Fudging with Firmware

High Level Security Board
16-17 November 2006
Königstein, Germany

Pierre Pronchery
n.runs AG

© 2006, n.runs AG

The talker

Pierre Pronchery

I work for n.runs AG

UNIX stuff
Network security
System programming
Operating Systems internals

© 2006, n.runs AG

n runs...
network · technology · security · consulting

Agenda

I. How does it look?

II. First peek under the hood

III. Identification

IV. Is there more to it?

V. Have some fun

© 2006, n.runs AG

n runs...
network · technology · security · consulting

Before we start

- Focusing on firmwares likely to host an Operating System
- Assumes you know how to obtain some:
  - Read your hardware documentation
  - Look for undocumented features
  - Check web sites ***extensively***
  - Use your imagination...

© 2006, n.runs AG

n runs...
network · technology · security · consulting

I. How does it look?

- Unpacking
  - Presentation
  - Compression
  - Bootloaders
  - Extraction
- Storing
  - Filesystems

© 2006, n.runs AG

n runs...
network · technology · security · consulting

Presentation

- Data may just be encoded in a trivial way
- ASCII versus EBCDIC
  - Don't take anything for granted!
- ASCII-armored data transfers:
  - UUENCODE
  - Base64
  - Intel HEX...
- History (or hype) decides

© 2006, n.runs AG

n runs...
network · technology · security · consulting

XXENCODE Principles

- Groups of 3 bytes (trailing zeros)
- Split groups into four 6-bit numbers
- Apply the following translation table:

```
0         1         2         3         4         5         6
01234567890123456789012345678901234567890123456789012345678901234567890123
|         |         |         |         |         |         |
+-0123456789ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz
```

© 2006, n.runs AG

n runs...
network · technology · security · consulting

UUENCODE Principles

- Same technique, using ASCII 32 to 95:

```
0         1         2         3         4         5         6
01234567890123456789012345678901234567890123456789012345678901234567890123
|         |         |         |         |         |         |
 !"#$%&'()*+,-./0123456789:;<=>?@ABCDEFGHIJKLMNOPQRSTUVWXYZ[\]^_
```

- More efficient than XXENCODE
- Seen in serial transfers (ARM platforms)

© 2006, n.runs AG

n runs... network · technology · security · consulting

UUENCODE Example

- UUENCODE has filename and permission:

```
$ echo BOOTME > bootme.txt
$ uuencode -e bootme.txt bootme.txt
begin 640 bootme.txt
'0D]/5$U%"K\!
`
end
```

- Strings “begin” and “end”

© 2006, n.runs AG

n runs...
network · technology · security · consulting

Base64 specifications

- Uses the same 3-to-4 byte technique
- Characters used vary, often [A-Za-z0-9+/]
- Some implementations have different names:
  - MIME
  - BinHex
  - Privacy-Enhanced Mail (PEM, as with SSL)
  - OpenPGP's Radix-64 (appends a CRC)

© 2006, n.runs AG

Base64 Example

- Output is usually as-is:

```
$ base64 -e bootme.txt
Qk9PVE1FCg==
```

- Easy to recognize: small set of characters
- Common way to obfuscate passwords
- More useful in protocol reversing (SOAP, ...)

© 2006, n.runs AG

n runs...
network · technology · security · consulting

BinHex Example

- BinHex was found on Mac OS
- Used file extensions “hex”, “hqx”, “hcx”, ...

```
(This file must be converted with BinHex 4.0)
:$f*TEQKPH#jdCA0d,R0TG!"6594%8dP8)3#3"!&m!*!%EMa6593K!!%!!!&mFNa
KG3,r!*!$&[rr$3d,BQPZD'9i,R4PFh3!RQ+!!"AV#J#3!i!!N!@QKUjrU!#3'[q
```

- Keep an eye on restricted sets of characters!

(file sample from Wikipedia's “BinHex” article)

© 2006, n.runs AG

n runs...
network · technology · security · consulting

Intel HEX Format

- From Wikipedia's definition:

« *Intel HEX is a file format for conveying binary information for applications like programming microcontrollers, EPROMs, and other kinds of chips. It is one of the oldest file formats available for this purpose.* »

- Text file, line delimited (CR/LF/NUL)
- Hexadecimal values in uppercase ASCII

```
| 1 | 2 3 | 4 5 6 7 | 9 a | cnt... | n-1 n |
| : | cnt | address | typ | data   | sum   |
```

© 2006, n.runs AG

Intel HEX Example

```
:10010000214601360121470136007EFE09D2190140
:100110002146017EB7C20001FF5F16002148011988
:00000001FF
```

(from http://www.cs.net/lucid/intel.htm)

- Even more limited character set
- Redundancy in the encoding (checksum) is an interesting challenge for automation

© 2006, n.runs AG

n runs...
network · technology · security · consulting

Compression

- Consumes resources
- Known formats:
  - ZIP
  - GZIP
  - BZIP2...
- May be modified by vendors
  - Altered signatures
  - Different algorithms supported

© 2006, n.runs AG

n runs... network · technology · security · consulting

GZIP

- Definition found in RFC1952
- Starts with \x1f\x8b
- Lots of false positives, check also compression method and level
- Includes CRC, timestamp, OS fields, and optionally a filename and a comment

```
+---+---+---+---+---+---+---+---+---+---+
|ID1|ID2|CM |FLG|     MTIME     |XFL|OS |
+---+---+---+---+---+---+---+---+---+---+
```

© 2006, n.runs AG

Bootloaders

- On 80x86 boot sector is 512 bytes long, ends with partition table and 0xAA55
- Typically starts with a jump and stack initialization
- Will talk about assembly later...

© 2006, n.runs AG

Unpackers

- Thinking about:
  - Executable unpackers
  - Boot-time unpackers
- Look for known algorithms and signatures
- Play with checksums

© 2006, n.runs AG

Filesystems

- FAT
- Ext2 (Linux)
- Ramdisks (ROMFS, CRAMFS, ...)

© 2006, n.runs AG

n runs...
network · technology · security · consulting

File Allocation Table

- Poorly documented ...or brain-dead
- Lots of erratic implementations
- Always little-endian
- Starts jumping: 0xeb??90 or 0xe9????
- Often magic: “MSWIN4.1”, “FAT”, “FAT12”, “FAT16”, 0x55AA, 0x61417272
- Often redundant: boot sector backup, long filenames, ...

© 2006, n.runs AG

n runs...
network · technology · security · consulting

CPIO

- As seen on Linux initrd ramdisks
- Just a list of members
- File header either binary or ASCII octal
- Otherwise looks like a stat struct: magic “070707”, dev, ino, mode, uid, gid, nlinks, rdev, mtime, filename length and filename

© 2006, n.runs AG

II. First peek under the hood

- Now you have a structure in mind
- Text forensics
- Binary forensics

© 2006, n.runs AG

n runs...
network · technology · security · consulting

Use the luck, forth

- Intuition matters
- “strings” is your friend
  - Common usernames
  - Common passwords
  - Operating System names, ...
- “hexdump” won't byte
- An automated tool would help a lot

© 2006, n.runs AG

n runs...
network · technology · security · consulting

Concrete example and demo

- CVE-2004-2556 Netgear WG602 super:5777364
- CVE-2004-2557 Netgear WG602 again superman:21241036
- CVE-2006-1002 Netgear WGT624 Gearguy:Geardog

Vendors never learn...

© 2006, n.runs AG

III. Identification

- Executable formats
- Processor architectures
- Operating Systems

© 2006, n.runs AG

n runs...
network · technology · security · consulting

Executable formats

- Tell a lot about the target platform
- Two major formats:
  - Portable Executable (PE)
  - Executable and Linking Format (ELF)
- Tend to be re-used:
  - The wheel is a bit complex to reinvent
  - Flexible and complete enough
  - Many tools already support them

© 2006, n.runs AG

n runs...
network · technology · security · consulting

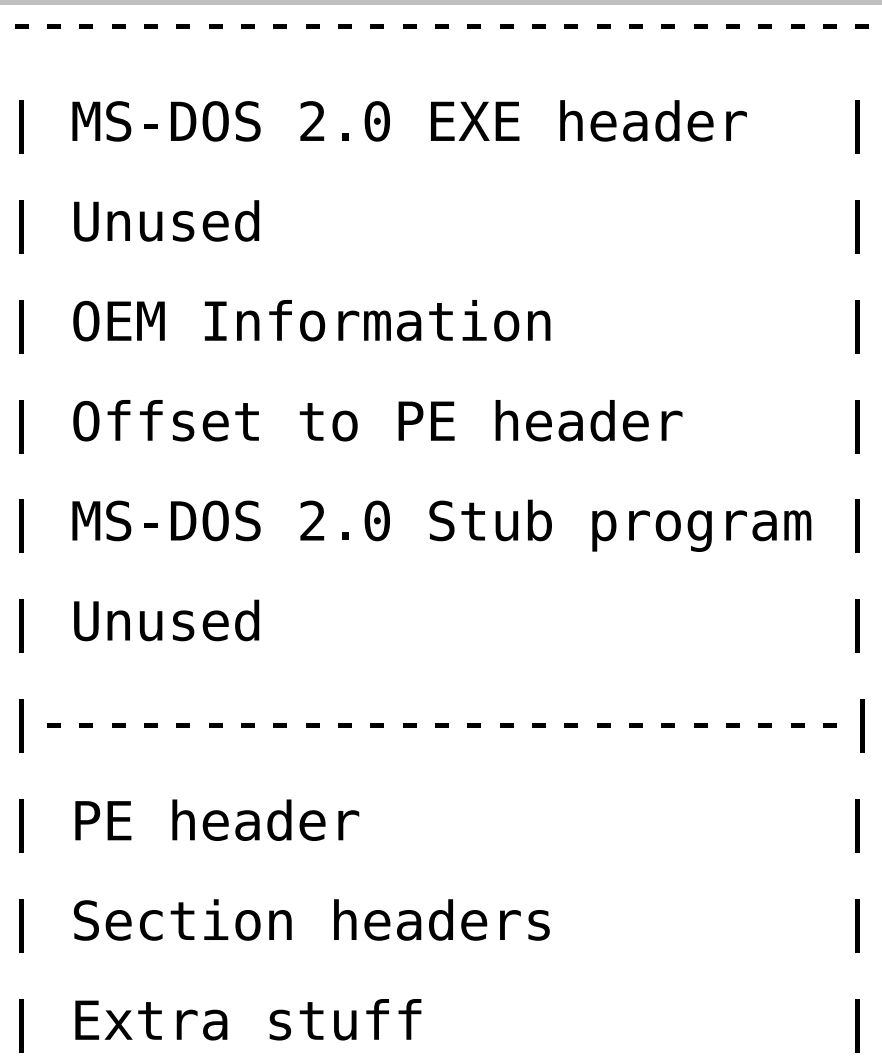
Portable Executable (PE)

- Inspired by UNIX's COFF
- Still compatible with MS-DOS 2.0
- “Windows is not portable” ...but CE is: ARM, MIPS, Hitachi SH3, SH4, SH5...
- Used for:
  - Executables and object files
  - Libraries (DLL) and device drivers
  - Screensavers even

© 2006, n.runs AG

n runs... network · technology · security · consulting

PE: Format overview



© 2006, n.runs AG

n runs... network · technology · security · consulting

PE: MS-DOS header

```
4d5a 9000 0300 0000 0400 0000 ffff 0000  MZ..............
b800 0000 0000 0000 4000 0000 0000 0000  ........@.......
0000 0000 0000 0000 0000 0000 0000 0000  ................
0000 0000 0000 0000 0000 0000 f000 0000  ................
0e1f ba0e 00b4 09cd 21b8 014c cd21 5468  ........!..L.!Th
6973 2070 726f 6772 616d 2063 616e 6e6f  is program canno
7420 6265 2072 756e 2069 6e20 444f 5320  t be run in DOS
6d6f 6465 2e0d 0d0a 2400 0000 0000 0000  mode....$.......
```

- Lots of magic to play with
- PE header is at `0xf0`

© 2006, n.runs AG

n runs... network · technology · security · consulting

PE: Actual header at 0xf0

```
5045 0000 4c01 0300 1084 7d3b 0000 0000  PE..L.....};....
0000 0000 e000 0f01 0b01 0700 0028 0100  .............(..
009c 0000 0000 0000 7524 0100 0010 0000  ........u$......
0040 0100 0000 0001 0010 0000 0002 0000  .@..............
0500 0100 0500 0100 0400 0000 0000 0000  ................
00f0 0100 0004 0000 fcd7 0100 0200 0080  ................
```

- I386, PE32 executable, linker 7.0, entrypoint at 0x00012475, created with Windows XP, requires NT 4.0, ...

© 2006, n.runs AG

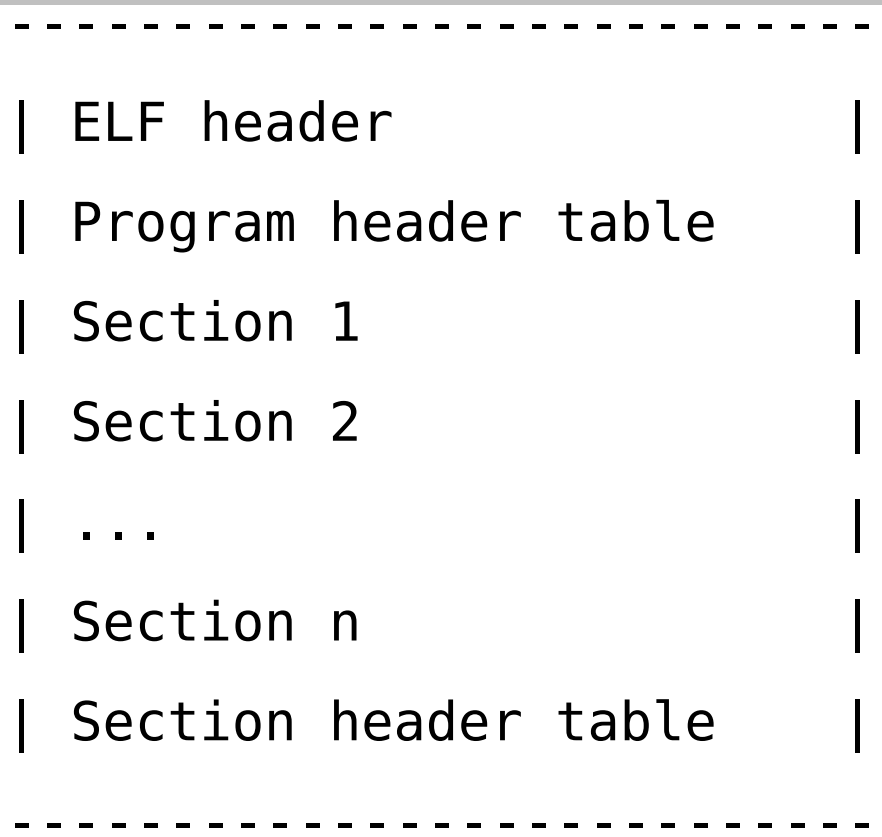
Executable & Linkable Format (ELF)

- Used on most UNIX systems
- Simpler than PE
- Very easy to spot: starts with “\x7fELF”

© 2006, n.runs AG

n runs...
network · technology · security · consulting

ELF: Format overview



© 2006, n.runs AG

n runs...
network · technology · security · consulting

ELF: Header structure

```
typedef struct {
  unsigned char   e_ident[16];Elf32_Half     e_type;
  Elf32_Half      e_machine;  Elf32_Word     e_version;
  Elf32_Addr      e_entry;    Elf32_Off      e_phoff;
  Elf32_Off       e_shoff;    Elf32_Word     e_flags;
  Elf32_Half      e_ehsize;   Elf32_Half     e_phentsize;
  Elf32_Half      e_phnum;    Elf32_Half     e_shentsiz
  Elf32_Half      e_shnum;    Elf32_Half     e_shstrndx;
} Elf32_Ehdr;
```

© 2006, n.runs AG

n runs...
network · technology · security · consulting

Processor architectures

- 80x86
- Sparc
- ARM
- MIPS
- m68k
- PowerPC

© 2006, n.runs AG

80x86

- Known hardware:
  - Your laptop
  - Soekris, Xbox, ...
- !!! Little-Endian !!!
- We know the standard boot processes
- There are other ways:
  - Load kernel from filesystem (Cobalt RaQs)
  - ...

© 2006, n.runs AG

80x86: Assembly overview

- Variable-size instructions
- Recurrent instructions:
  - push %ebp, mov %esp, %ebp => “\x55\x89\xe5”
  - leave, ret => “\xc9\xc3”

© 2006, n.runs AG

n runs...
network · technology · security · consulting

Acorn RISC Machine

- Known hardware:
  - embedded systems (music, games, phones)
  - DEC StrongARM, Intel XScale (PDAs)
- 32-bit architecture and opcodes
- Little or Big-endian at will
- Newer support 16-bit opcodes (Thumb)

© 2006, n.runs AG

MIPS

- Known hardware:
  - Workstations: SGI, DECstation, ...
  - Networking: Alcatel Speedtouch Pro, Linksys WRT, Cisco 36*0 and 7*00, WebTV, ...
  - Game consoles: N64, PSX, PS2, PSP
- 32-bit, 64-bit and hybrid versions
- Fixed-size opcodes
- Boots either little or big endian

© 2006, n.runs AG

n runs...
network · technology · security · consulting

PowerPC / CELL

- Known hardware:
  - Legacy Apple computers
  - NCD Explora X-Terminals
  - Game consoles
    - Nintendo's GameCube
    - Sony's PlayStation 3
    - Microsoft's Xbox 360

© 2006, n.runs AG

Operating Systems

- Well known: Linux, Windows CE
- Networking classics: Cisco's IOS, JuniperOS, ...
- Real-time: QNX, VxWorks

© 2006, n.runs AG

QNX

- UNIX for embedded systems
- Also found on regular PCs
- True microkernel
- Cisco IOS-XR (high availability) is based on QNX

© 2006, n.runs AG

n runs...
network · technology · security · consulting

VxWorks

- Another RTOS POSIX system
- Goes into space: Mars Orbiter
- ...and in your hardware:
  - some Linksys WRT54G
  - LiteON DVD recorders
  - digital cameras
  - Motorola SURFboard cable modems
  - some Xerox printers...

© 2006, n.runs AG

IV. Is there more to it?

- Deciphering

© 2006, n.runs AG

Deciphering

- Encrypted content is by definition random for the eyes (without the key)
- Again looking for any clue:
  - signatures
  - patterns
- Definitely not my specialty :(
- There is encryption and encryption

© 2006, n.runs AG

n runs...
network · technology · security · consulting

Some facts however

- Embedded systems are often slow
- Every hardware capability may not be available when booting
- If it is an algorithm, the logic is there: reverse it!
- If there is a key, it is there in the clear: find it!
  (exception: if it is in the hardware, save a few million $ for the microscope)

© 2006, n.runs AG

Cryptographic signatures

- Ask, ermm... a cryptograph
- Or Dan Kaminsky, he makes pretty pictures
- Seriously, drawing graphs helps

© 2006, n.runs AG

Cryptographic patterns

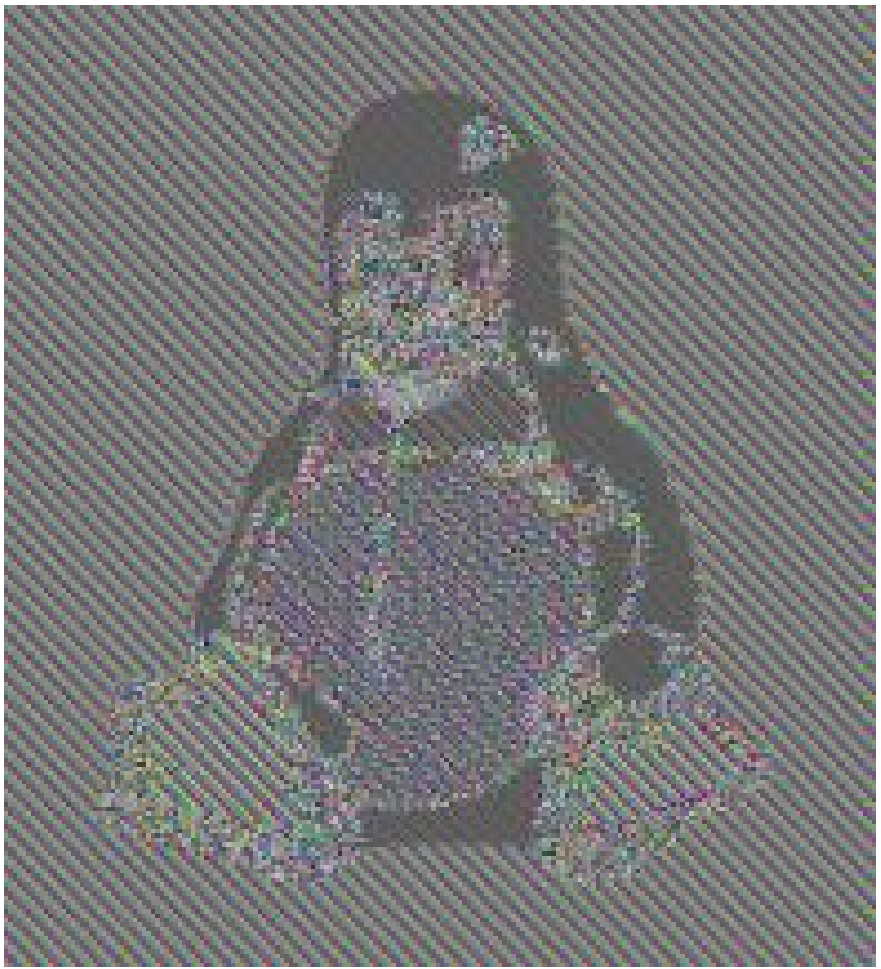
- Different encryption mechanisms
  - ECB Electronic Code Book
  - CBC and PCBC
  - CTR
  - ...

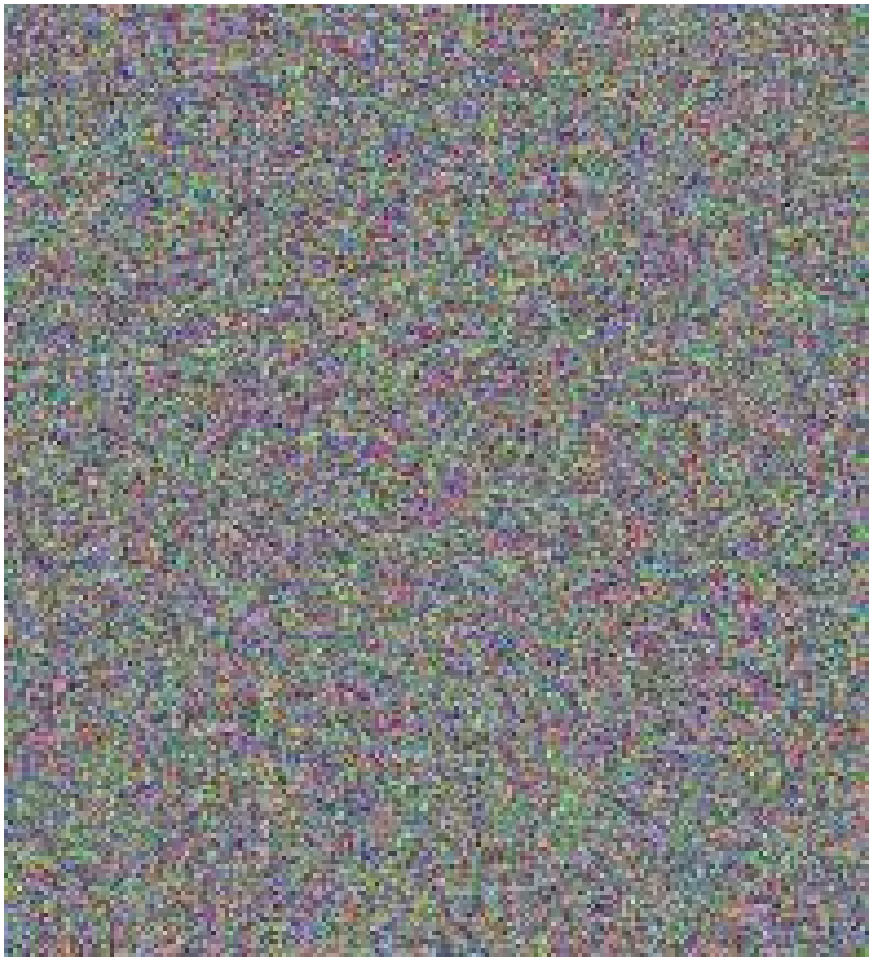
© 2006, n.runs AG

n runs...
network · technology · security · consulting

Cryptographic patterns

ECB versus CBC: patterns may still be found





© 2006, n.runs AG

V. Have some fun

- Disassembly
- Emulation
- Debugging

© 2006, n.runs AG

Disassembly software

- nasm
- GNU binutils
- OllyDbg
- IDA Pro

© 2006, n.runs AG

n runs...
network · technology · security · consulting

Disassembly: IDA Pro

Supported architectures:

- IA-32
- MIPS
- ARM... PDP-11

Supported operating systems:

- Windows
- Linux
- OS/2...

© 2006, n.runs AG

n runs...
network · technology · security · consulting

Emulation software

- VMWare, VirtualPC, Plex86, ...
- Bochs, QEMU, ...
- PearPC
- GXEmul, SimOS, MipsSim, vmips, ...
- Cisco 7200 Emulator

© 2006, n.runs AG

Emulator: Bochs

- Available on Windows, Linux, *BSD, ...
- Free software (GPL)
- Emulates IA-32 and AMD64
- Software simulation only
- Includes a debugging system
- Works with gdb

© 2006, n.runs AG

n runs...
network · technology · security · consulting

Emulator: QEMU

- Now for Linux, *BSD, MacOS X, Windows
- Free software (GPL)
- Emulates many platforms:
  - IA-32 and AMD64, up to 255 processors
  - Sparc (sun4m/32 bits and sun4u/64 bits)
  - ARM (ARM926E and ARM1026E)
  - MIPS...
- Runs binaries cross platform (Linux host)

© 2006, n.runs AG

n runs...
network · technology · security · consulting

References

- http://en.wikipedia.org/wiki/Cipher_block_chaining
- http://en.wikipedia.org/wiki/QNX
- Wikipedia is great
- http://www.netbsd.org/Ports/emulators.html
- Assembly reference books
- The “specifications” part of your users manuals
- And so on...

© 2006, n.runs AG

Contact information

- http://www.nruns.com/
  We make the network run!