Stealing From Thieves: Breaking IonCube VM to RE Exploit Kits

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About @halsten

- Reverse Engineering
- Automation of RE tasks
- Virtualization
- Regular project-euler problem solver (ranked #1 locally)
- Old crackmes writer and solver

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Not Covered

- Recovering the license file
- Cracking the license decryption algorithm
  - DRM law
- Decompilation of VM Handlers and restoring original PHP source
  - Out of scope

What is ionCube?

- Packer/Compressor

What is ionCube?

- Packer/Compressor
- Protector/Virtualizer

Why Protect?

- Intellectual property

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  - Algorithm implementation

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Why Protect?

- Intellectual property
  - – Algorithm implementation
  - – Serial checking routines
  - – Hard-coded configurations

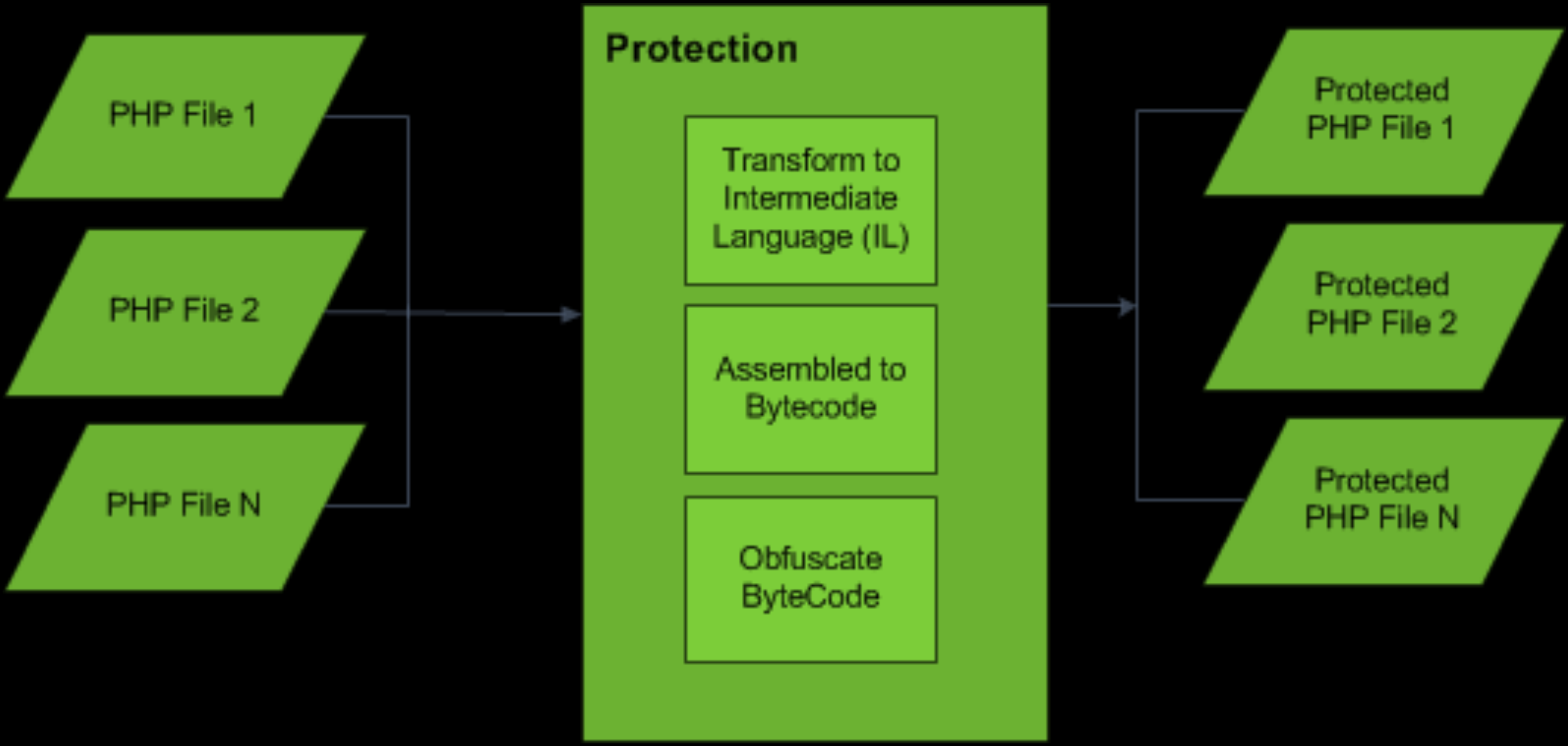
  …
- Public distribution without modification to the original source

PE Packer vs. PHP Encoder

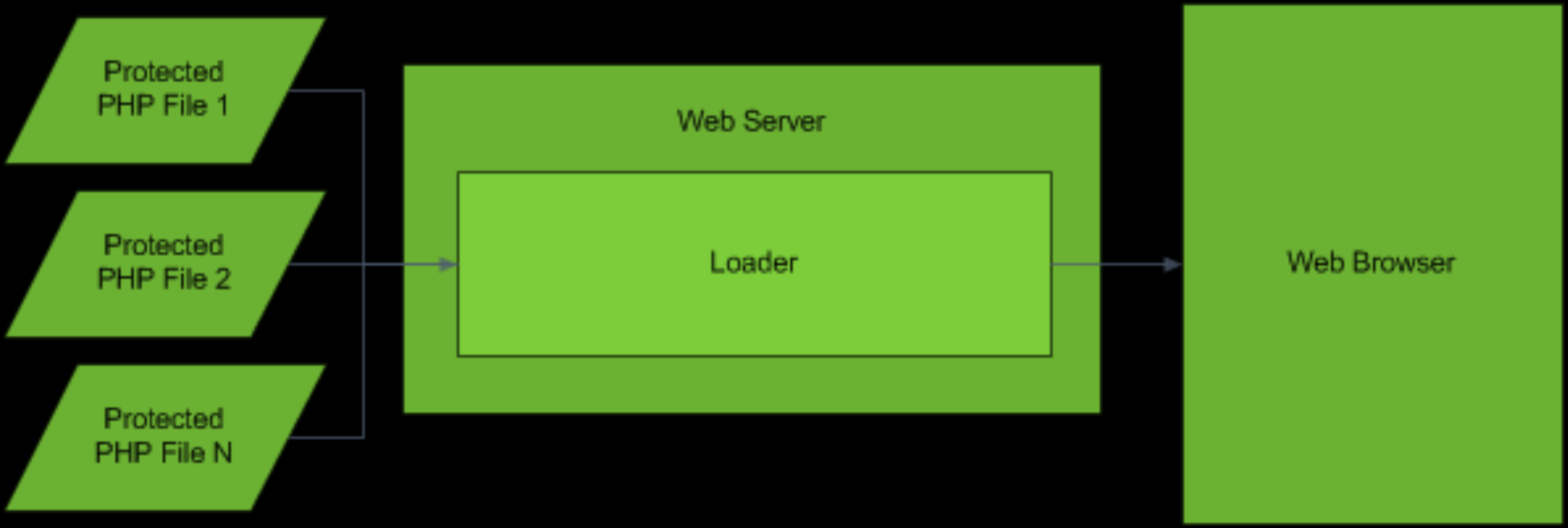
- Traditional PE Packers compress/protect the x86 code and uses its stub to decompress/unprotect it back in during execution

- PHP Encoders has to rely on the ZEND technology (php->zend_opcodes)

How does it work? (Compilation)



How does it work? (Run-Time)



VM Architecture

- Stack based VM (example: .NET, Java)
- Byte Code is obfuscated after compilation
- Uses some crypto for VM header and parameter encryption
- Uses Zend Engine

VM Internals

- Crypto used within the encoder and the VM
  - Custom Base64
  - Adler32
  - CRC32
  - SHA-1
  - MD5
  - BlowFish (Counter Mode Encryption [CTR])
  - Modified Mersenne Twister

Example of a Protected PHP File

```
<?php //00337
if(!extension_loaded('ionCube Loader')){$__oc=strtolower(substr(php_uname(),0,3));
    $__ln='/ioncube/ioncube_loader_'.$__oc.'_'.substr(phpversion(),0,3).
    (($__oc=='win')?'.dll':'.so');$__oid=$__id=realpath(ini_get('extension_dir'));
    $__here=dirname(__FILE__);if((@$__id[1])==':'){$__id=str_replace('\
    \','/',substr($__id,2));$__here=str_replace('\\','/',substr($__here,2));}
    $__rd=str_repeat('/..',substr_count($__id,'/')).$__here.'/';
    $__i=strlen($__rd);while($__i--){if($__rd[$__i]=='/'){$__lp=substr($__rd,0,$__i).
    $__ln;if(file_exists($__oid.$__lp)){$__ln=$__lp;break;}}}@dl($__ln);}else{echo('The
    file '.__FILE__." is corrupted.\n");return 0;}if(function_exists('_il_exec')){return
    _il_exec();}echo('This encoded file cannot be run. Please run the file ioncube-
    loader-helper.php for more information.');return 0;
?>
```

```
4+oV5E3tizCOGmZayKycyFdfdNEYKcDQ2UctWQgi5wUMAYDSmMVeoLZpTJYlsb2ZS87vmUDNyJXy
u6mBqXBOY8uBDM8S9FpfYpOU8H2UybP4eoySb3gsXR3LRDVhZQOE547VladmAtDtg672Z0axEinz
4Q0KK4ySJmQf/y74+9n0mQxv89e/3ORP/KEy9C7qQ57ANCp167ft8uwqnxmMG2B0FghtwVsgbjWW
TRM9HpX9RfSRUpbRfJyiWM77aOjzW9XB2eAJyxqd/T5a5+EXVl7auGnQ2ZiQhbeeajCwKRwWP0X9
N8VmcedG2VriSa6TMSY++2C4zLx5FcRziK7DMb2vYBQA0IhN8SOiVv4t5JIzumywsmq9bHtAZLdU
62oKLWPotyYaB7R/+nSDX4s7Vwifp0nXJe8NQ5zI36p4UMmoZnHHKC/+oFab7U7rI4uC707fwrhr
b95eZu1QsG+TWFhNjn3Ao9UClGrvoye+fIL7xrq=
```

How does it work? (Internally)

- There’s only 1 way to find out, lets see what the loader is doing under the hood

Breaking ionCube
Extracting the RAW DATA

- Decode the RAW DATA using a custom Base64 character set ("0123456789ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz+/”)

  and not (“ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz0123456789+/”)

```
4+oV5E3tizCOGmZayKycyFdfdNEYKcDQ2UctWQgi5wUMAYDSmMVeoLZpTJYlsb2ZS87vmUDNyJXy
u6mBqXBOY8uBDM8S9FpfYpOU8H2UybP4eoySb3gsXR3LRDVhZQOE547VladmAtDtg672Z0axEinz
4Q0KK4ySJmQf/y74+9n0mQxv89e/3ORP/KEy9C7qQ57ANCp167ft8uwqnxmMG2B0FghtwVsgbjWW
TRM9HpX9RfSRUpbRfJyiWM77aOjzW9XB2eAJyxqd/T5a5+EXVl7auGnQ2ZiQhbeeajCwKRwWP0X9
N8VmcedG2VriSa6TMSY++2C4zLx5FcRziK7DMb2vYBQA0IhN8SOiVv4t5JIzumywsmq9bHtAZLdU
62oKLWPotyYaB7R/+nSDX4s7Vwifp0nXJe8NQ5zI36p4UMmoZnHHKC/+oFab7U7rI4uC707fwrhr
b95eZu1QsG+TWFhNjn3Ao9UClGrvoye+fIL7xrq=
```

Breaking ionCube
Extracting the RAW DATA

- Check for encoded VM restrictions and rules
- Header size (<?php //0) -> 10 bytes + 4 bytes (size of loader)
- Determine the starting offset of the loader

Breaking ionCube
Extracting the RAW DATA

- Get PHP version (DWORD)
  - Compare with HARD-CODED values (BINARY MODE)
    - 0xDEADC0DE
    - 0x3FBC2883
    - 0x217582F
    - 0x149FEC13
    - 0x67A6BF45
    - 0x9EB67AC2

Breaking ionCube
Extracting the RAW DATA

- Compare against other HARDCODED values (BASE64 MODE)
  - 0y4h
  - BrWN
  - 4+oV
  - HR+c
  - mdgs

Breaking ionCube
Validating the RAW DATA

- Read a DWORD for the VM version (0x00) XOR the value with 0x2853CEF2 and compare with HARDCODED values
  - dwVer = ReadDWORD() ^ 0x2853CEF2
    - 0x17EFE61 (v1)
    - 0x2A4496DD (v2)
    - 0x3CCC22E1 (v3)
    - 0x4FF571B7 (v4)
    - 0xA0780FF1 (v5)
    - 0xB6E5B430 (v6)
    - 0xF6FE0E2C (v7)

Breaking ionCube
Process the RAW DATA

- Calculate dwFileSizeKey (DWORD)
  - dwFileSizeKey = ((dwRawBinaryDataSize + 12321) ^ 0x23958CDE)
- Read Header Information (struct)
  - dwHeaderFileSizeKey (DWORD +0x00)
  - dwHeaderSize (DWORD +0x04)
  - dwHeaderKey (DWORD +0x08)

Breaking ionCube
Process the RAW DATA

- Calculate Header Size using the following formula
  - dwCalculatedHeaderSize = (((dwHeaderSize ^ 0x184FF593) + (-0x0C21672E)) ^ dwHeaderKey)
  - dwFillData1 (DWORD +0x0C)
  - dwFillData2 (DWORD +0x10)
  - dwFillData3 (DWORD +0x14)
- dwFillData1/dwFillData2/dwFillData3 (encoded during runtime with 0xFF “<“)
- Calculate Header File Size Key
  - dwCalculatedHeaderFileSizeKey = (dwHeaderFileSizeKey ^ dwHeaderKey)

Breaking ionCube
Process the RAW DATA

- Validate Key
  - If (dwFileSizeKey != dwCalculatedHeaderFileSizeKey)
    - Difference -> ABS(dwFileSizeKey - dwCalculatedHeaderFileSizeKey)
    - Recover the Key
      - dwNewCalculatedHeaderFileSizeKey = ((dwCalculatedHeaderFileSizeKey – 12321) ^ 0x23958CDE)
- Initialize MT PRNG with dwHeaderKey

Breaking ionCube
Process the RAW DATA

- Read the Header Data and Checksum values.
- Header consists of multiple chunks (struct)
  - Parse Header Chunks
    - Loop while (dwCounter <= dwCalculateHeaderSize)
      - dwChunkFlag (BYTE)
      - dwChunkSize (BYTE)
  - Read the MD5 checksum of the Raw Data (0x10 BYTES)

Breaking ionCube
Process the RAW DATA

- Validate ADLER32 checksum for the encoded VM
  - START: EncodedVM + 0x04
  - END: EncodedVM.EOS

```
4+oV5E3tizCOGmZayKycyFdfdNEYKcDQ2UctWQgi5wUMAYDSmMVeoLZpTJYlsb2ZS87vmUDNyJXy
u6mBqXBOY8uBDM8S9FpfYpOU8H2UybP4eoySb3gsXR3LRDVhZQOE547VladmAtDtg672Z0axEinz
4Q0KK4ySJmQf/y74+9n0mQxv89e/3ORP/KEy9C7qQ57ANCp167ft8uwqnxmMG2B0FghtwVsgbjWW
TRM9HpX9RfSRUpbRfJyiWM77aOjzW9XB2eAJyxqd/T5a5+EXVl7auGnQ2ZiQhbeeajCwKRwWP0X9
N8VmcedG2VriSa6TMSY++2C4zLx5FcRziK7DMb2vYBQA0IhN8SOiVv4t5JIzumywsmq9bHtAZLdU
62oKLWPotyYaB7R/+nSDX4s7Vwifp0nXJe8NQ5zI36p4UMmoZnHHKC/+oFab7U7rI4uC707fwrhr
b95eZu1QsG+TWFhNjn3Ao9UClGrvoye+fIL7xrq=
```

- Extract CRC from Header
  - dwCRC == dwCalculatedADLER32

Breaking ionCube
Process the RAW DATA

- Decrypt Chunk Key using the following algorithm

```
foreach (BYTE dwB in dwMD5Checksum) {
        ROR(dwB, 3)
}
```

- Decrypt Header with the following algorithm

```
while (Header.POSITION != EOS) {
        while (dwMD5Checksum.POS != EOS) {
                x = ReadDWORD()
                y = dwMD5Checksum.ReadBYTE()
                z = (x ^ Rand_MT(0xFF) ^ y)
        }
}
```

- At this point we have extracted ionCube Header in Binary format

Breaking ionCube
Interpreting the Header

- Read dwVersionData for the Header version (DWORD)
- Read dwMinimumLoaderVersion (DWORD)
- Read dwObfuscationFlags
  - Decode dwObfuscationFlags
    - VARIABLES -> 0x0004
    - FUNCTIONS -> 0x0008
- Read dwHeaderCustomLoaderEventMessagesCount (DWORD)
- Read a fixed sized string for szObfuscationHashSeed with fixed size of dwHeaderCustomLoaderEventMessagesCount

Breaking ionCube
Interpreting the Header

- Try to extract dwByteCodeKey
  - Doesn’t exist?
    - Assume a HARD-CODED value of 0x363432
  - Exists?
    - Read it normally
      - If (dwByteCodeKey == 0x92A764C5)
        - » SPECIAL CASE: LicenseFile(+EnforceLicense)
          - License File exists?
            - YES: GOOD
            - NO: Could be calculated and recovered

Breaking ionCube
Interpreting the Header

- Read dwIncludedXORKey (HARD-CODED value: 0xE9FC23B1)
- Read dwNumberOfStructsToRead which will specify how many structures to read based on the encoding of the original file
  - LicenseString (restricted by the value of dwSize)
    - dwDummy (DWORD)
    - dwSize (DWORD)
  - Check for DisableCheckingofLicenseRestriction (pointed by dwDummy3)
    - dwDummy1 (DWORD)
    - dwDummy2 (DWORD)
    - dwDummy3 (DWORD)

Breaking ionCube
Interpreting the Header

- Check for LicensePassphrase (restricted by the value of dwSize)
  - dwDummy (DWORD)
  - dwSize (DWORD)
- Check if there is a CustomErrorCallback file (restricted by the value of dwSize)
  - dwDummy (DWORD)
  - dwSize (DWORD)
- Check if there is a CustomErrorCallbackHandler (restricted by the value of dwSize)
  - dwDummy (DWORD)
  - dwSize (DWORD)

Breaking ionCube
Interpreting the Header

- Check for EnableAutoPrependAppendFile (pointed by dwDummy3)
  - dwDummy1
  - dwDummy2
  - dwDummy3
- Skip 2 dummy DWORD and a calculated number of bytes
  - dwCalculatesBytes = ABS(dwNumberOfStructsToRead – 5)

Breaking ionCube
Interpreting the Header

- Decode the CustomErrorMessages (the following) with the later algorithm
  - Corrupt-file
  - Expire-file
  - No-permissions
  - Clock-skew
  - Untrusted-extension
  - License-not-found
  - License-corrupt
  - License-expired
  - License-property-invalid
  - License-server-invalid
  - Unauth-including-file
  - Unauth-included-file
  - Unauth-append-prepend-file

Breaking ionCube
Interpreting the Header

- Read dwNumberOfCustomizedErrorMessages which will determine how many structs to read later
- Loop through dwNumberOfCustomizedErrorMessages and read the struct
  - dwCustomErrorMsgID (BYTE)
  - szCustomErrorMsg
    - WARNING: NULL-TERMINATED strings (skip \’0’)

Breaking ionCube
Interpreting the Header

- Decode IncludeFileRestrictions
  - Read dbNumberOfIncludeRestrictionsEntriesToRead (BYTE)
  - Loop through dbNumberOfIncludeRestrictionsEntriesToRead and read 2 sets of arrays of structs
    - Read dbDummy (BYTE) [NOT IMPORTANT]
    - Set 1 (IncludeKey)
    - Set 2 (IncludeKeyHandler)

Breaking ionCube
Interpreting the Header

- Both Set 1 and 2 need to be decoded using the following algorithm
  - Read wSize (WORD)
  - Calculate Z = (wSize ^ dwIncludeXORKey) & 65535)
  - Using the calculated Z we can extract the full data and fully decode it using the following algorithm

```
Do {
        a = ReadDWORD()
        b = (a ^ dwIncludedKey)
} while (!EOS)
```

Breaking ionCube
Interpreting the Header

- Read dbNumberOfServerRestrictedItems (BYTE)
- Loop through dbNumberOfServerRestrictedItems and read a struct
  - Read dbNumberOfRows (BYTE)
  - Read dbNumberOfColumns (BYTE)
    - Loop through dbNumberOfColumns
      - Read dbDataType (BYTE)
        - » Decode dbDataType
          - 0 -> IP
          - 1 -> MAC
          - 3 -> NOT IMPORTANT
          - 4 -> DOMAIN

Breaking ionCube
Interpreting the Header

- IP
  - Read dbNumberOfIPEntries
    - Loop through dbNumberOfIPEntries
      - Read dbUseNetMask
        - 0 -> will use netmask
        - 1 -> will not use netmask
      - Read IP Address in reverse order
        - dbIP4
        - dbIP3
        - dbIP2
        - dbIP1
      - Read netmask in reverse order
        - dbNetMask4
        - dbNetMask3
        - dbNetMask2
        - dbNetMask1

Breaking ionCube
Interpreting the Header

- MAC
  - Read dbNumberOfMACEntries
    - Loop through dbNumberOfMACEntries
      - Read szMAC (6 BYTES)

Breaking ionCube
Interpreting the Header

- Domain
  - Read dbNumberOfDomainEntries
    - Loop through dbNumberOfDomainEntries
      - Read szDomain (NULL-TERMINATED)

Breaking ionCube
Interpreting the Header

- Compute dwCalculatedAdler32 for the encoded VM
  - Difference between extracted and calculated? (Un/modified)

Breaking ionCube
Interpreting the Extra Header

- Read 0x28 bytes which contains the Extra Header
- Read wMinorVersion (WORD)
- Read wMajorVersion (WORD)

Breaking ionCube
Interpreting the Extra Header

- Read dwPHPFlags
  - Decode dwPHPFlags
    - 0x001
    - 0x002
    - 0x004
    - 0x008
    - 0x010
    - 0x020 (allow run with untrusted extensions)
    - 0x040 (php5 body)
    - 0x080 (vm handlers are encrypted)
    - 0x100
    - 0x200 (obfuscate function names)
    - 0x400 (encrypt strings)
    - 0x800 (obfuscate strip line numbers)
    - 0x1000 (obfuscate variable names)
    - 0x2000 (encryption flag)
    - 0x4000
    - 0x8000

Breaking ionCube
Interpreting the Extra Header

- Read dbEncoderGenerationNumber (BYTE)
- Read dbEncoderMajorNumber (BYTE)
- Read dbEncoderMinorNumber (BYTE)
- Read dbEncoderEnhancementNumber (BYTE)

Breaking ionCube
Interpreting the Extra Header

- Read dwMemberID (DWORD) [registration data]

```
If (license exists  and license restrictions are enforced) {
    dwByteCodeKey = (0x363432 + RAND(_time())
}
```

Breaking ionCube
Interpreting the Extra Header

- Morph the dwByteCodeKey using the following algorithm

```
If (dwServerRestrictionItems exists) {
        dwByteCode_MT_XORKey = (0x92492493 / 0x1000) * (dwByteCode_MT_InitKey / 0x1000)
dwByteCode_MT_XORKey = ByteCode_MT_XORKey + ByteCode_MT_InitKey)
dwByteCode_MT_XORKey = (int)(dwByteCode_MT_XORKey / 4)

If (dwByteCode_MT_XORKey < 0) {
        dwByteCode_MT_XORKey++
}

dwByteCode_MT_XORKey = (dwByteCode_MT_XORKey  - (13 * dwServerRestrictionItems))

}
Else {
        dwByteCode_MT_XORKey = dwByteCode_MT_InitKey
}
```

((((dwByteCode_MT_InitKey * 0x92492493 >> 32) + dwByteCode_MT_InitKey) >> 2) – 13 * dwServerRestrictionItems

Breaking ionCube
Interpreting the Extra Header

- Read dwCopyOfIncludedXORKey (DWORD)
- Read dwUnknown1 (DWORD)
- Read dwUnknown2 (DWORD)
- Read wUnknown3 (WORD)
- Read dbUnknown4 (BYTE)
- Read dbUnknown5 (BYTE)
- Read dwEvalTimeMinEncryption
  - dwEvalTimeMin = dwEvalTimeMinEncryption + 10233976199
- Read dwEvalTimeMaxEncryption
  - dwEvalTimeMax = dwEvalTimeMaxEncryption + 83941958

- 0x4AD70D0D -> 16.10.2009
- 0x740A9780 -> 11.09.2031
- CONST dwSecondsPerDay = 86400 (24h * 60m * 60s)

Conclusion

- VM uses a simplistic Stack based approach
- Encryption/Encoding methods are weak and easily broken
- Relies too much on XOR based encryption
- LOTS of HARD-CODED constants
- Loader is easily patched (no protection, x86 code easily read)
- Couple of bugs in the Loader through hand-crafted VM (exploitable?)

Q & A

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