protected	highly skilled, motivated	4-6 weeks
VMProtect	experienced reverse engineer	12 month
mass market malware		minutes-hours

Time-Limited Protection

- Obfuscation provides time-limited protection
- An adversary will require greater-than-zero length of time to extract an asset from an obfuscated program.
- How can we get useful levels of protection from individual transformations that only provide time-limited protection?

Hohl, Time Limited Blackbox Security: Protecting Mobile Agents From Malicious Hosts

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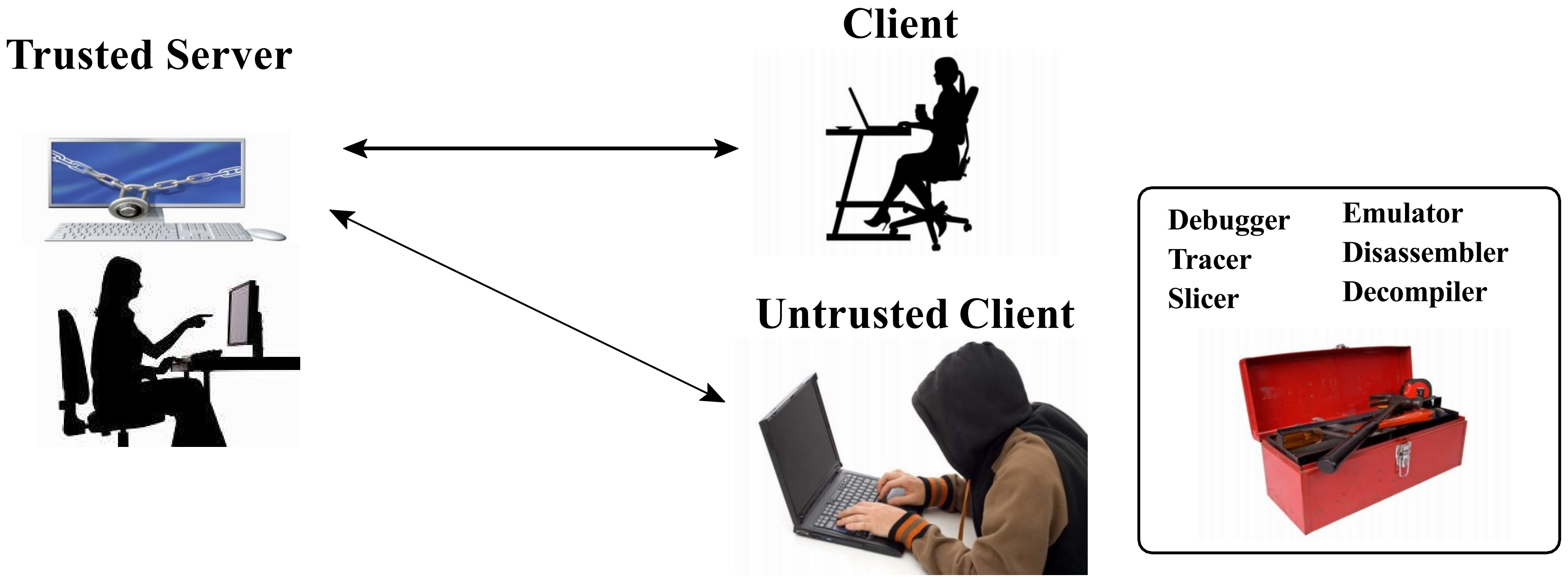
Remote MATE Attacks

Credits: Prof. Christian Collberg

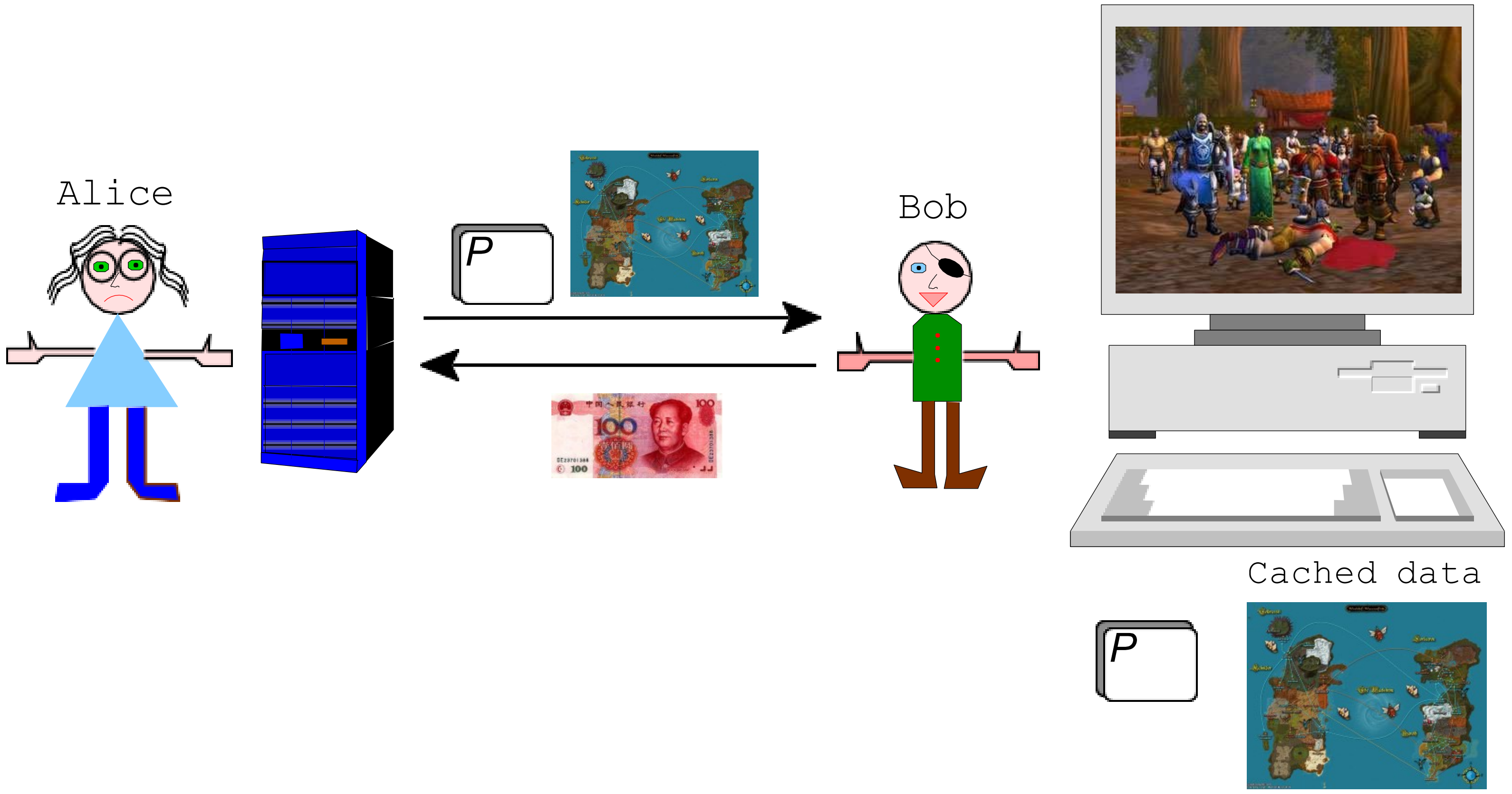
Remote MATE Attacks

- R-MATE attacks occur in distributed systems
  - where untrusted clients are in frequent communication with trusted servers over a network
  - where a malicious user can get an advantage by compromising an untrusted device.



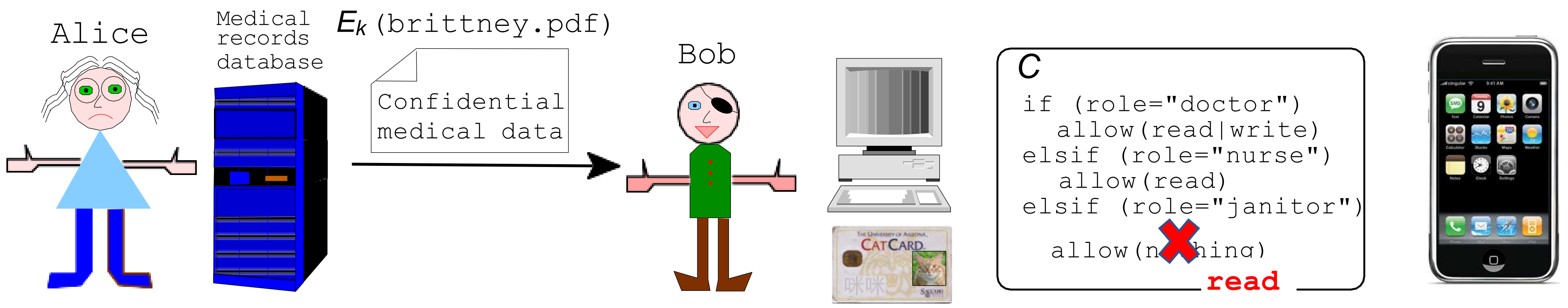
Protecting networked video games

- Prevent Cheating or game cracks from malicious users



Protecting medical records

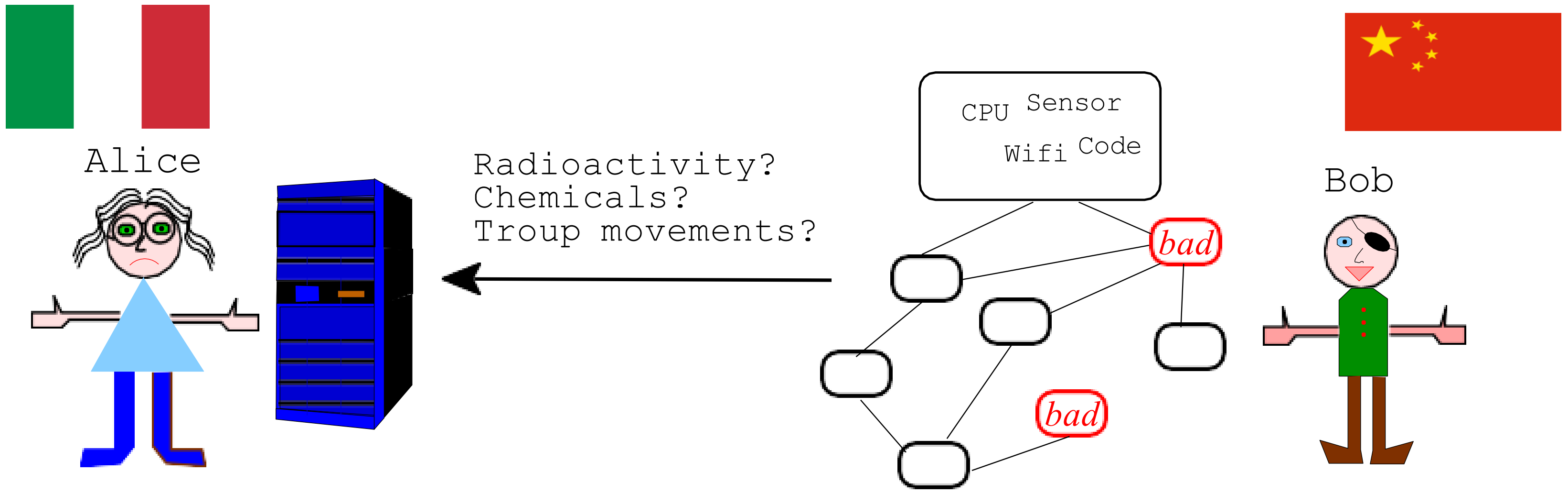
- Medical records must be protected from improper access and improper modification.
- Records are stored on one secure site, accessed from multiple (sometimes mobile) devices.



```
if (role="doctor")
   allow(read|write)
elsif (role="nurse")
   allow(read)
elsif (role="janitor")
   allow(nothing)
```

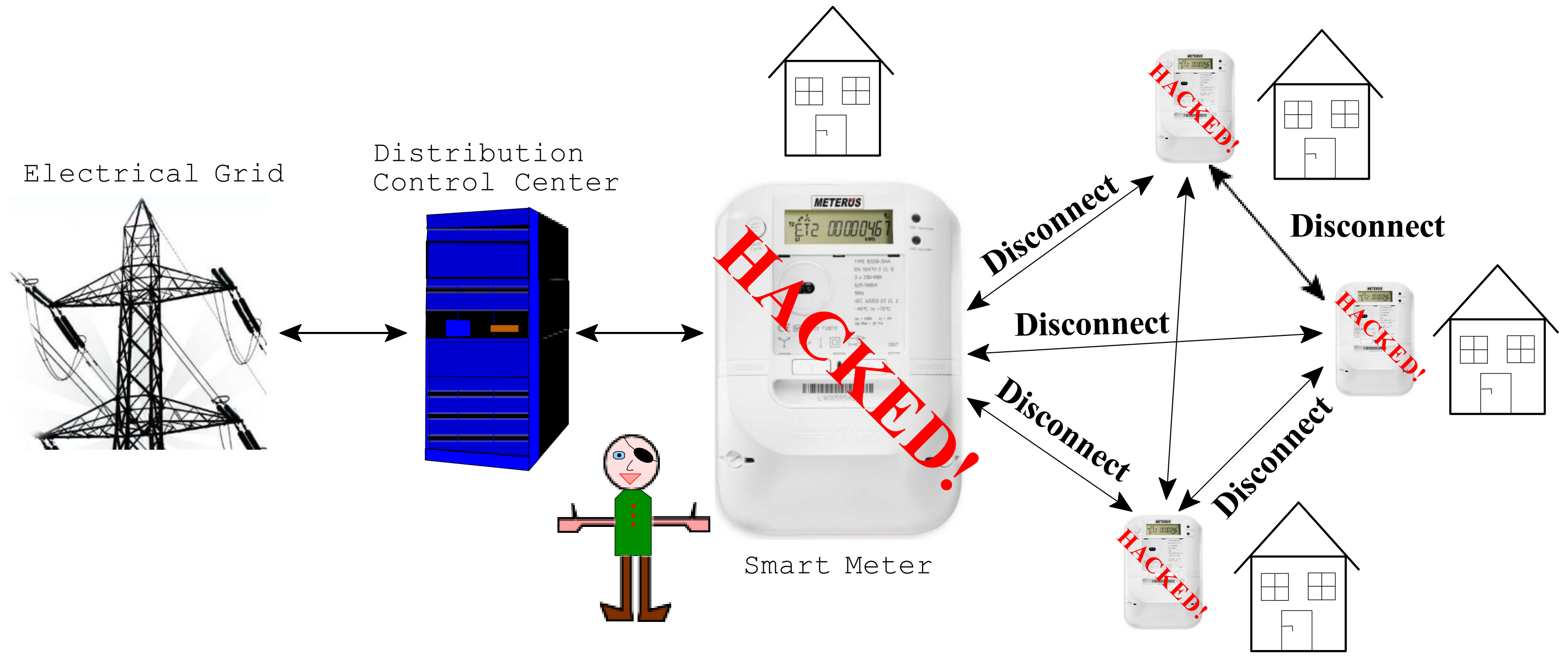
Wireless sensor networks

- Sensor networks are common in military scenarios.
- The enemy can intercept/analyse/modify sensors.



Advanced Metering Infrastructure

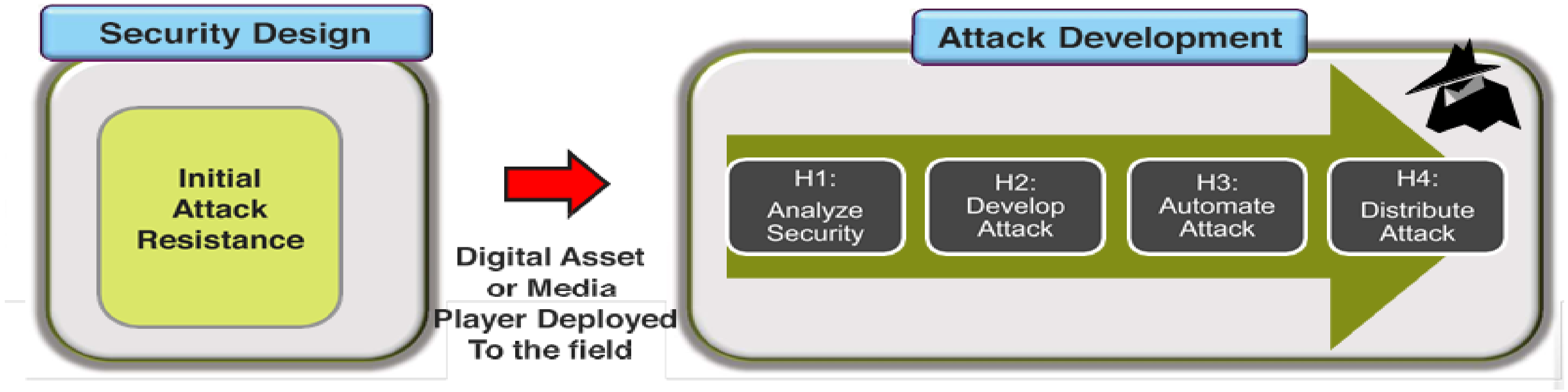
- Selective black-outs, consumers can adjust usage based on current costs, small-scale energy production, . . .



Dynamic Security

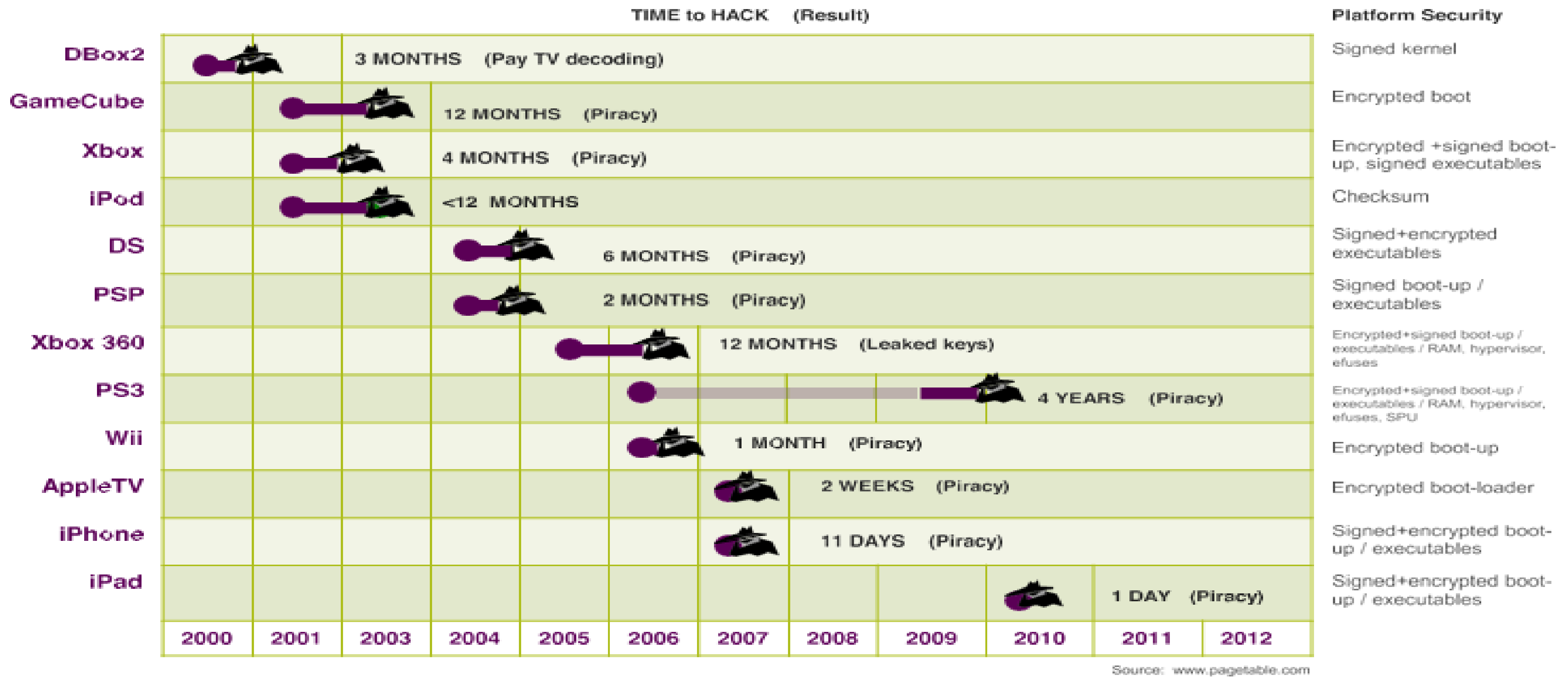
Static Security

- Typical approach to security is to assume that the initial design will remain secure over time
- Anything can be hacked given enough time and effort
  - Set top boxes, C apps, Mobile devices
- Content Owners want to know
  - How will you limit potential damages if there is a breach?
  - What is your renewability strategy?



Static Security

All popular platforms that rely on static security have been permanently hacked

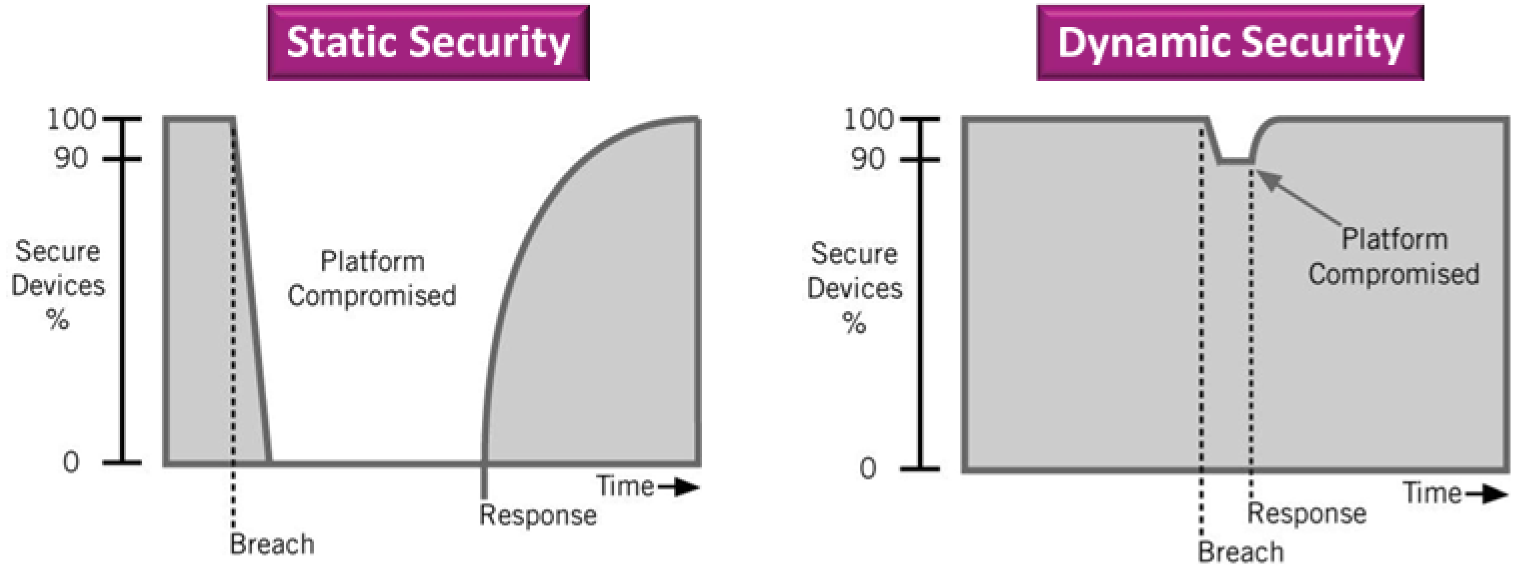


What is Dynamic Security?

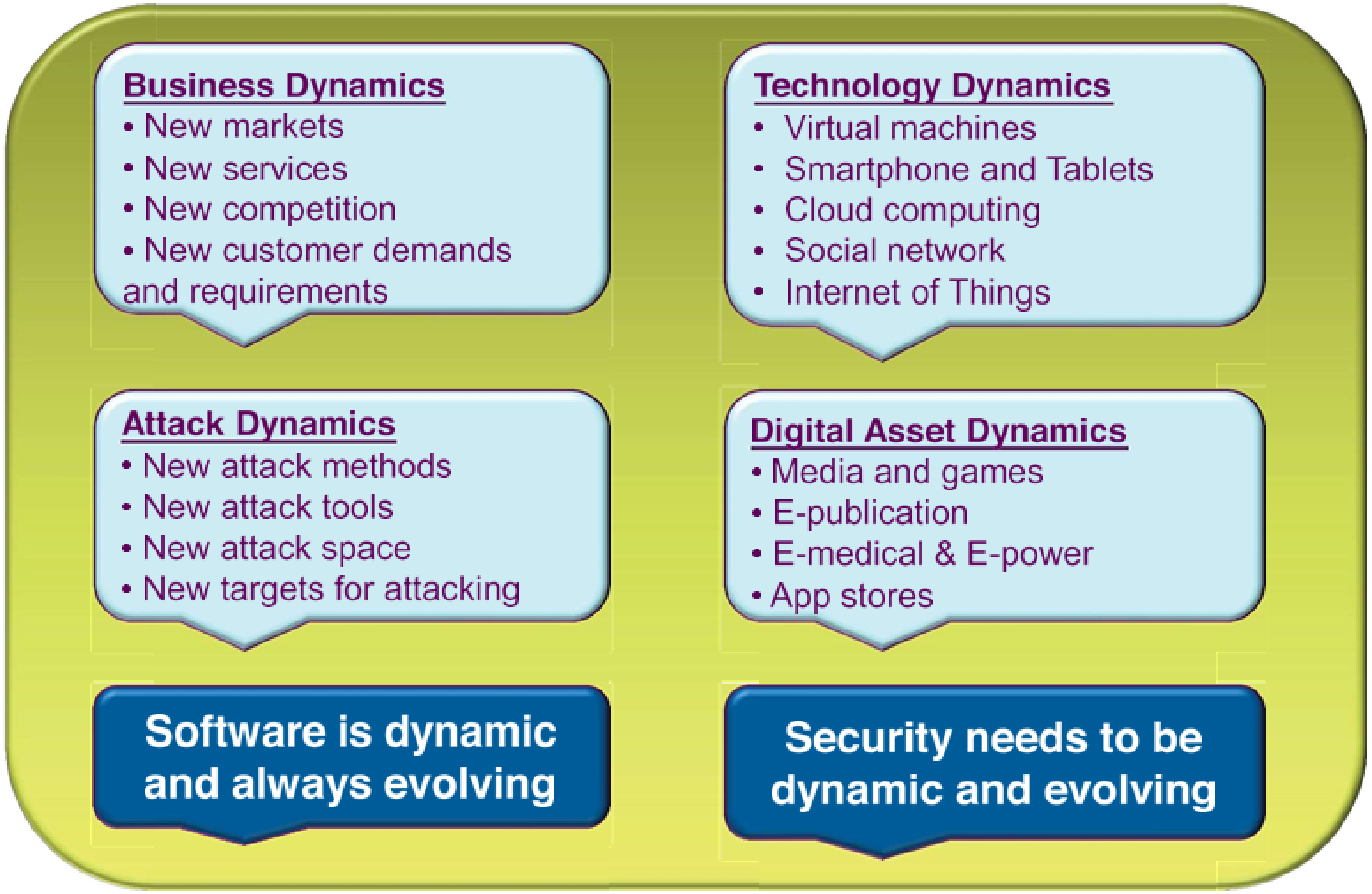
- It is a security model that enables the protection of digital assets against unauthorized use through the upgrade and renewal of the underlying security in the field.
- Proactive Prevention
  - Monitor hacker channels to understand attack techniques
  - Apply security updates to reset hacker’s clock
- Reactive reduction
  - Limits the impact of a breach before it has a big impact
- Benefits
  - Mitigate breach impact and business disruption
  - Thwart potential hacks before they happen

Static vs Dynamic Security

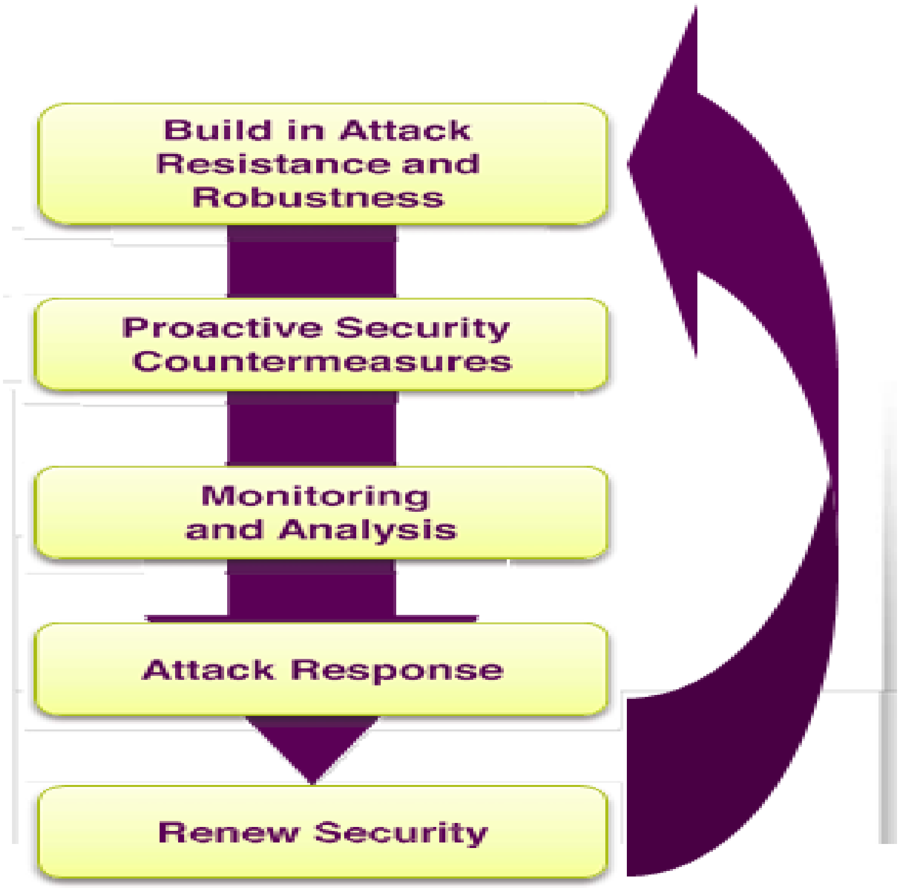
- Once static security breaks, the entire security is gone and hard to be restored
- Once dynamic security breaks, the security can be renewed and restored immediately in a planned way



Dynamic Security is Essential



Security Lifecycle Management


Build in Attack Resistance and Robustness
Proactive Security Countermeasures
Monitoring and Analysis
Attack Response
Renew Security

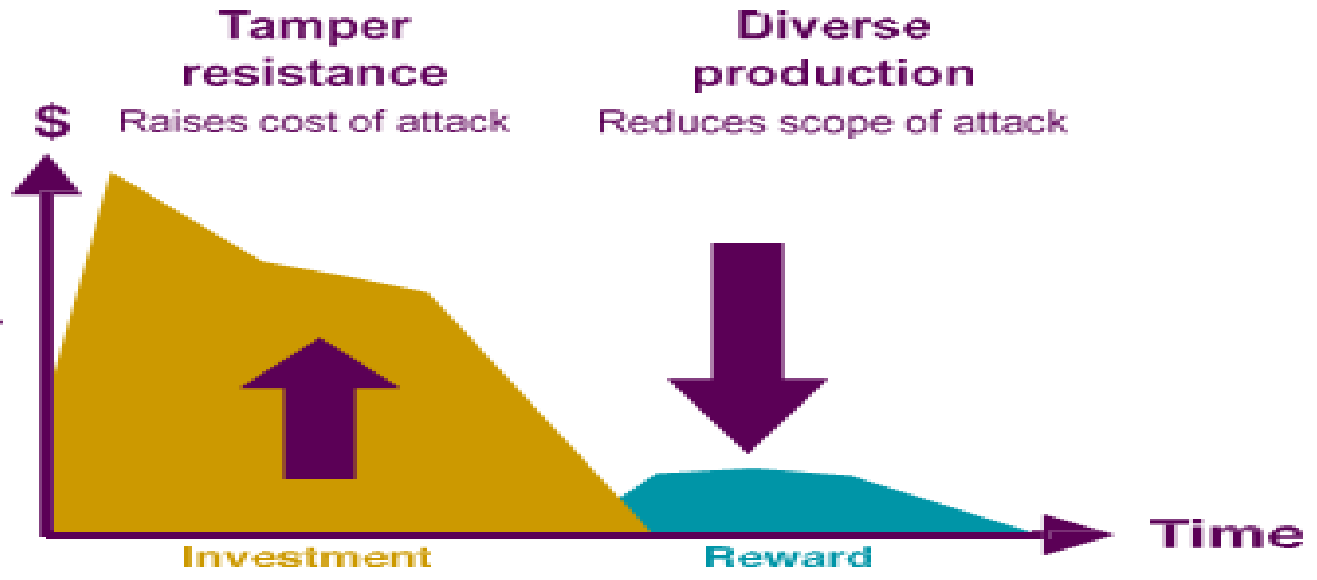
Software Protection

Deploying Obfuscation

- Monitor adversarial communities
- Be prepared with new technologies
- Give adversaries a diversity of targets
  - Spatial diversity
  - Temporal diversity
  - Semantic diversity
- Remote Attestation

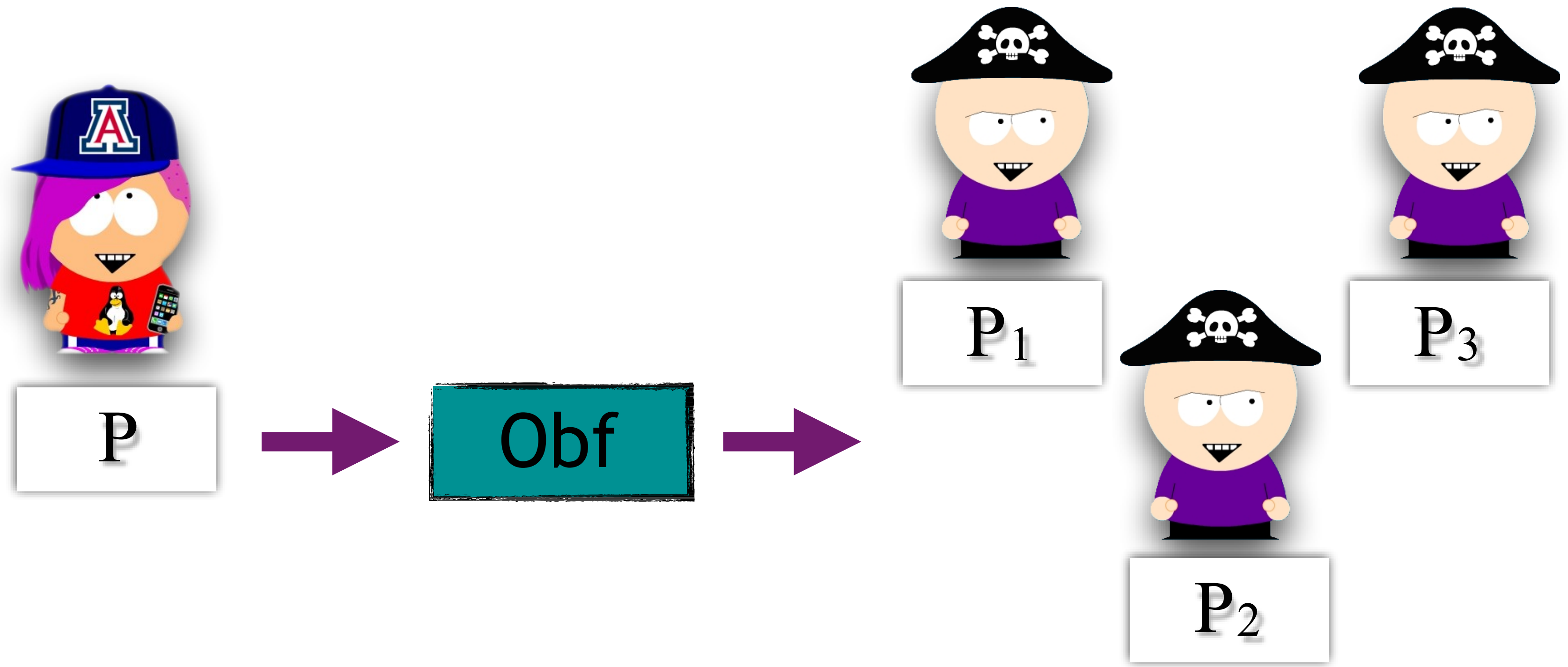
Software Diversity

- Minimize scope of attack
- Prevent automated attacks
- Provide rapid recovery in the event of an attack
- Make the business unattractive to the hacker



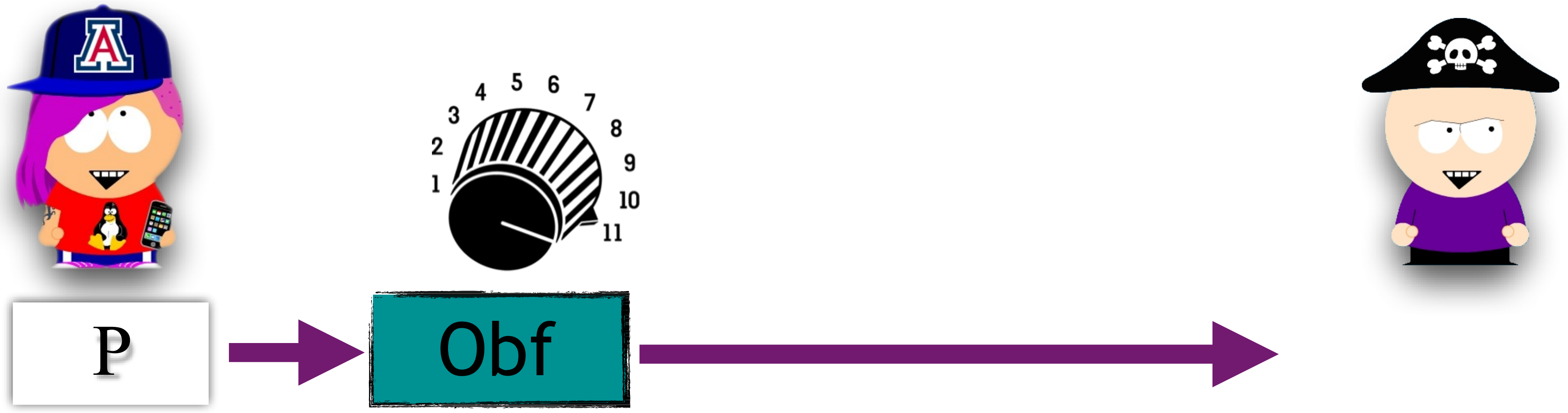
Spatial Diversity

- Prevent collusion by giving each adversary a differently obfuscated program



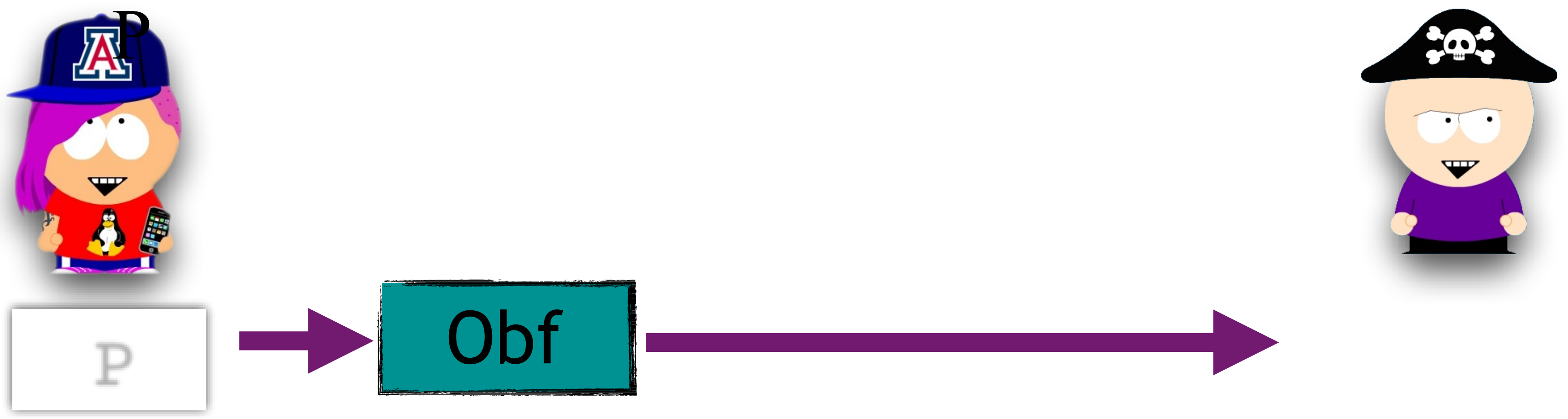
Temporal Diversity

- Adversary sees a sequence of code variants over time
- Overwhelm his analytical abilities
- Small time window to execute an attack



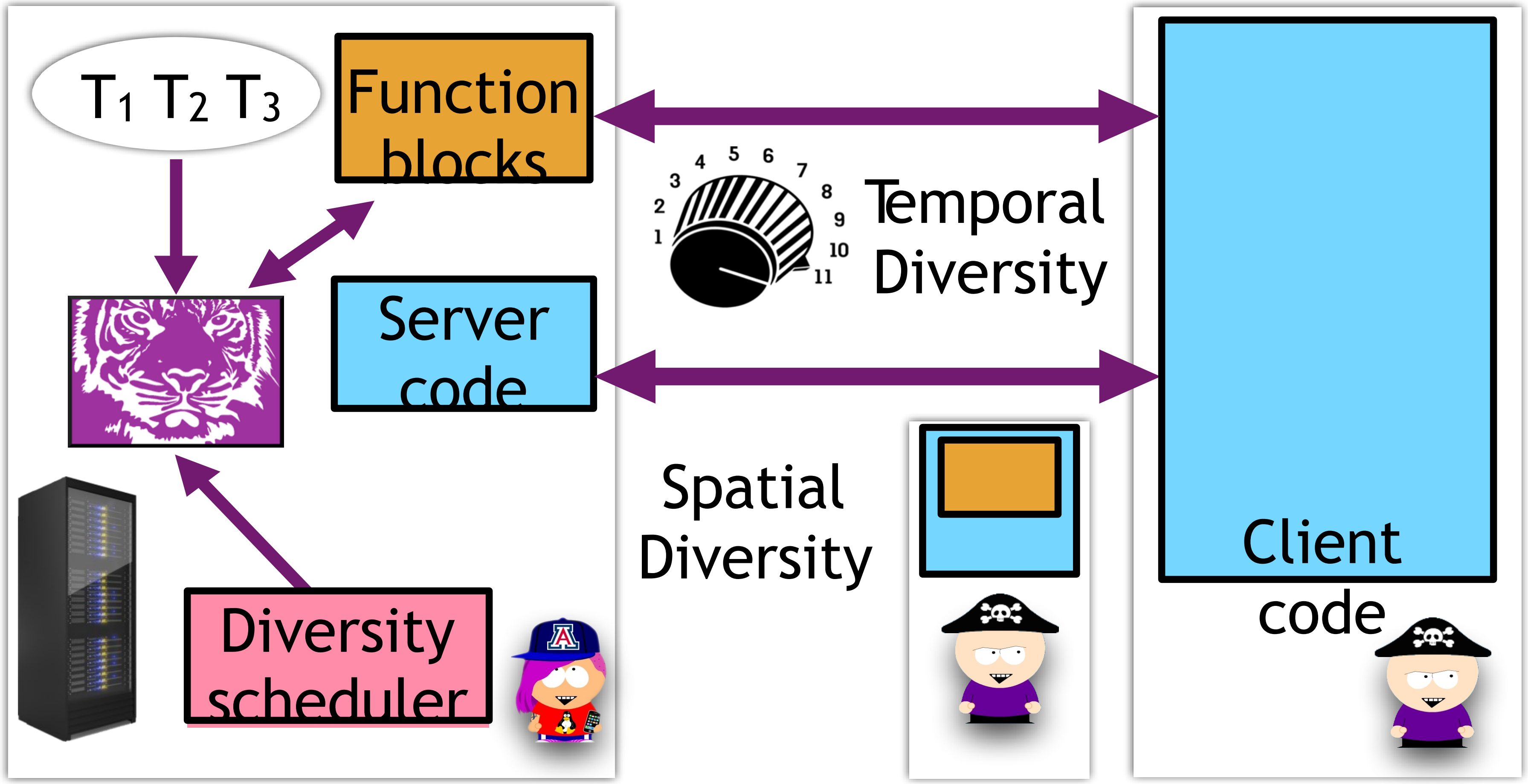
Semantic Diversity

- Code variants are semantically incompatible
- Previously cracked code variants have no value
- Known as “Software Aging”



Jakobsson, et al., Discouraging Software Piracy Using Software Aging, S&P in DRM, 2002

Continuous Replacement



Collberg, et al., Distr. app. tamper detection via continuous softw. updates, ACSAC'12

Remote Attestation

- Extending the idea of Code Guards by sending hashes to a trusted server
  - Decouple hash calculation from hash verification
- "Prove your integrity” challenges
- Challenge = mobile code sent from trusted entity to the client
  - run a different testsuite on the App code and O.S. System and collect results
  - Results checked by the trusted server to detect tampering

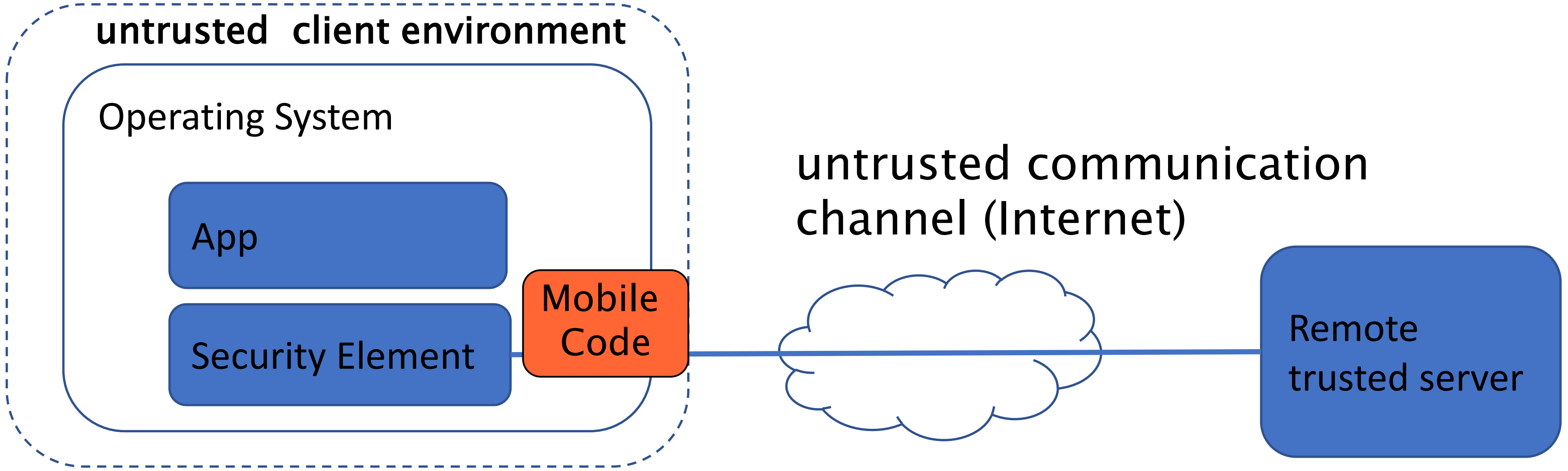
Renewable Remote Attestation

- Tamper-detection code (Self-checkers) are usually embedded in code but they might be removed/ disabled
- Mobile code sent from server linked at run-time
  - to renew self-checkers of binary integrity
- Prototype based on JVM TI extension

P. Falcarin, R. Scandariato, and M. Baldi, "Remote trust with aspect oriented programming," in IEEE Int. Conf. on Advanced Information and Networking Applications (AINA-06), 2006.
R. Scandariato, Y. Ofek, P. Falcarin, and M. Baldi, "Application-Oriented Trust in Distributed Computing," in IEEE Int. Conference on Availability, Reliability and Security (ARES-2008).

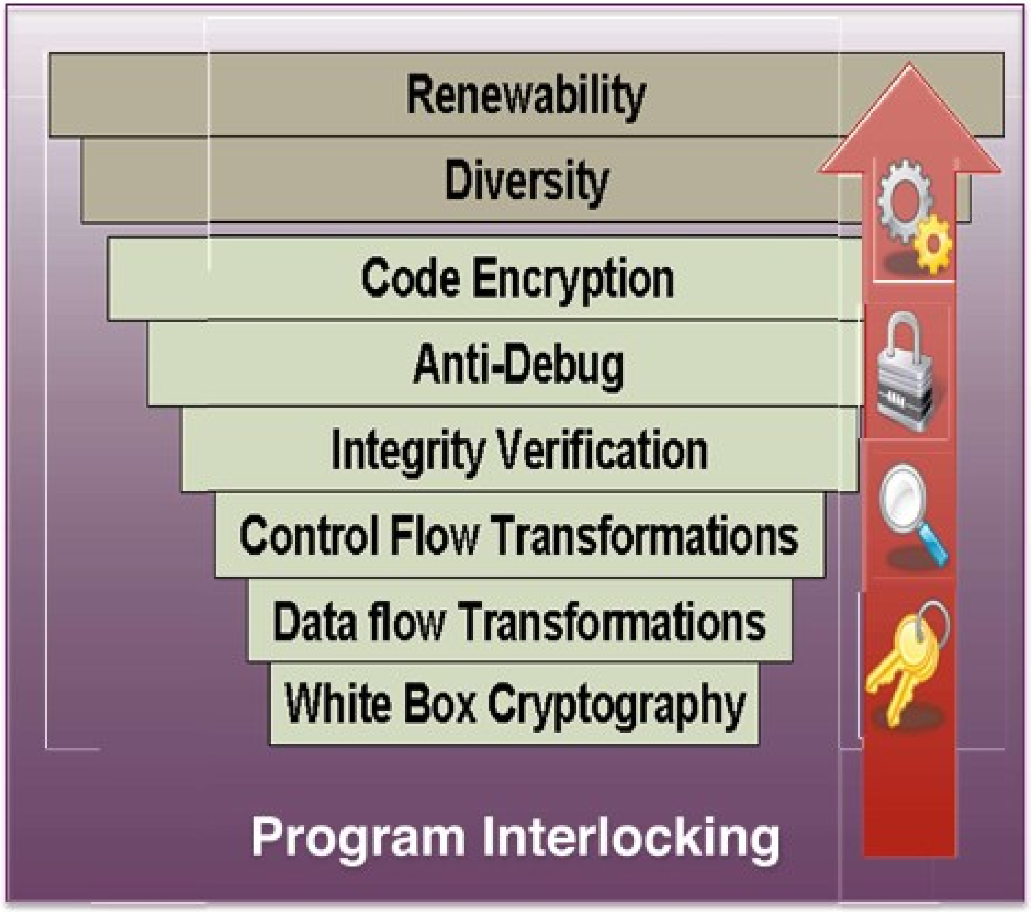
Network-based protections & Mobile Code

- Code mobility makes more difficult to tamper with the code
- Mobile Code from Remote trusted server can be applied on
  - App ➔ Dynamic Binary Obfuscation
  - Op. System ➔ Remote Attestation
  - Security element ➔ Renewable protections (self-checkers)


untrusted client environment
Operating System
App
Security Element
Mobile Code
untrusted communication channel (Internet)
Remote trusted server

Multi-Layer and Interlocked Protection

- Protection application code against collection of attacks
- Provides a multi-layered and interlocked defences
- Flexible and modular to choose the right combination of defences
- Making Security inseparable from your software



Conclusions

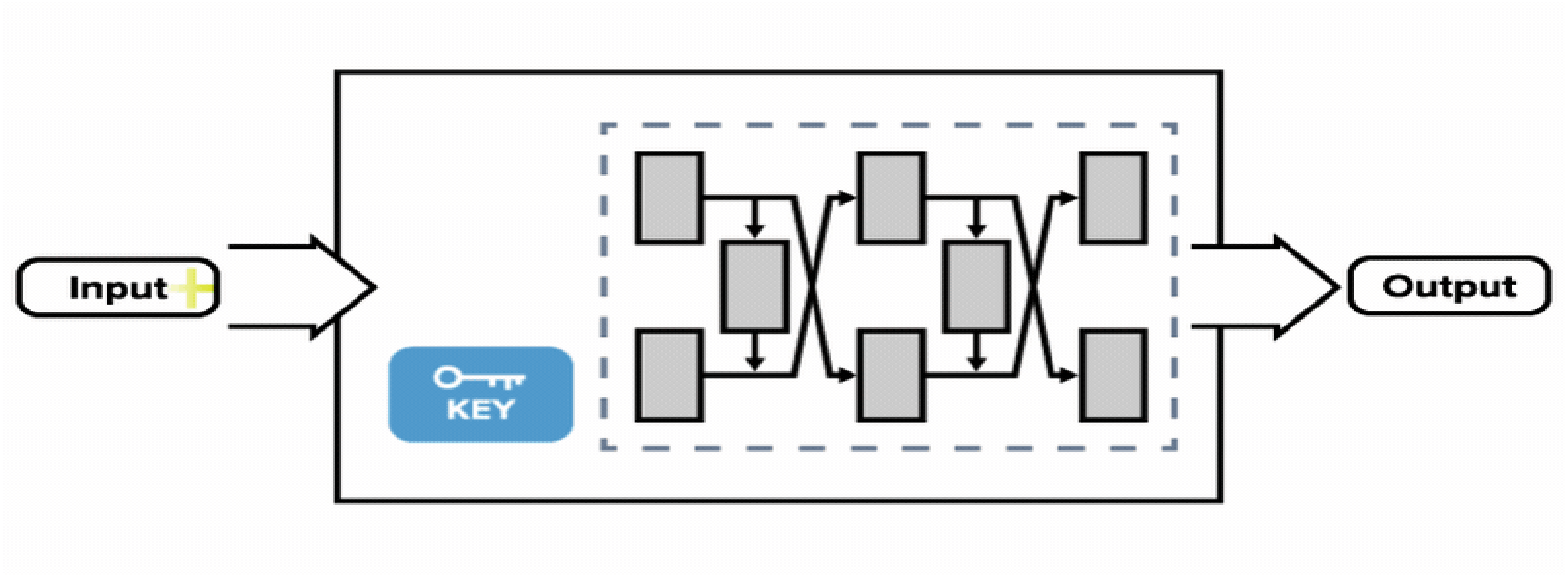
- Scenarios where obfuscation can be useful
- Obfuscating transformations that give time-limited protection
- Updatable security for longer-term protection

- But, how do we know we’re doing anything good?

White Box Cryptography

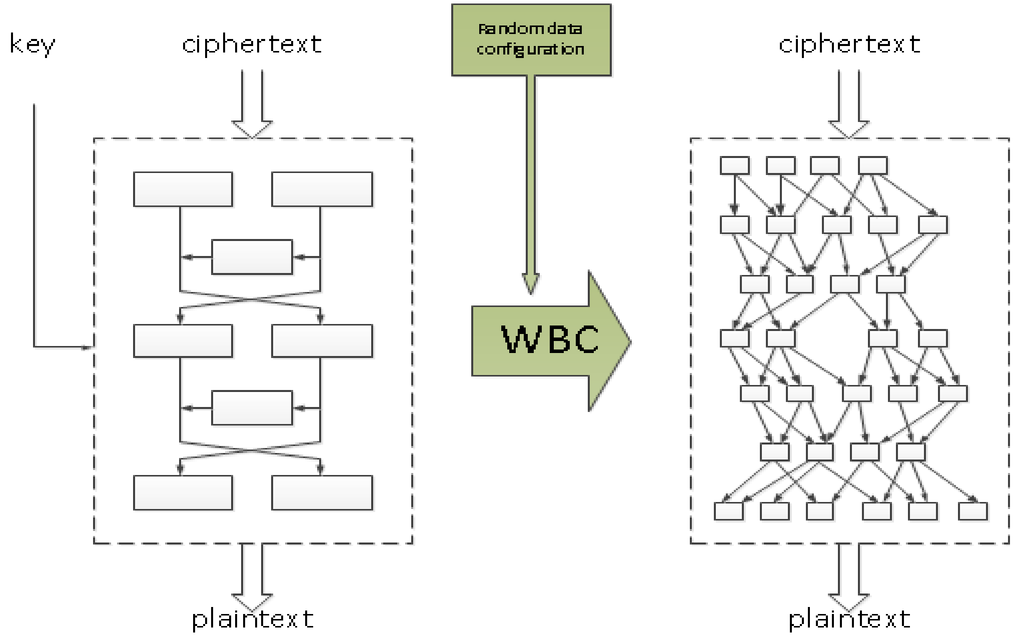
The problem

- A standard encryption algorithm requires that the key be present.
- The key is visible in a debugger at run-time.
- Attackers could easily grab secret keys from the binary implementation, from memory, or intercept information that would lead to disclosure at execution time.



White Box Cryptography

- *White-box encryption* is an obfuscation approach which can resist to key extraction attacks (Chow et al)
- Embed the secret key in “haystack” of code and data
- Strong Obfuscation of crypto code

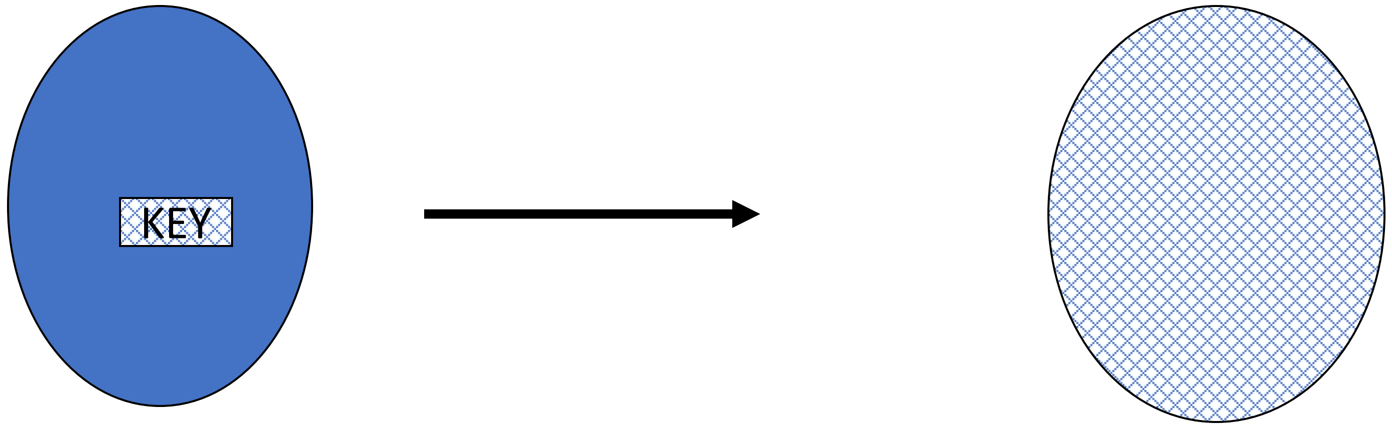


WBC Applications

- Software Agents
  - Embedded cryptographic keys for signing purposes
- Digital Rights Management (DRM)
- Smart Card Technology
- Asymmetric crypto system

White Box Crypto General Idea

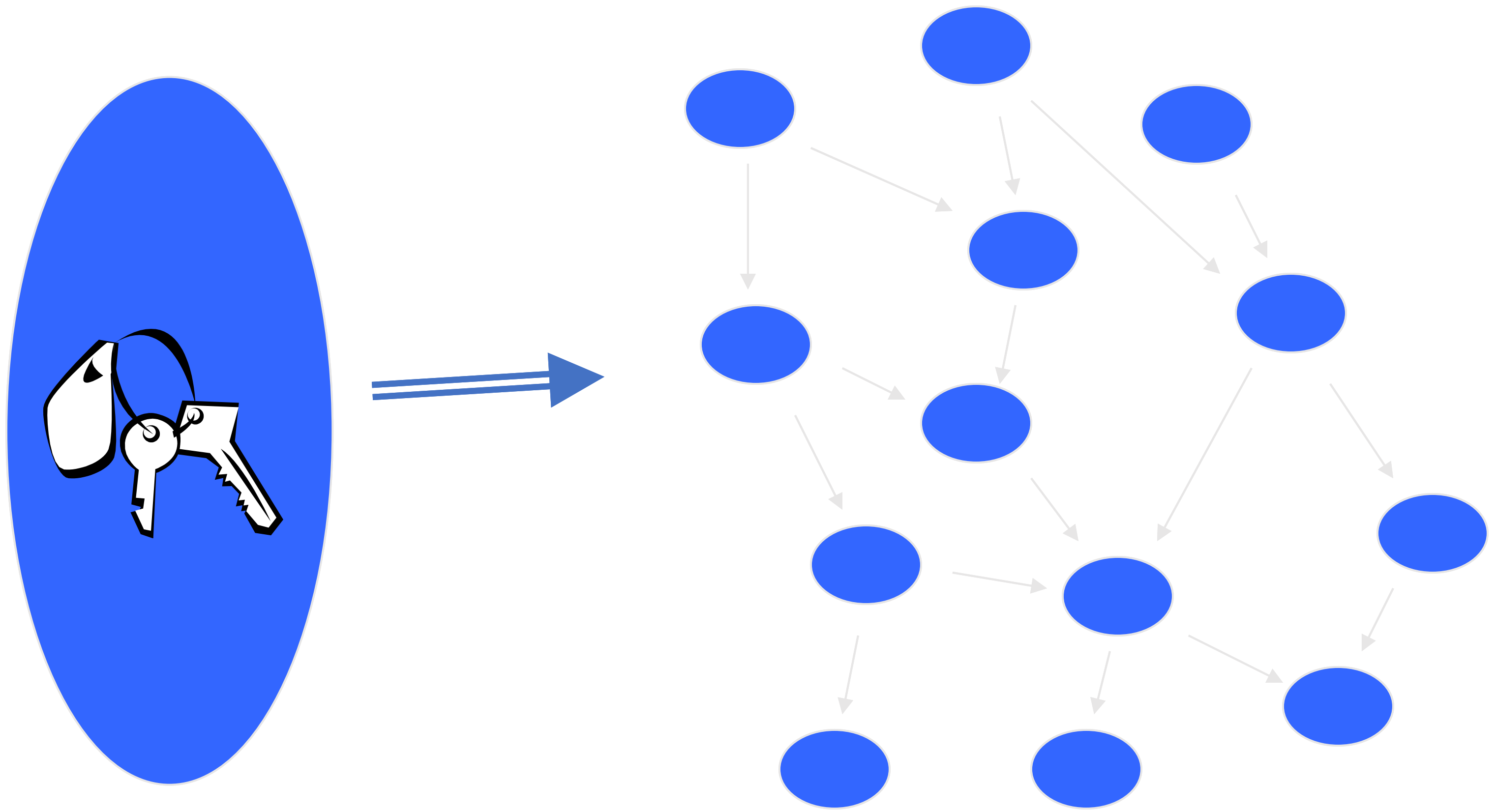
Spreading embedded secret information



Thus, forcing an attacker to understand a greater part of the implementation

How?

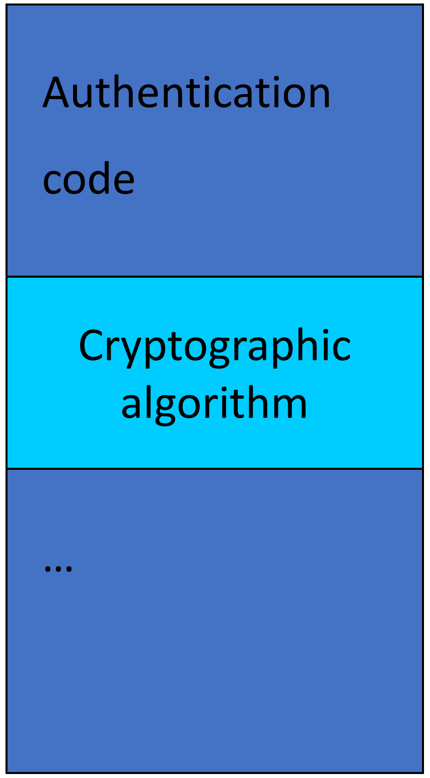
- White-Box
- Transformations



Transform an algorithm into a series of key-dependent lookup tables

WBC General idea

Expanding the cryptographic border



- External function encoding

$$E'_k = g \circ E_k \circ f$$

- Attacker:
  - Analyse E'_k
  - Isolate random bijections g, f
  - Analyse E_k to find k
- Goal: make isolation difficult

White-Box Transformations

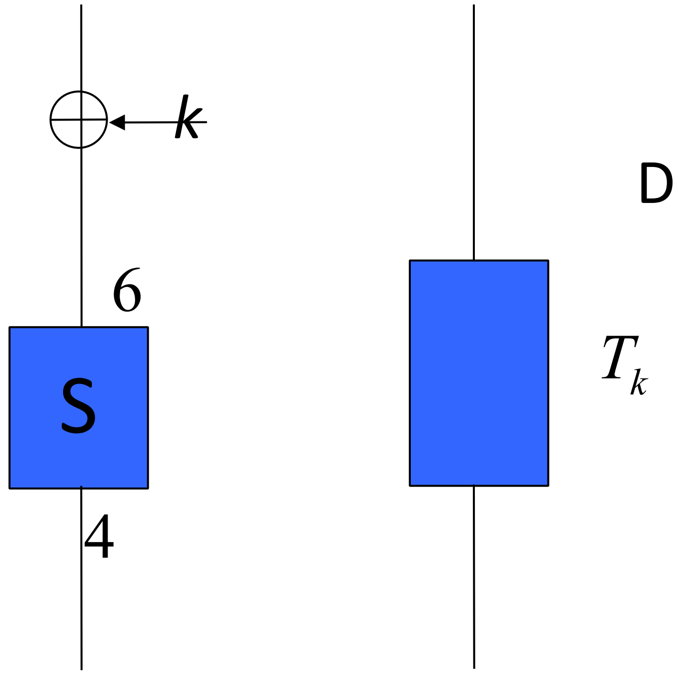
- Partial Evaluation
- Combined Function Encoding
- By-Pass Encoding
- Split Path Encoding
- …

Techniques apply on cryptographic algorithms build with XOR, substitution and permutation functions

- AES, DES, …

White-Box Transformations (2)

- Partial Evaluation

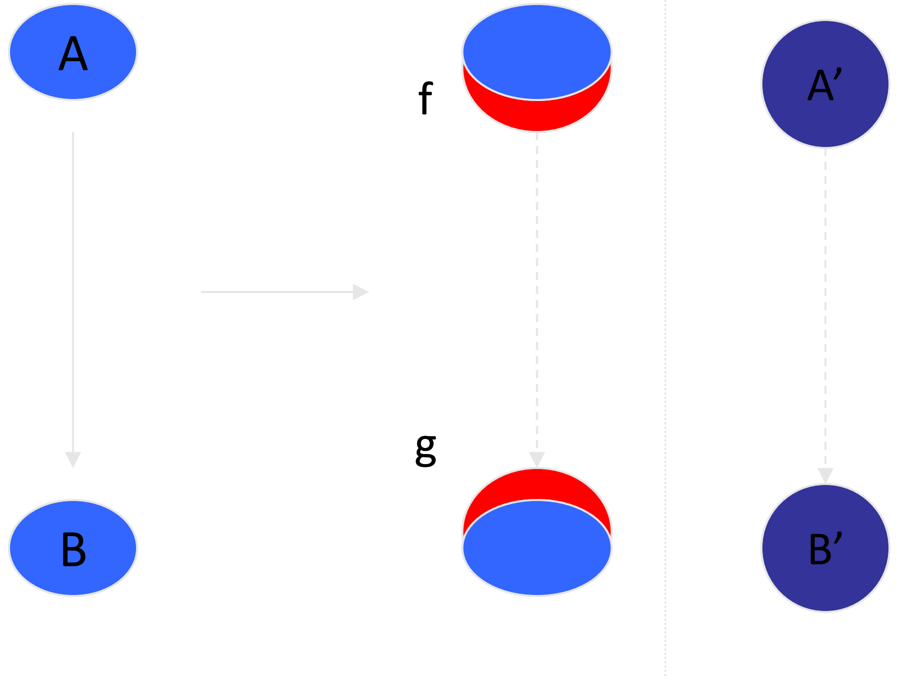


$$T_k = S(x \oplus k)$$

Definition of a new key-dependent lookup table

White-Box Transformations (3)

- Internal Function Encoding



Choose random bijection f

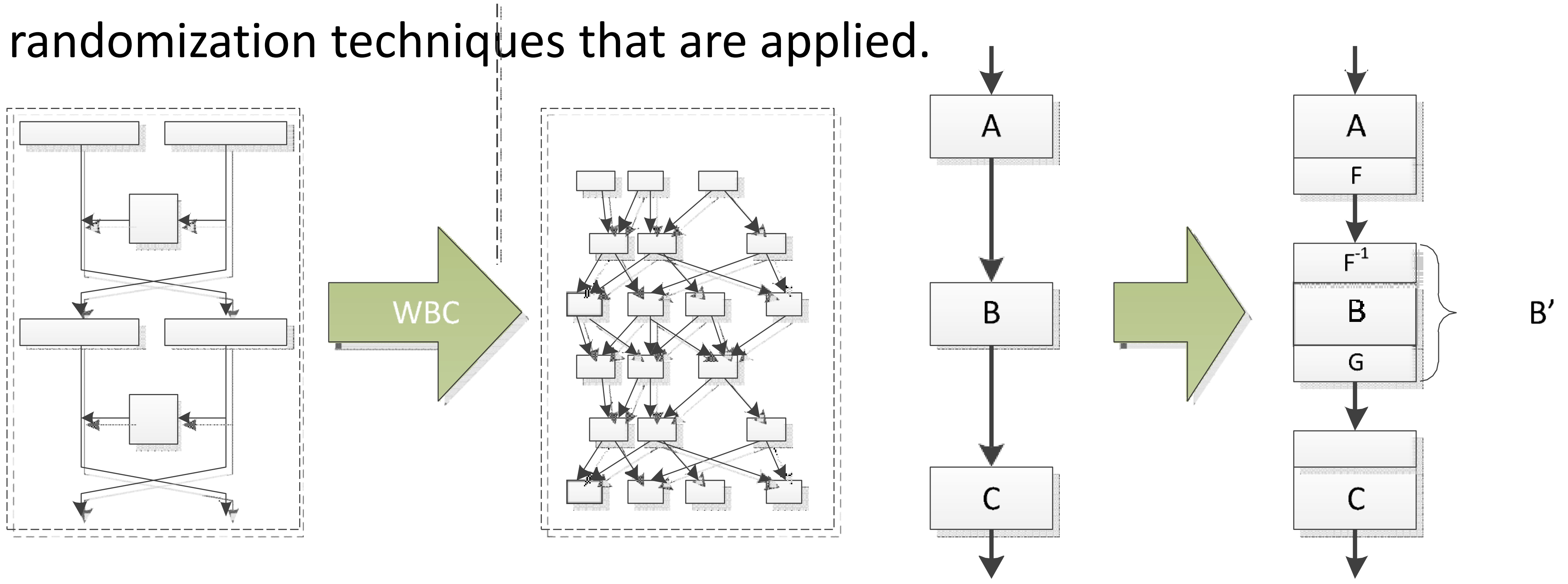
and $g = f^{-1}$

Encoded version:

$$\begin{cases} A' = f \circ A \\ B' = B \circ g \end{cases}$$

Chow et al. WB implementation

- The secret key is hard-coded into the lookup tables and protected by randomization techniques that are applied.



(a) Transformation into network of lookup tables

(b) Encoded lookup tables

White Box Encryption in DRM Systems

- White-box encryption approach pre-evaluates all the operations related to keys and replaces corresponding codes.
- Each function XORs the plaintext with a round key, and then employs a lookup table and a permutation box to produce the output.

Some Numbers

- DES
  - Chow et al.: 4,54 Mb
  - Improvement by Link et al.: 2,25 Mb
- AES
  - Normal implementation: 4.352 bytes
  - Chow et al.: 770.048 bytes

    177 times bigger, 55 times slower

    3104 lookups

Local Security

- Internal function encoding provides local security
- A’ is known. Because the bijection f is random, no information can be revealed of A
- Similar to one time path

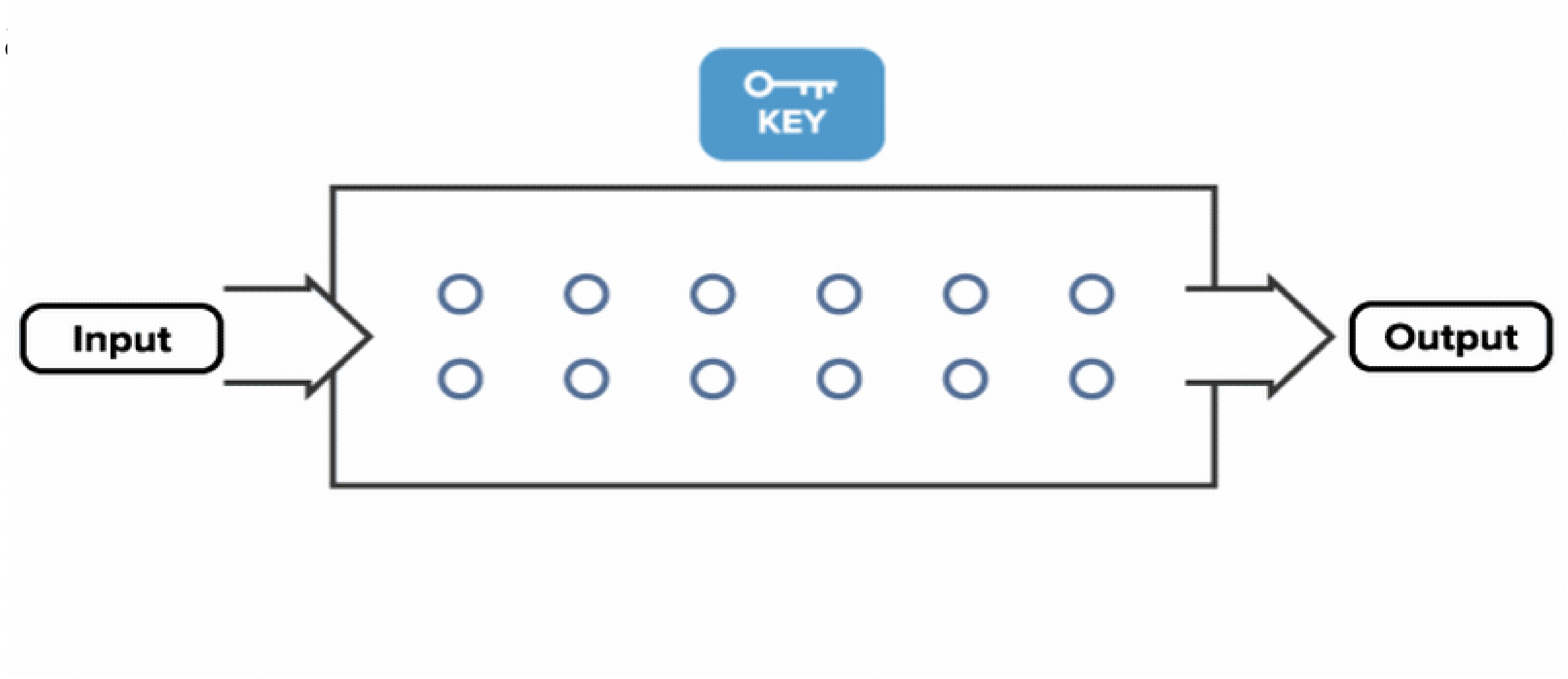
Global Security

- Currently no proof
- Can we guarantee white-box security?
- Trade-off between performance and level of security

- AES: Cryptanalysis by Billet et al. (2004)

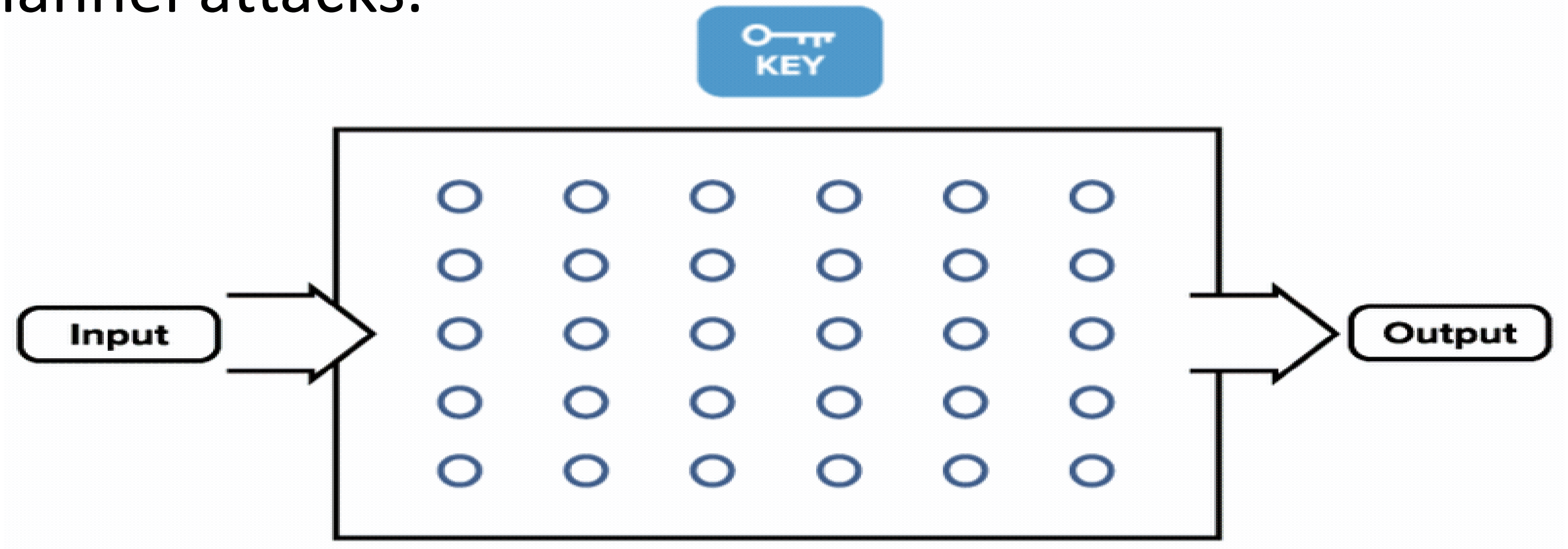
White-Box Cryptography recap

- White-box technology hides the key.
- 2nd generation white-box tools attempt to randomize execution behaviour (Chow et al., 2002)
- The basic flow of the algorithm is unchanged and is vulnerable to side-channel



White-Box Cryptography

- New 3rd generation white-box tools hide the key and randomise **ALL** execution behaviours.
- They provide greater depth and strength of security and are not vulnerable to side-channel attacks.



1. https://paceap.com
2. http://Irdeto.com

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