Flowers for Automated Malware Analysis

Chengyu Song and Paul Royal
College of Computing
Georgia Institute of Technology

Agenda

- Modern Malware
- History of Malware Analysis
  - Technologies, Detections, Transparency Requirements
- Inverting Environment Detection
  - Flashback
- Defeating Automated Malware Analysis
  - Host Identity-based Encryption (HIE)
  - Instruction Set Localization (ISL)
- Discussion
  - Potential Countermeasures
- Conclusion

Modern Malware

Modern Malware

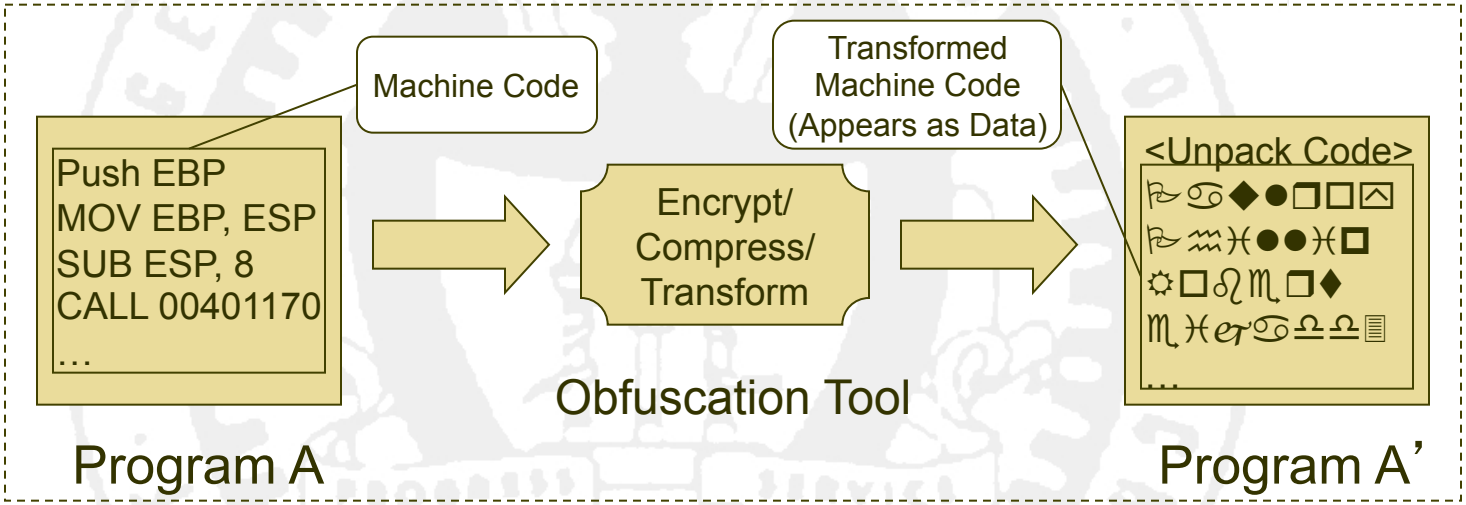
- **The centerpiece of current threats on the Internet**
  - **Botnets (Spamming, DDOS, etc.)**
  - **Information Theft**
  - **Financial Fraud**
- **Used by real criminals**
  - **Criminal Infrastructure**
  - **Domain of Organized Crime**

Malware Cont'd

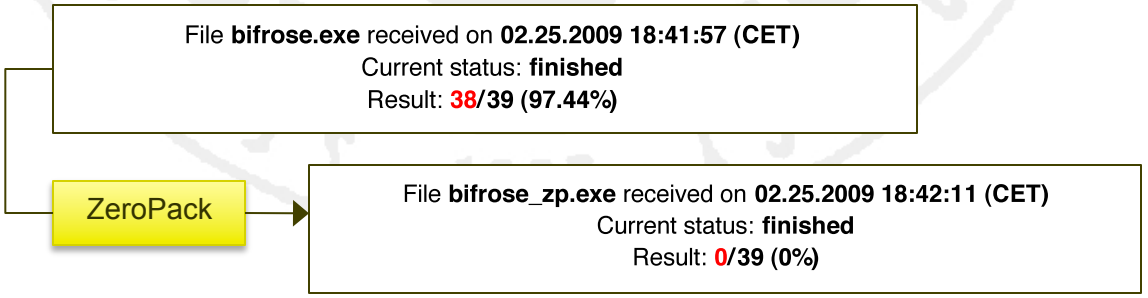
- **There is a pronounced need to understand malware behavior**
  - **Threat Discovery and Analysis**
  - **Compromise Detection**
  - **Forensics and Asset Remediation**
- **Malware authors make analysis challenging**
  - **Direct financial motivation**

Malware Obfuscations

- **Pictorial Overview**

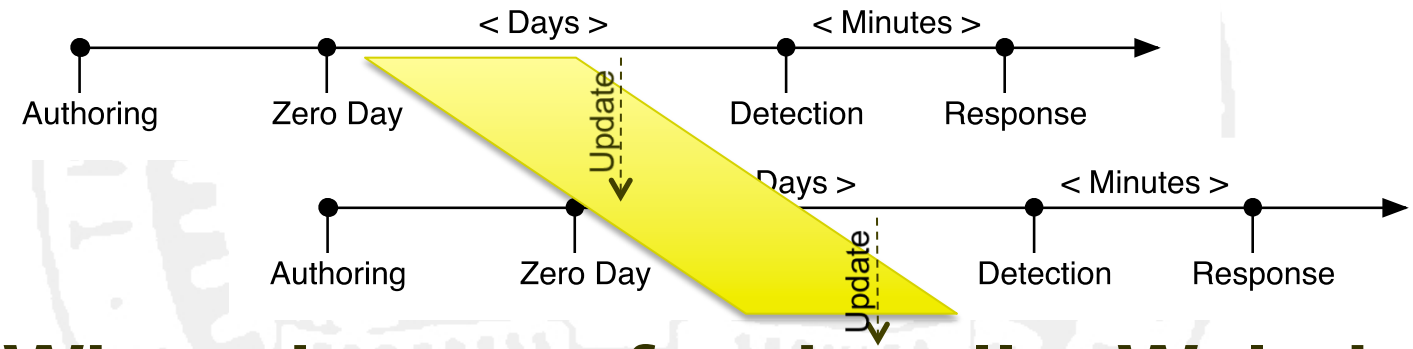


- **Project ZeroPack**



Obfuscations Cont'd

- **Server-side Polymorphism**
  - **Automate mutations**



- **When done professionally: Waledac**

Collected on 12/30/2008

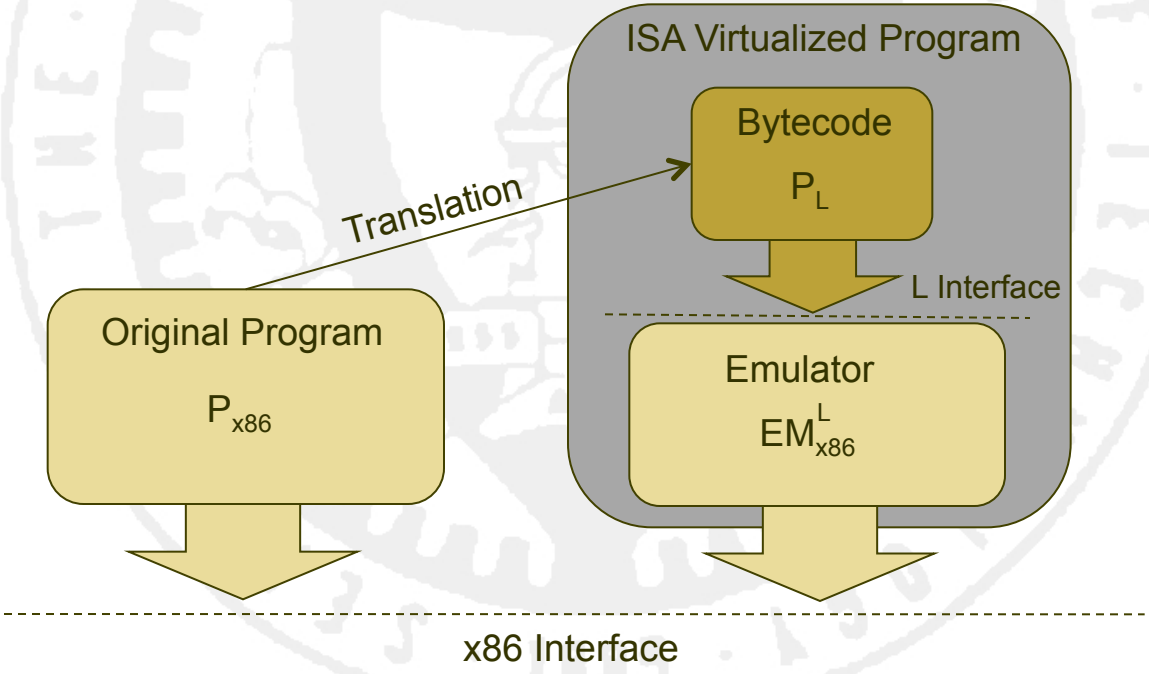
File **postcard.exe** received on **02.25.2009 22:03:16 (CET)**
Current status: **finished**
Result: **35/39 (89.75%)**

Collected on 2/25/2009

File **disc.exe** received on **02.25.2009 21:53:13 (CET)**
Current status: **finished**
Result: **11/39 (28.21%)**

Obfuscations Cont'd

- **ISA Virtualized Malware**
  - **VMProtect, Code Virtualizer**



History of Malware Analysis Technologies

In-guest Tools

- **Reside in the analysis environment**
- **Vulnerable to detection of monitoring instrumentation**

```
HMODULE kernel32 = NULL;
void *createfile_function_pointer = NULL;
unsigned char opcodes[2];

kernel32 = LoadLibrary("kernel32");
createfile_function_pointer =
      (void*)GetProcAddress(kernel32, "CreateFileA");
memcpy(opcodes, createfile_function_pointer, sizeof
(opcodes));

if(opcodes[0] == 0xFF && opcodes[1] == 0x25){
      puts(“Instrumentation detected.”);
}
```

Reduced-privilege VMMs

- **Operate through sensitive data structure relocation, binary software translation**
- **Vulnerable to detection of side effects**
- **In older versions of VMWare, SYSRET treated as NOP when executed in ring 3**

Whole-system Emulators

- **Operate by emulating processor ISA (e.g., x86)**
- **Vulnerable to detection of unfaithful CPU emulation**

```
#include <stdlib.h>
#include <stdio.h>
#include <windows.h>

int seh_handler(struct
                _EXCEPTION_RECORD
                *exception_record,
   void *established_frame,
   struct _CONTEXT *context_record,
   void *dispatcher_context)
{
      printf("Malicious code here.\n");
      exit(0);
}
```

```
int main(int argc, char *argv[]) {

      unsigned int handler =
            (unsigned int) seh_handler;

      printf("Attempting detection.\n");

      __asm("movl %0, %%eax\n\t"
            "pushl %%eax\n\t"::
            "r" (handler): "%eax");
```

```
      __asm("pushl %fs:0\n\t"
            "movl %esp, %fs:0\n\t");

      __asm(".byte 0x26, 0xcf");
      __asm("movl %esp, %eax");
      __asm("movl %eax, %fs:0");
      __asm("addl $8, %esp");

      return EXIT_SUCCESS;
}
```

Hardware Accelerated VMs

- **Operate through use of hardware virtualization extensions (e.g., Intel VT-x or AMD SVM)**
  - **Extensions to x86 ISA (new instructions)**
- **Certain instructions cause VMExits**
  - **Must be handled correctly**
- **Older versions of KVM terminate with unhandled exit on guest execution of VMREAD**

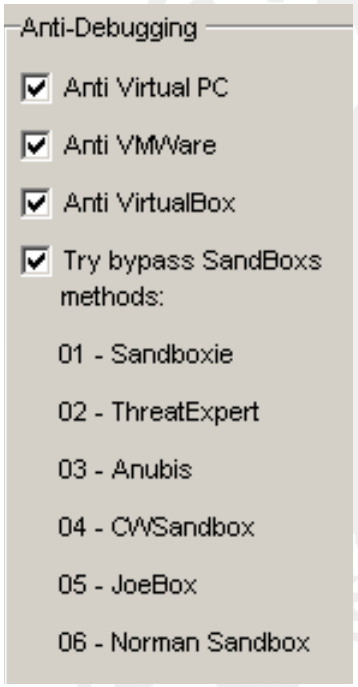
Transparency Requirements

- **Higher Privilege**
- **No Non-privileged Side Effects**
- **Same Instruction Execution Semantics**
- **Identical Exception Handling**
- **Identical Notion of Time**

Requirements Cont'd

- **In-guest Tools**
  - **No higher privilege**
  - **Non-privileged side effects**
  - **Exception handling issues**
- **Reduced Privilege Guests (VMware, etc)**
  - **Non-privileged side effects**
- **Emulation (QEMU, Simics)**
  - **No identical instruction execution semantics**

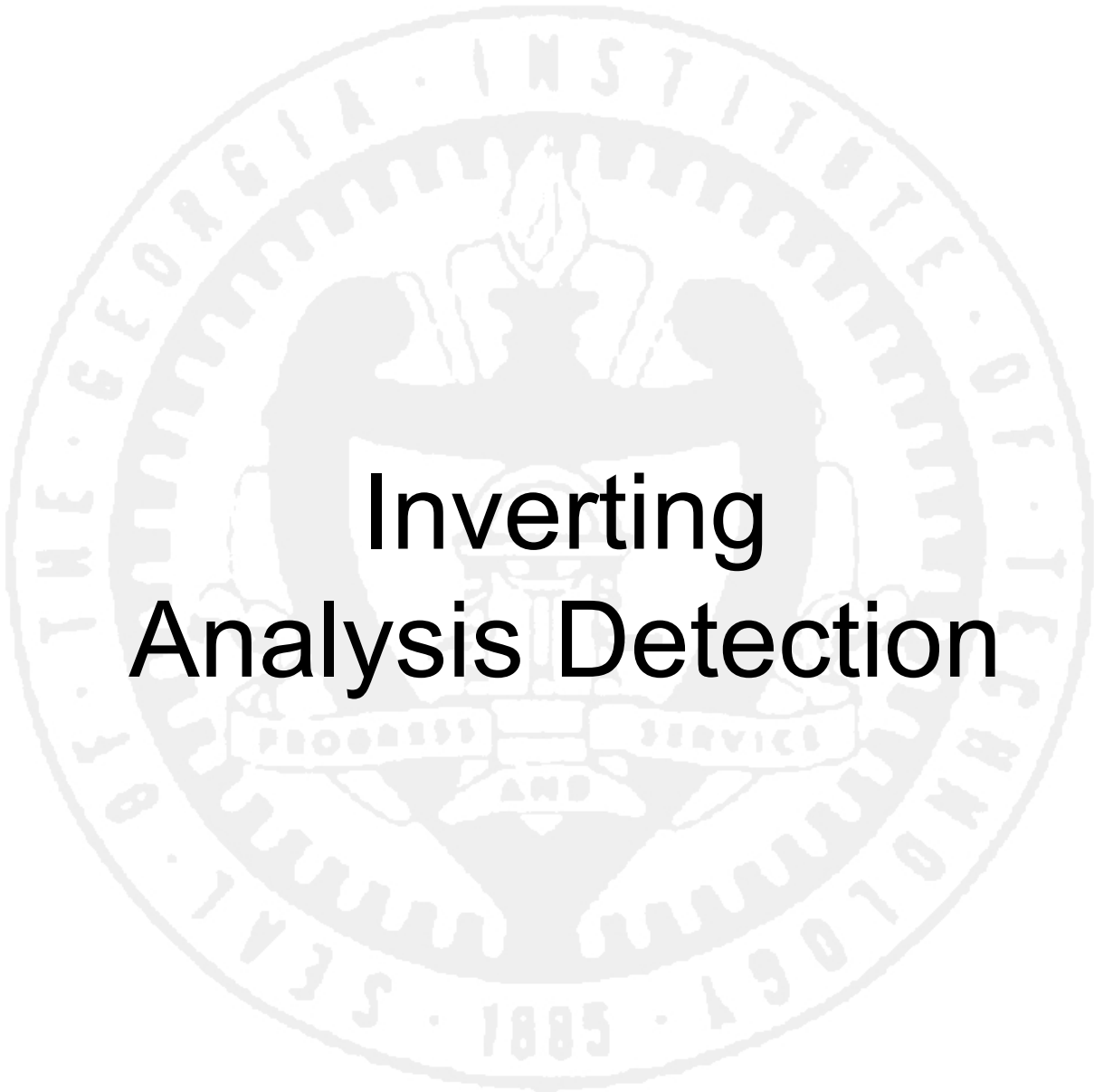
State of Detection



- **Analysis tool/environment detection is a standard, inexpensive option**

State of Detection Cont'd

- **Detections by Popular Malware**
  - **Conficker**
    - **Checks for relocated LDT**
  - **TDL4**
    - **Checks for device emulation via WQL**
  - **Bredolab**
    - **Checks for device emulation via DeviceIoControl()**



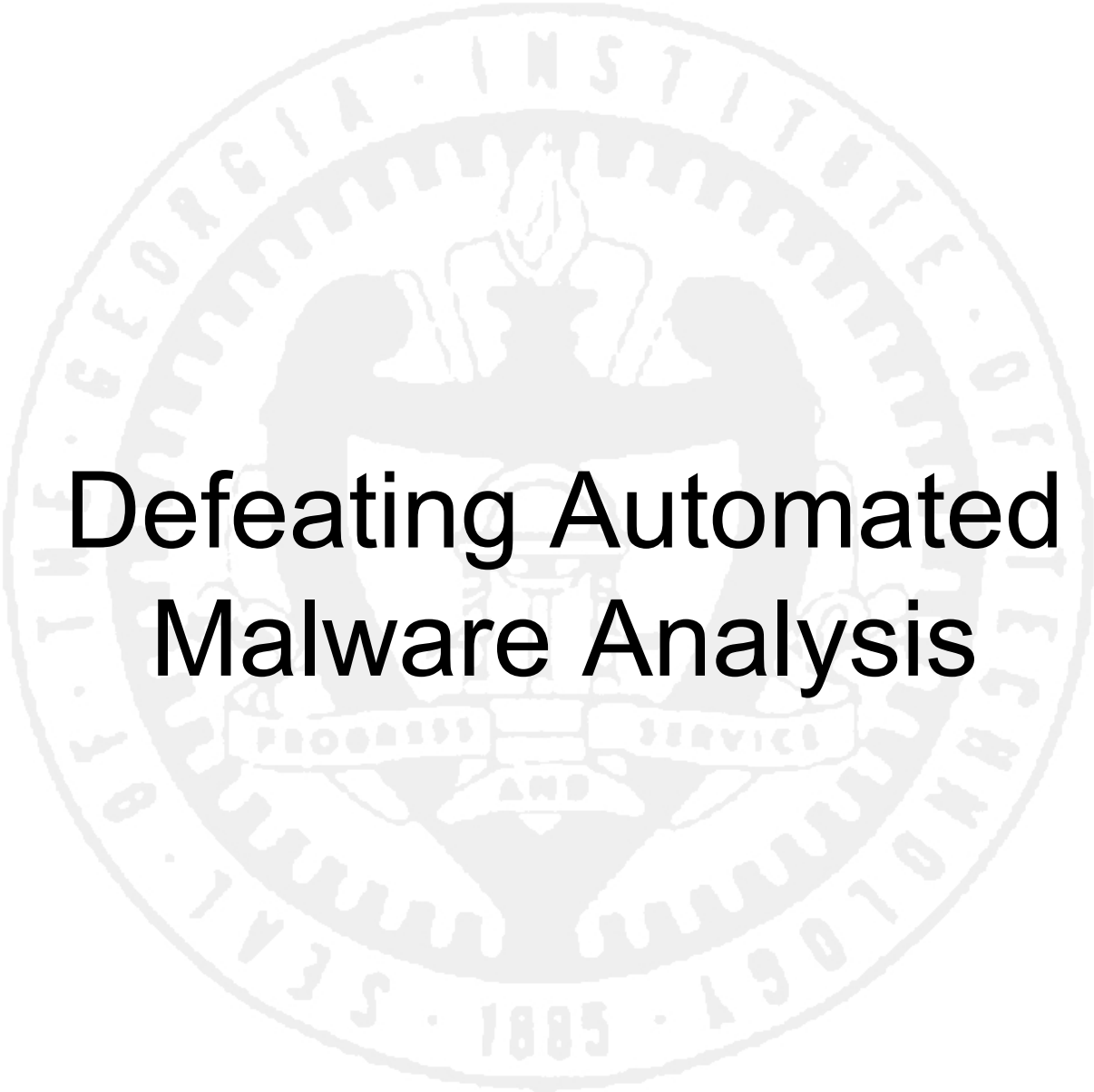
Inverting Analysis Detection

Nature of the Arms Race

- **Until recently, malware was "analysis environment aware"**
  - **Detect analysis environments**
  - **Execute successfully otherwise**
- **Malware could be "analysis environment oblivious"**
  - **Exploit observation that malware is overwhelmingly collected in one environment and analyzed in another**
  - **Bind to and successfully execute only on originally infected host**

Flashback

- **Propagated in part by drive-by downloads**
- **Payload is only intermediate agent**
  - **Agent gathers hardware UUID, submits request to C&C for full version**
  - **Hardware UUID hashed (MD5), hash used as decryption key to RC4 stream cipher**
  - **Full version will only run on host with same hardware UUID**



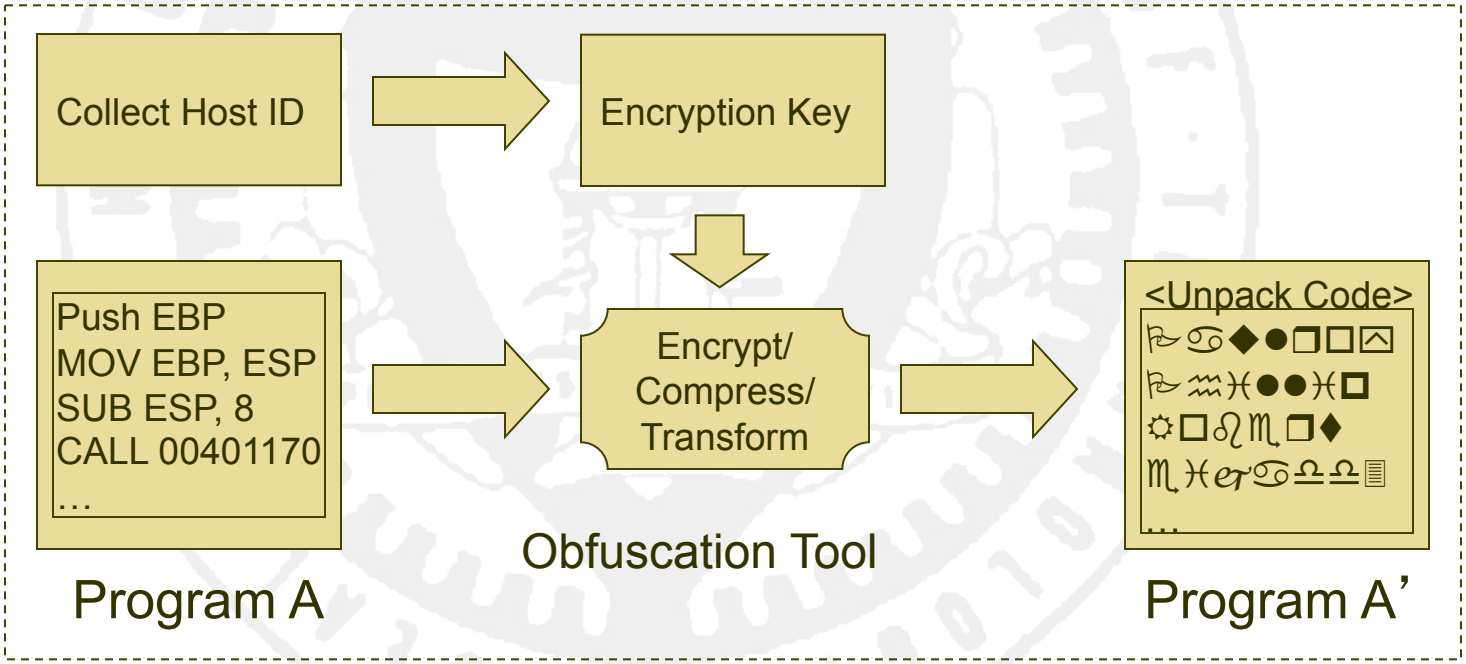
Defeating Automated Malware Analysis

Malware DRM

- **Goal**
  - **Make automated malware analysis ineffective and unscalable**
- **Approach**
  - **Cryptographically bind a malware instance to the originally infected host**
- **Techniques**
  - **Host Identity-based Encryption (HIE)**
  - **Instruction Set Localization (ISL)**

Host Identity-based Encryption

- **Replace random encryption key with a key derived from host identity**



- Host ID: Information that can uniquely identify a host

HIE Cont'd

- **What to encrypt**
  - **Full binary?**
    - **May not be a good idea**
    - **Leaves hint for brute-force cracking**
  - **Instead, only encrypt critical mechanisms**
    - **For example, encrypt C&C domain names or portions of domain name generation algorithm (DGA)**

HIE Cont'd

- **Requirements for Host ID**
  - **Unique**
  - **Invariant (to avoid false positives)**
    - **Can be as short as lifecycle of the malware campaign (e.g., days or weeks)**
  - **Can be gathered without privileges**
  - **No special hardware support**

HIE Cont'd

- **Prototype Host ID (Windows)**
  - **Subset of Process Environment Block**
    - **Username, Computer Name, CPU Identifier**
  - **MAC Address**
  - **GPU Information**
    - **GetAdapterIdentifier**
  - **User Security Identifier (SID)**
    - **Randomly generated by the OS**
    - **Unique across a Windows domain**

HIE Cont'd

- **Key Derivation Function (KDF)**
  - **Key = KDF(ID, Salt, Iteration)**
  - **ID = Concatenation of all information**
  - **Salt = Random number >= 64 bits**
  - **Work Factor/Iteration = 10+/100+**
  - **KDF = Bcrypt or SHA family**

HIE Cont'd

- **Deployment Logistics**
  - **Host ID must be determined before malware instance is installed**
    - **Use intermediate downloader agent**
  - **Intermediate agent could be used by researchers to obtain instance bound to analysis environment**
    - **Use short-lived, one-time URLs similar to password reset procedures**

HIE Cont'd

- **Advantages**
  - **Protections of Modern Cryptography**
    - **Knowledge of how key is derived does not affect the integrity of the protection**
  - **Sample Independence**
    - **Intelligence collected from one malware instance provides no advantage in analyzing another**

Instruction Set Localization

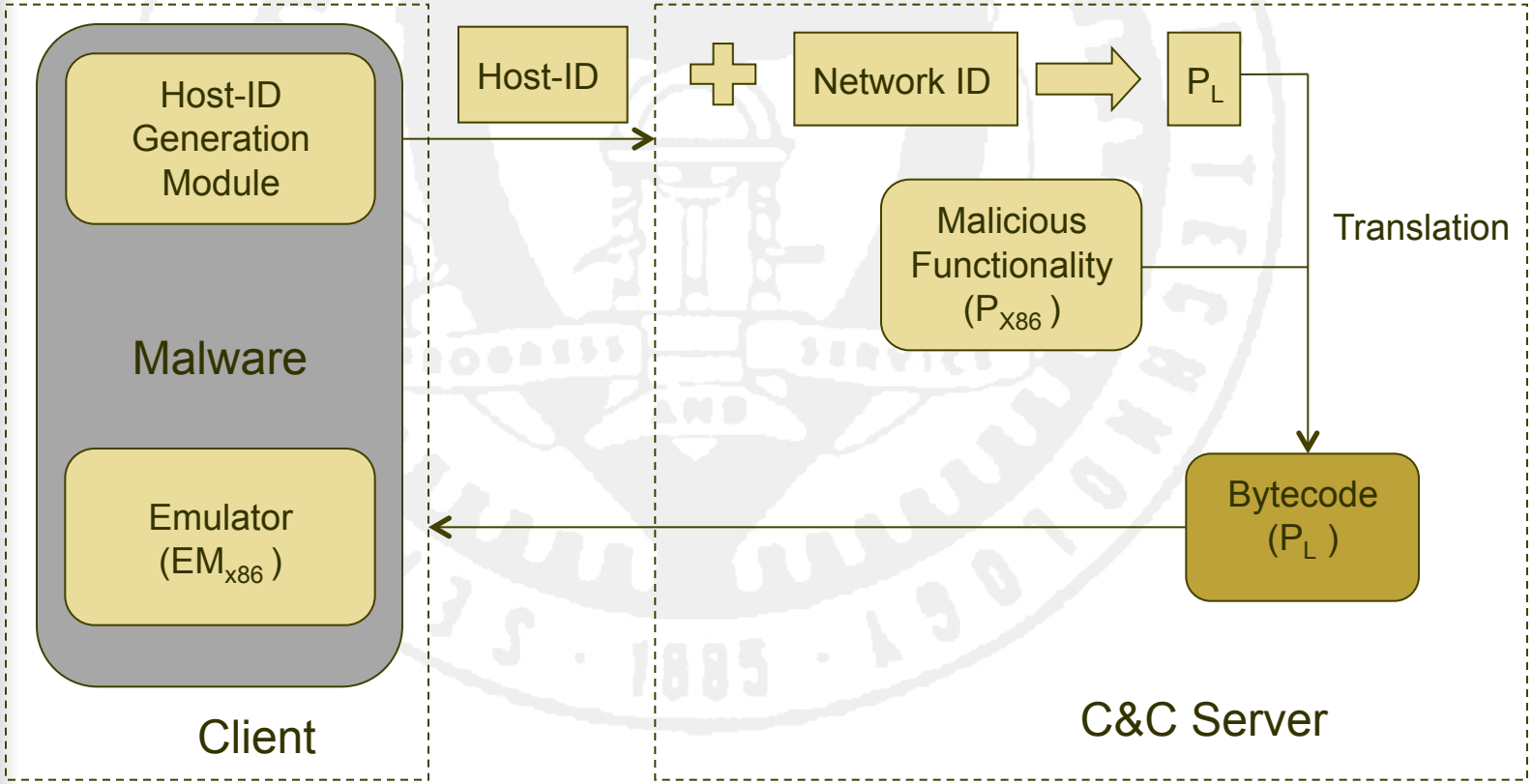
- **Why ISL?**
  - **Pure host-based protection is not sufficiently resistant to forgery**
- **Goal of ISL**
  - **Use C&C server to "authenticate" malware client based on both host and network identity**
  - **Decouple malicious functionality to prevent offline analysis**

ISL Cont'd

- **Malware as Platform-as-a-Service**
  - **HIE-protected binary contains no malicious functionality**
  - **Binary acts as interpreter of bytecode for malicious tasks served by C&C**
  - **Task Bytecode**
    - **Can be unique to each executable**
      - **A different bytecode ISA for each host**
    - **Alternatively, can be protected by key derived from both host and network-level identifiers**

ISL Cont'd

- **Replace random instruction set with instruction set bound to the host**



ISL Cont'd

- **Prototype Network ID**
  - **Geo-location**
    - **Granularity of state/province level (IP address is not stable)**
      - **Permits certain level of mobility**
  - **Autonomous System Number (ASN)**
    - **Geo-location may be outdated or incorrect**
  - **Collected at C&C**
    - **Considered intractably difficult to forge**

ISL Cont'd

- **Alternative to Unique Instruction Sets**
  - **Instruction set derivation is not trivial**
  - **Use *task decryption key***
    - **Assigned when the malware instance is delivered to the host**
    - **Encrypt bytecode tasks using the unique ID (the key derived from host ID and network ID)**
      - **KDF = HMAC(unique ID), or keyed hash, with the secret key kept at C&C server**

ISL Cont'd

- **Advantages**
  - **HIE-protected binary is only an interpreter (contains no malicious functionality)**
    - **Instance cannot be analyzed offline**
  - **Complementary to HIE for tasks served to the interpreter**
    - **Unless the analyst can correctly mimic the host and network environment, tasks will not decrypt/execute**

Discussion

Operational Security

- **Both HIE and ISL use modern cryptography**
  - **Same environment must be provided for successful analysis**
  - **Without access to original environment, entire key space must be searched**
    - **Key space can be of arbitrary size**
  - **Some configurations may be impossible to duplicate**

Operational Security Cont'd

- **HIE and ISL are insensitive to analysis techniques**
  - **General knowledge of these techniques does not compromise protections offered**
  - **Granularity of analysis used does not affect protections**
  - **Protections can be broken only if the configuration parameters of the original execution environment are matched**

Potential Countermeasures

- **Analyze malware on the original infected host**
  - **Approach would require allowing otherwise blocked suspicious/known malware to execute on a legitimate system**
    - **Could impact business operations and continuity**
    - **Would have complex legal and privacy implications**
- **Use high-interaction honeypot**
  - **Bind malware to analysis environment by replicating compromise circumstances**
    - **Inefficient**
    - **Bound samples will comprise only a small portion of all collected samples**

Countermeasures Cont'd

- **Collect and duplicate host and network environment information**
  - **Depending on the information, may have privacy and policy problems**
  - **Duplicating network identifier requires analysis system deployment on an unprecedented and globally cooperative scale**

Countermeasures Cont'd

- **Collect and duplicate only host identifier, record and replay the network interaction in separate environment**
  - **Without small additional protection, could bypass ISL**
  - **Mitigated by using SSL/TLS to encrypt the C&C channel**

Countermeasures Cont'd

- **Employ allergy attack**
  - **Make the information used by HIE and ISL unstable**
    - **For example, change MAC address, username, SID for every program invocation**
    - **Malware would not execute correctly successfully on the infected host**
  - **Would affect a variety of legitimate software**
  - **Success would depend on the willingness of users to accept security over usability**

Conclusion

- **Historically, malware has been "analysis environment aware"**
- **Recent developments (e.g., Flashback) show that malware can be "analysis environment oblivious"**
  - **Primitive DRM-like technologies can be matured (e.g., HIE and ISL)**
- **Future work must mitigate these protections or examine alternatives to threat detection and analysis**

Please fill out your feedback forms.

Questions?