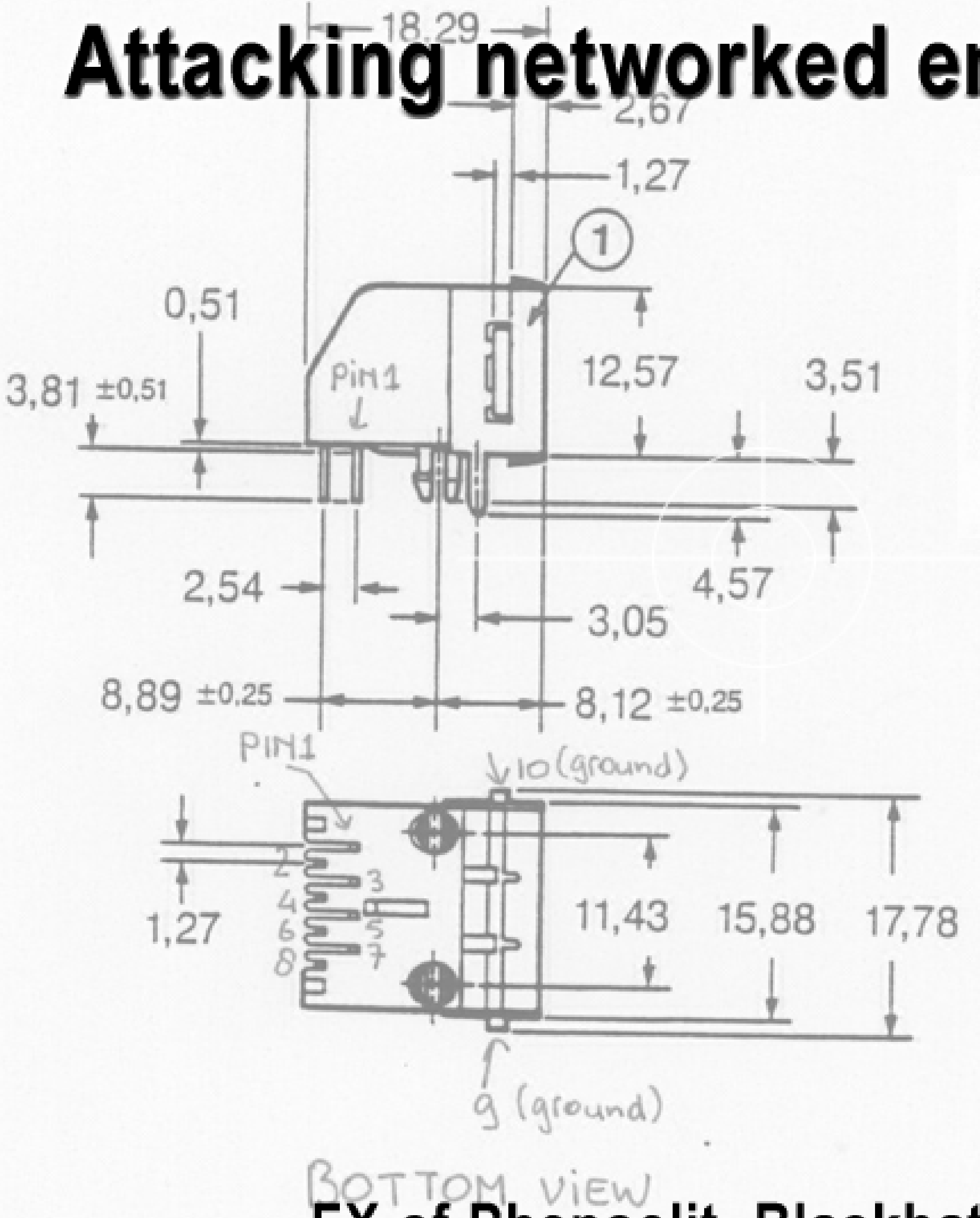
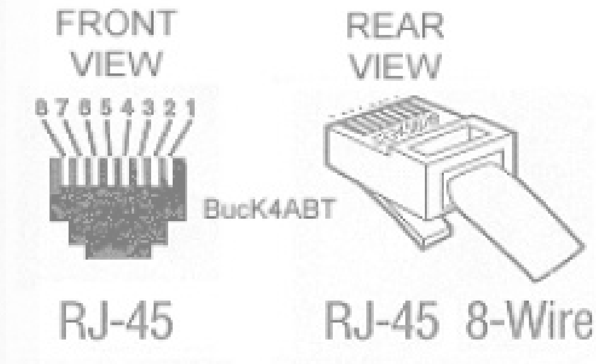
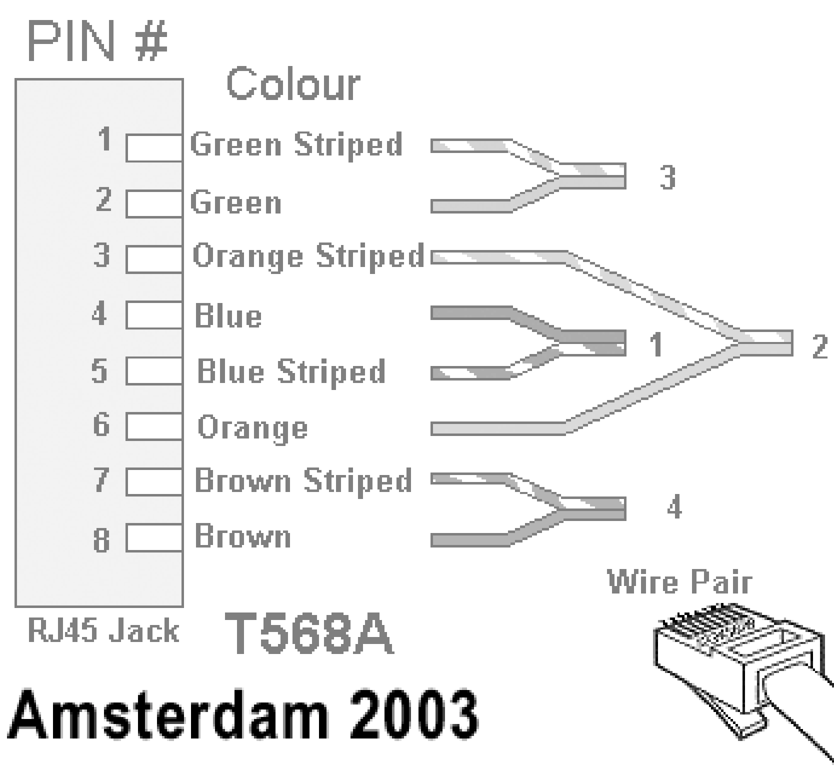
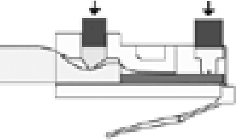
# Attacking networked embedded systems

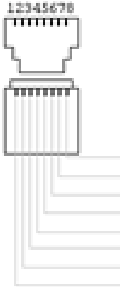


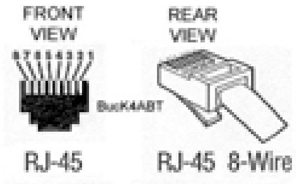

FX of Phenoelit, Blackhat Amsterdam 2003



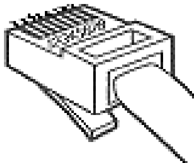


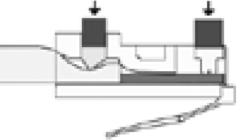
# Today‘s Session

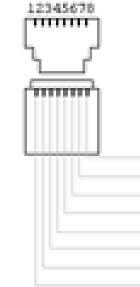
- Design failures in embedded systems
  - Examples of design failures
  - Exploiting a design failure
- Software vulnerabilities in embedded systems
  - Examples of software vulnerabilities
  - Exploiting a software vulnerability in a common embedded system





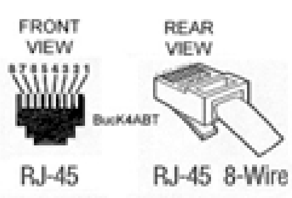





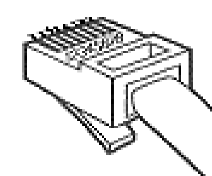



# What‘s a Embedded System ?

- (Small) computer system enclosed in electronic device
- Custom operating system, designed to provide specific functionality to the device it‘s running on
- Operating System is often monolithic
- No or limited separation of software components and access levels inside
- No or limited ability to add third party software

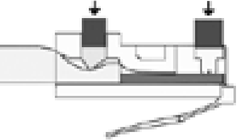




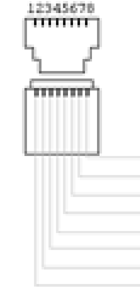



# Design failures

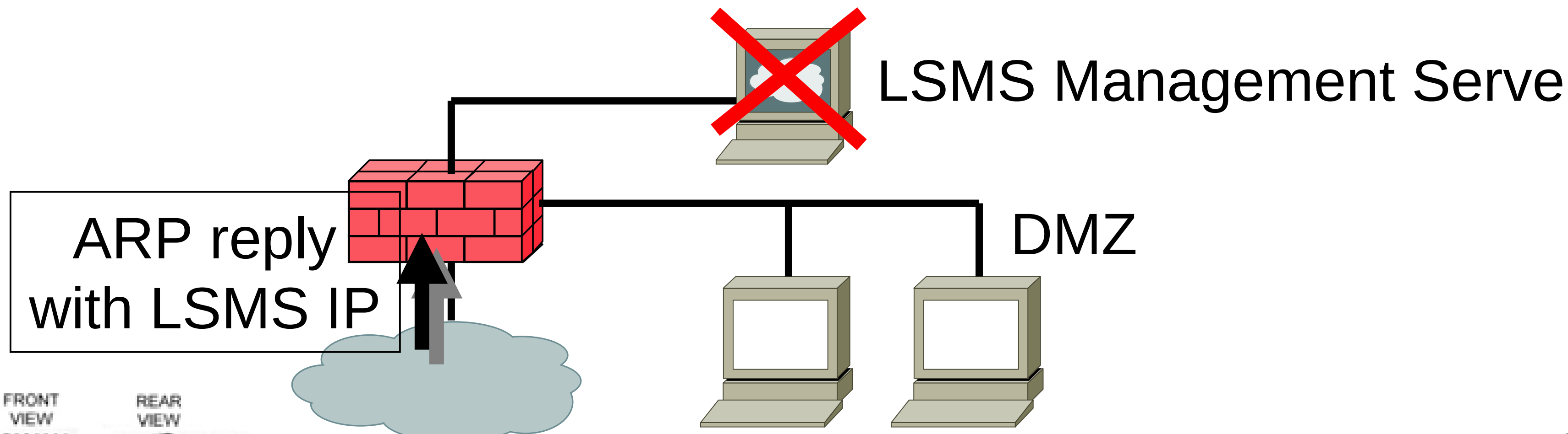
- Undocumented functionality
  - Developer backdoors
  - Auto-something features
  - Legacy functions
- Ignored standards
- Uncontrolled increase of complexity
  - New subsystems
  - Additional access methods
  - Inconsistent access restrictions

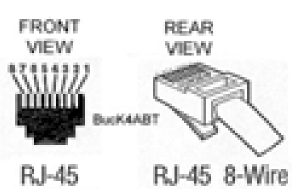


# Design failures
# Case 1: Lucent Brick

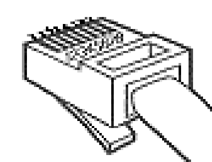


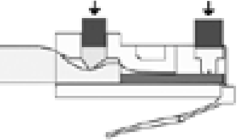
- Layer 2 Firewall running Inferno OS
- ARP cache design failures
  - ARP forwarded regardless of firewall rules
  - ARP reply poisoning of firewall
  - ARP cache does not time out

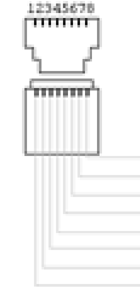




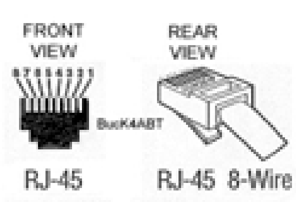





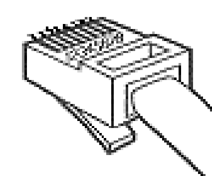


# Design failures
# Case 2: Ascend Router

- Undocumented discovery protocol
- Special packet format to UDP discard port
- Leaks information remotely
  - IP address/Netmask
  - MAC address
  - Name and Serial number
  - Device type
  - Features
- Can set IP address and name using SNMP write community (Default: „write“)

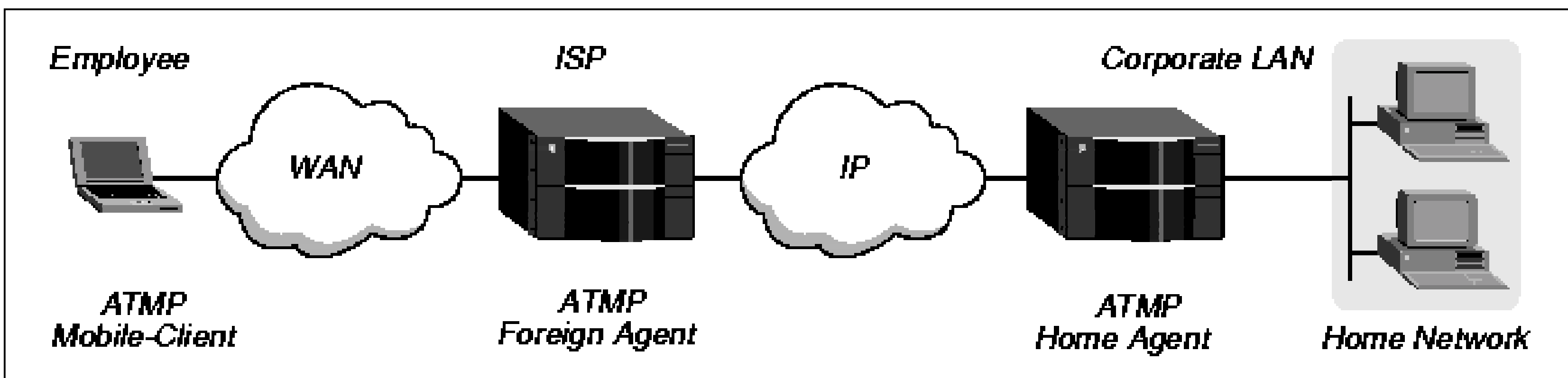


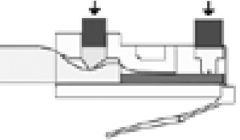


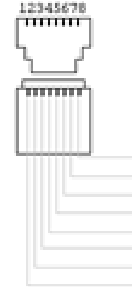



# Design failures
# Ascend Router - ATMP

- Ascend Tunnel Management Protocol
  - RFC 2107
  - Dynamic GRE Tunnel creation
- RFC concept uses complicated setup:

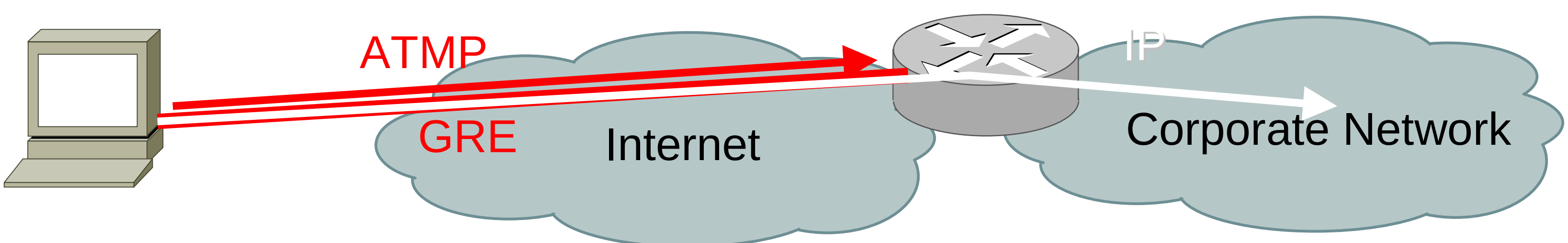


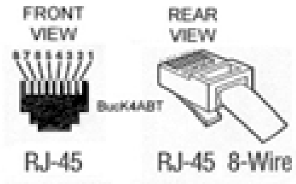




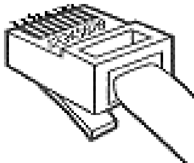
# Design failures Phenoelit ATtackMP

- Protocol implementation flaw
  - Every Ascend device seems to run it
  - No authentication required
  - No configuration required
- Building a tunnel
  - ATMP challenge/response → Tunnel ID
  - GRE using this Tunnel ID as key





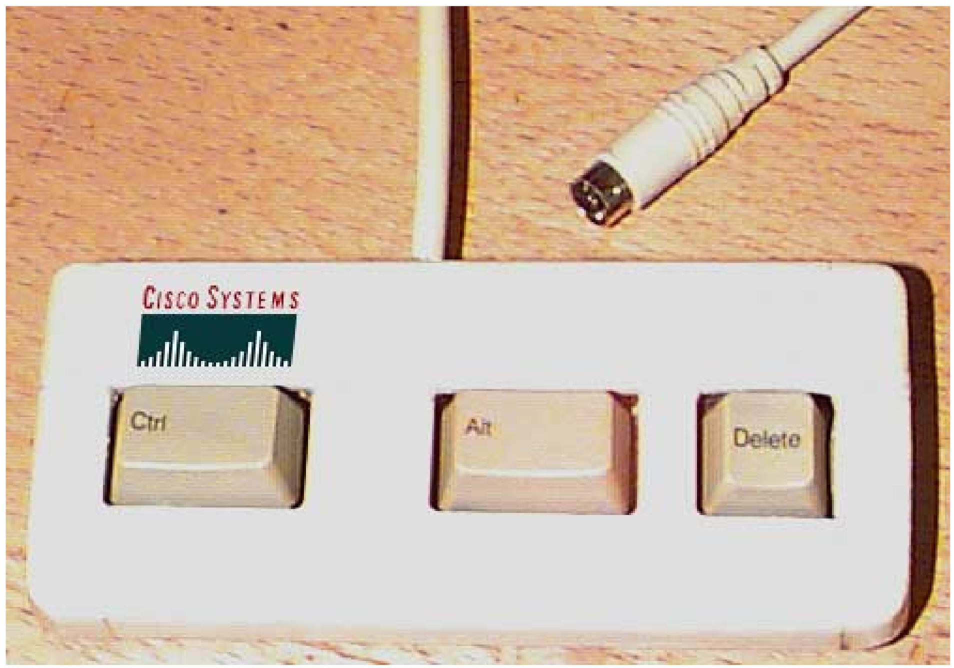



# Cisco IOS EIGRP

- Enhanced IGRP uses automagic neighbor discovery
- Flooding Cisco IOS with random neighbor announcements causes segment wide DoS
  - Router ARPs for the neighbor IP as long as the EIGRP timer did not expire
  - Timer value provided by attacker in packet, max over 18 hours
- IOS 11.x allows attack as unicast

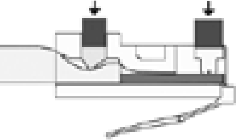
# Cisco IOS EIGRP

- Affected IOS versions: ALL
- Cisco‘s fix: none

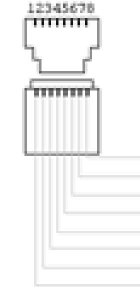


# Exploiting a design failure: HP Printers

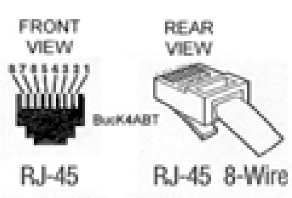
- Various access methods:
  - Telnet,HTTP,FTP,SNMP,PJL
- Various access restrictions
  - Admin password on HTTP and Telnet
  - IP access restriction on FTP, PJL, Telnet
  - PJL security password
- Inconsistent access restriction interworkings
  - SNMP read reveals admin password in hex at .iso.3.6.1.4.1.11.2.3.9.4.2.1.3.9.1.1.0
  - HTTP interface can be used to disable other restrictions (username: laserjet)



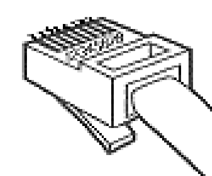
# HP Printers: PJL

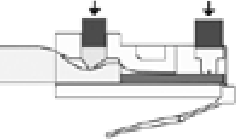


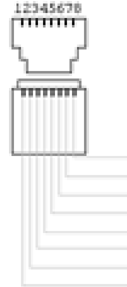
- PJL (Port 9100) allows access to printer configuration
  - Number of copies, size, etc.
  - Locking panel
  - Input and output trays
  - Eco mode and Power save
  - I/O Buffer
- Security relies on PJL password
  - key space of 65535.
  - max. 6 hours for remote brute force





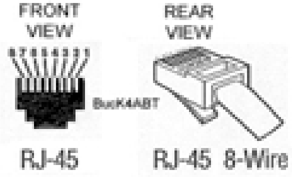





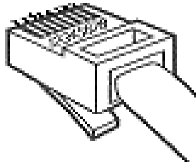


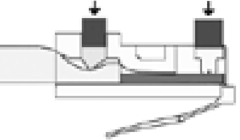
# HP Printers: PJL

- PJL (Port 9100) allows access to printer file systems on DRAM and FLASH
  - Spool directory contains jobs
  - PCL macros on printer
- More file system content (later models)
  - Firmware
  - Web server content
  - Subsystem configuration
- Printer can be used as PJL-based file server

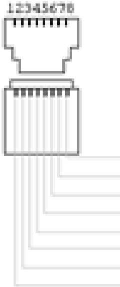




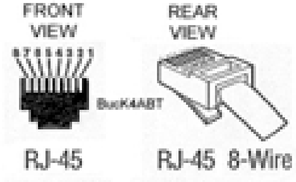





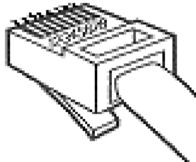
# Phenoelit vs. PJL: PFT



- Tool for direct PJL communication
  - Reading, modifying and writing environment variables
  - Full filesystem access
  - Changing display messages
  - PJL „security“ removal
- Available for Linux and Windows including libPJL for both platforms
- Windows GUI version „Hijetter“ by FtR
- ... and of course it‘s open source

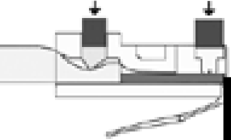
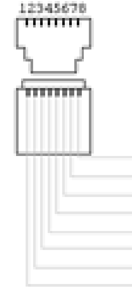




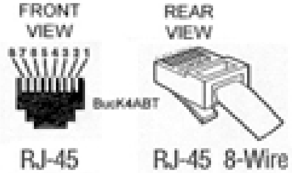
# HP Printers: ChaiVM [1]

- ChaiVM is a Java Virtual Machine for embedded systems
- HP Printers 9000, 4100 and 4550 are officially supported.
- HP 8150 also runs it.
- ChaiVM on printers comes completely with web server, static files and objects.
- Everything lives on the printer‘s file system.

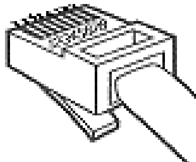



# HP Printers: ChaiVM [2]

- Chai standard loader service
  - http://device_ip/hp/device/this.loader
  - Loader is supposed to validate JAR signature from HP to ensure security
- HP released new EZloader
  - HP signed JAR
  - No signatures required for upload
- Adding services via printer file system access to 0:\default\csconfig
- ~~HP Java classes, documentation and tutorials available~~

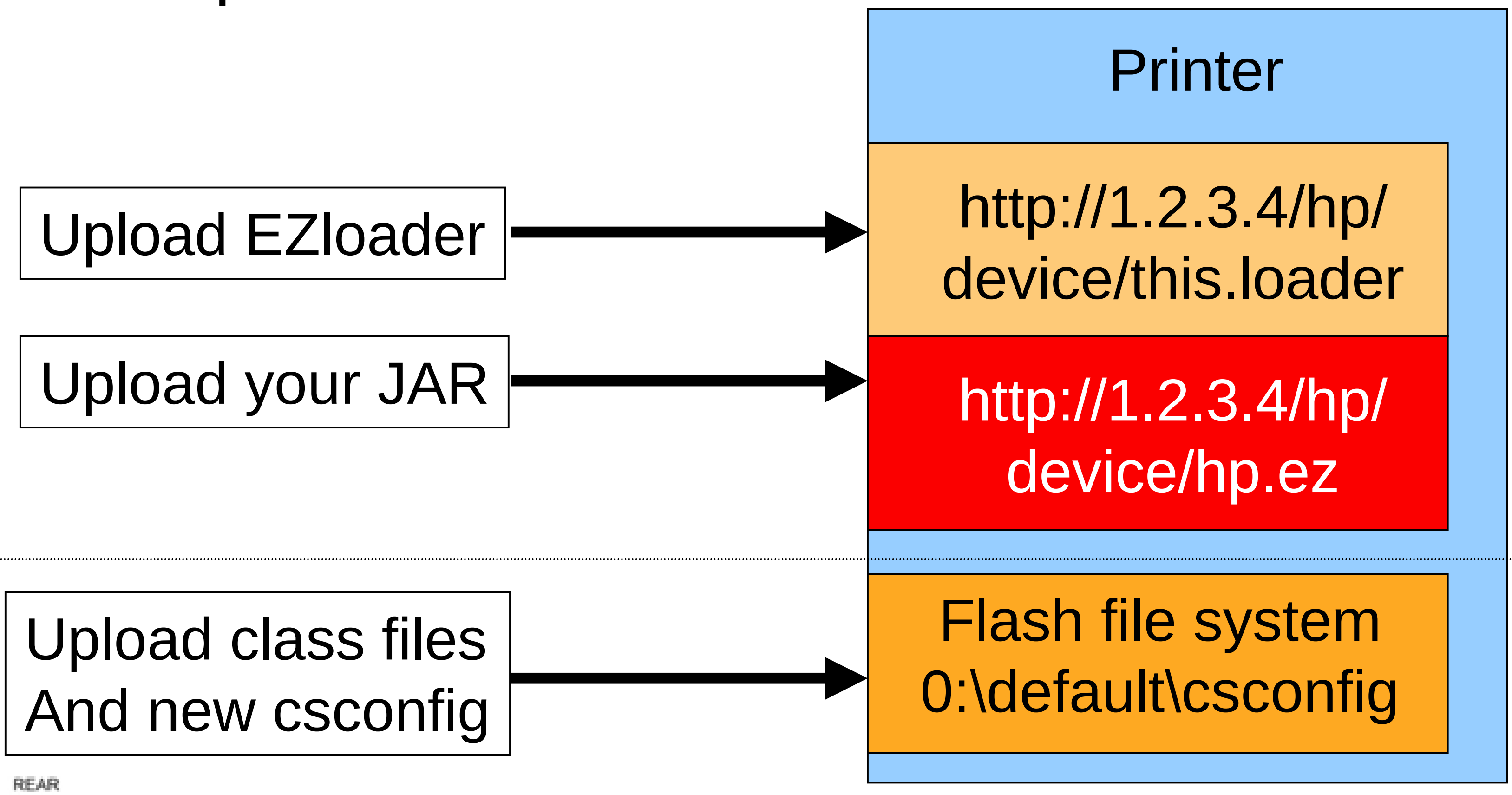




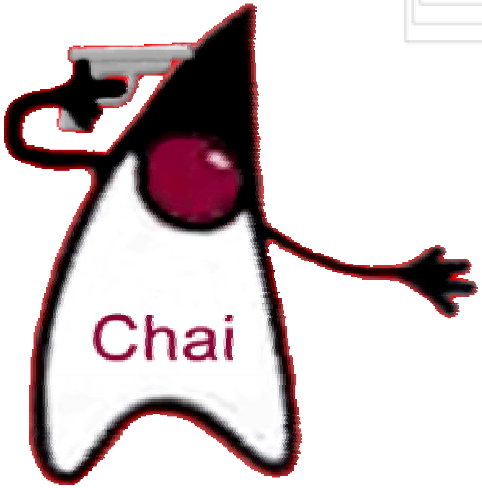
# HP Printers: ChaiVM [3]

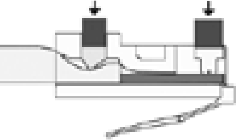
- Getting code on the printer



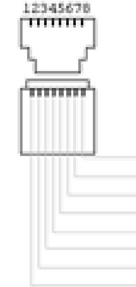
# HP Printers: ChaiVM [4]

- ChaiVM is quite instable
  - Too many threads kill printer
  - Connect() to unreachable hosts or closed port kills VM
  - Doesn't always throw an Exception
  - Huge differences between simulation environment and real-world printers
  - Unavailability of all instances of a service kills VM
- To reset printer use SNMP set: .iso.3.6.1.2.1.43.5.1.1.3.1 = 4

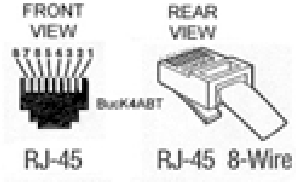




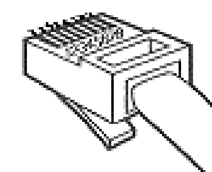
# HP Printers: Things you can do...




- Phenoelit ChaiPortScan
  - Web based port scanner daemon for HP Printers with fixed firmware
- Phenoelit ChaiCrack
  - Web based crypt() cracking tool for HP Printers
- Phenoelit BNC
  - Transparent web based TCP proxy for HP Printers

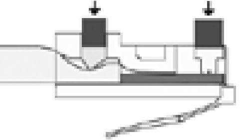




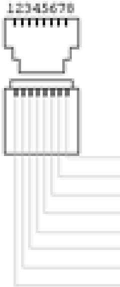



# HP Printers: ChaiVM [5]

- ChaiServices are fully trusted between each other
- ChaiAPNP service supports Service Location Protocol (SLP)
  - **find other devices and services**
- Notifier service can notify you by HTTP or Email of „interesting events“
- ChaiOpenView enables ChaiVM configuration via SNMP
- ChaiMail service is „designed to work across firewalls“.
  - **Issue commands to your Chai service via Email!**

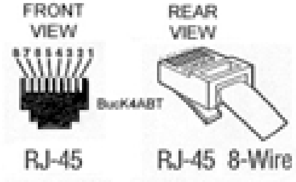


# HP Printers

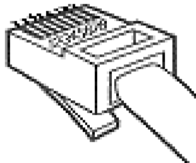


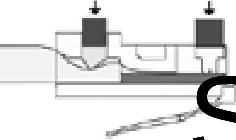

Tools and source available at

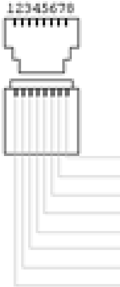
http://www.phenoelit.de/hp/





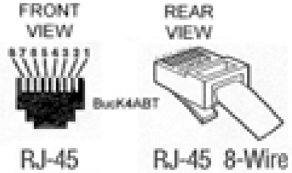





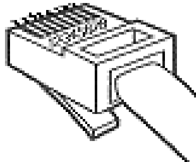


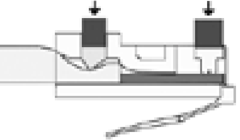
# Software Vulnerabilities

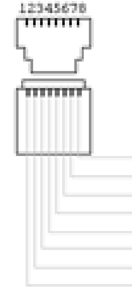
- Classic mistakes are also made on embedded systems
  - Input validation
  - Format strings
  - Buffer overflows
  - Cross Site Scripting
- Most embedded HTTP daemons vulnerable
- Limited resources lead to removal of sanity checks





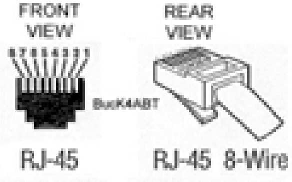





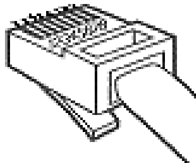


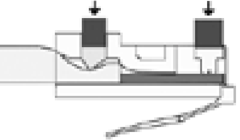
# Buffer overflows

- Xedia Router
  (now Lucent Access Point)
  - long URL in HTTP GET request crashes router
- Brother Network Printer (NC-3100h)
  - Password variable in HTTP GET request with 136 chars crashes printer
- HP ProCurve Switch
  - SNMP set with 85 chars in .iso.3.6.1.4.1.11.2.36.1.1.2.1.0 crashes switch
- SEH IC-9 Pocket Print Server
  - Password variable in HTTP GET request with 300 chars crashes device

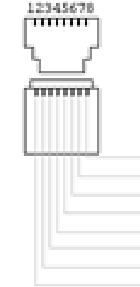




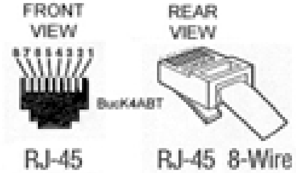





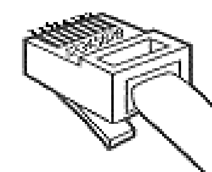
# Common misconceptions



- Embedded systems are harder to exploit than multipurpose OS's
- You have to reverse engineer the firmware or OS to write an exploit
- You need to know how the sys-calls and lib functions work to write an exploit
- The worst thing that can happen is a device crash or reboot



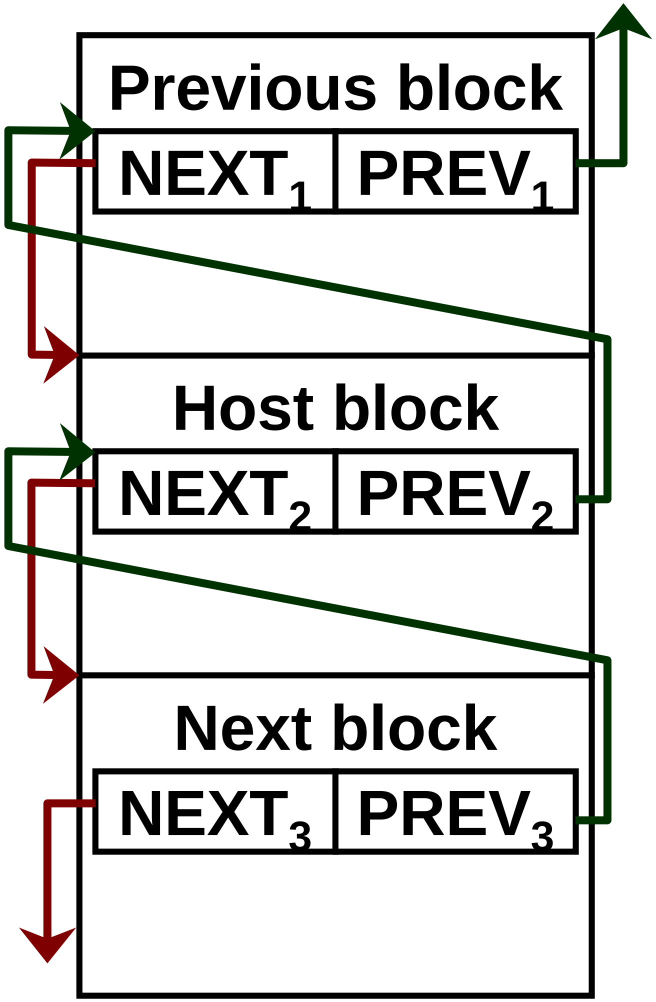


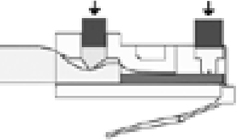
# Proving it wrong: A Cisco IOS Exploit

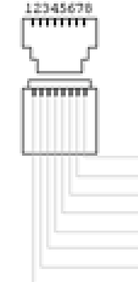
- Exploiting an overflow condition in Cisco Systems IOS to take over the Router.
- The process you crash is tightly integrated into the OS, so you probably crash the whole OS as well
- According to Cisco, memory corruption is the most common bug in IOS. So it's probably a heap overflow.
- Vulnerability for research:
  Buffer overflow in IOS (11.1.x – 11.3.x)
  TFTP server for long file names

# Heap Layout

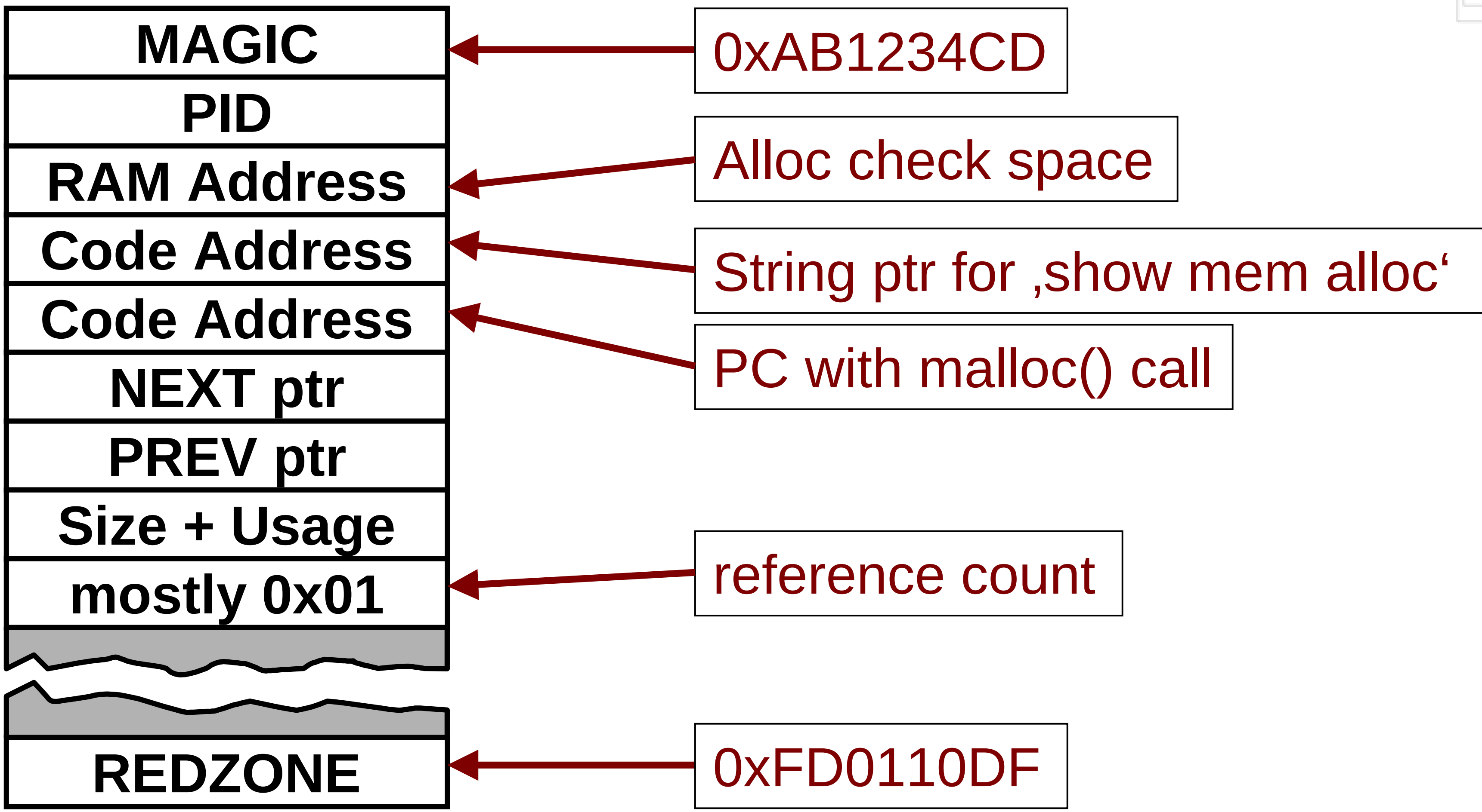


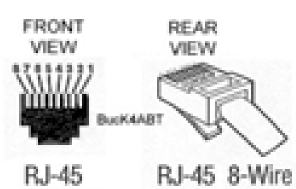

- Two different memory areas: main and IO memory
- Double linked pointer list of memory blocks
  - Same size in IO
  - Various sizes in main
- Probably based off a tree structure
- A single block is part of multiple linked lists



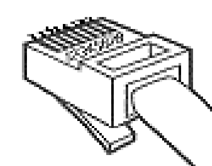


# Block layout



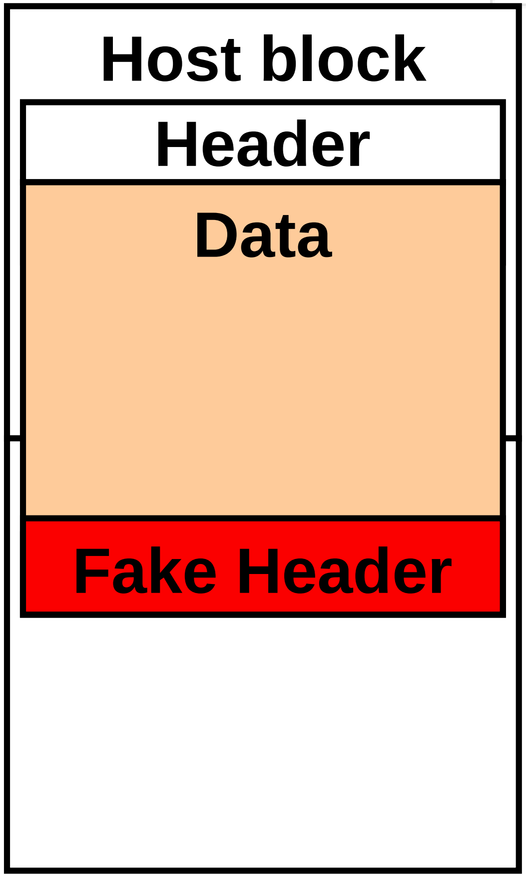





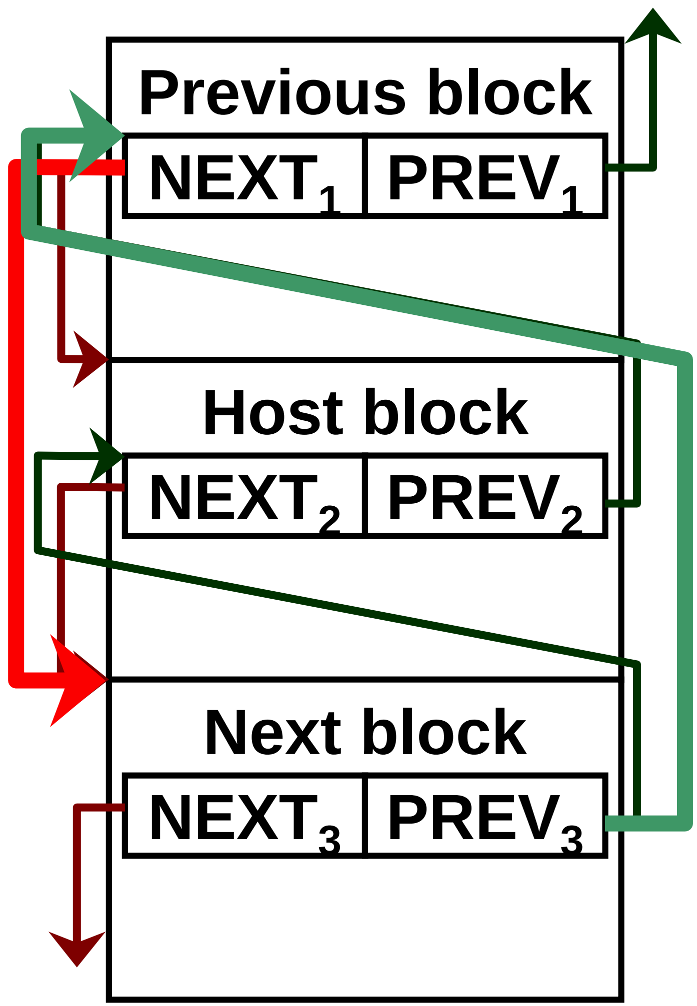



# Theory of the overflow

- Filling the „host block“
- Overwriting the following block header – hereby creating a „fake block“
- Let IOS memory management use the fake block information
- Desired result: Writing to arbitrary memory locations

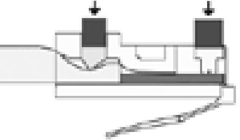


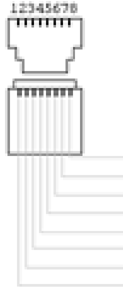
# A free() on IOS




- Remember: Double linked pointer list of memory blocks
- Upon free(), an element of the list is removed
- Pointer exchange operation, much like on Linux or Windows

```
Host->prev=next2;
(Host->next2)+prevofs=prev2;
delete(Host_block);
```

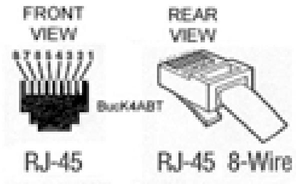




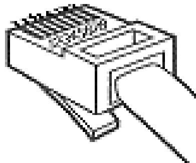
# The requirements

| |
|---|
| MAGIC |
| PID |
| RAM Address |
| Code Address |
| Code Address |
| NEXT ptr |
| PREV ptr |
| Size + Usage |
| mostly 0x01 |
| REDZONE |

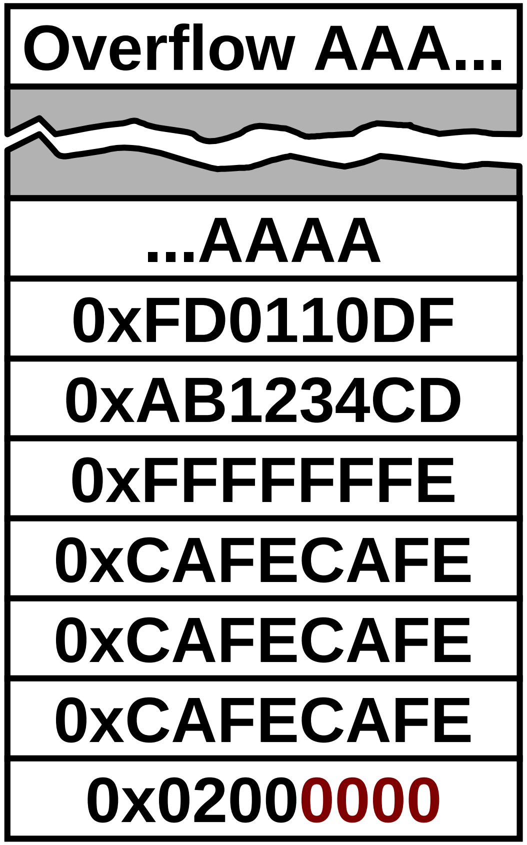
- Required:
  - MAGIC, RED ZONE
  - PREV PTR
  - Size
- Unchecked:
  - Wasted pointers
  - NEXT PTR
- „Check heaps“ process validates MAGIC and REDZONE
- Performing an overflow up to the NEXT ptr is possible.





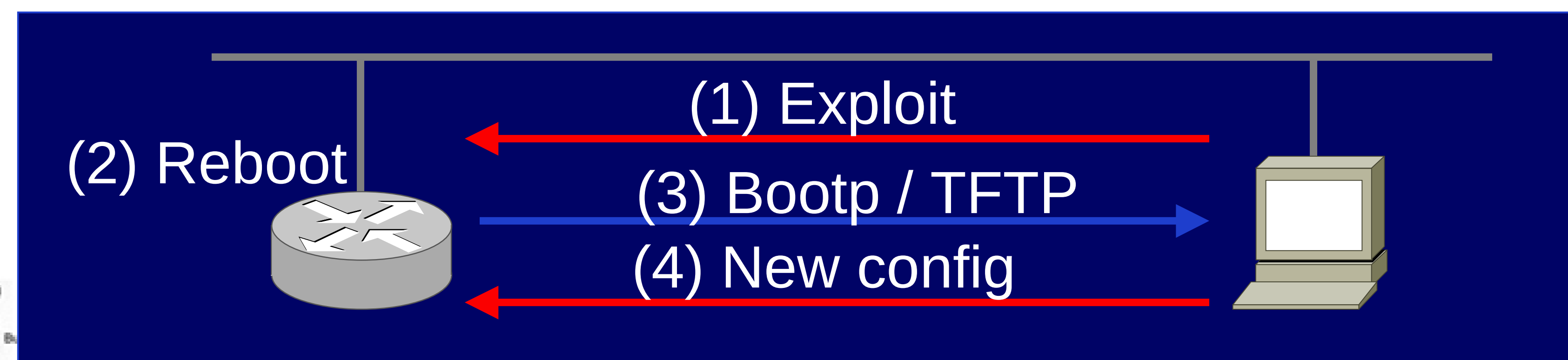
# Taking the first: 2500




- Cisco 2500 allows anyone to write to the NVRAM memory area
- Since NEXT ptr is not checked, we can put 0x02000000 (NVRAM) in there
- The 0x00 bytes don‘t get written because we are doing a string overflow here
- The pointer exchange leads to a write to NVRAM and invalidates it (checksum error)

# Taking the first: 2500

- NVRAM gets invalidated by exploit
- Device reboots after discovering issue in memory management („Check heaps“ process)
- Boot without valid config leads to BOOTP request and TFTP config retrieval
- Result: **Attacker provides config**



# Getting around PREV

- PREV ptr is checked while the previous block is inspected before the free()
- Test seems to be:

```
if (next_block->prev!=this_block+20)
        abort();
```

- Perform uncontrolled overflow to cause device reboot
  - Proves the device is vulnerable
  - Puts memory in a predictable state
  - Crash information can be obtained from network or syslog host if logged (contains PREV ptr address)

# Free memory blocks


- Free memory blocks carry additional management information
- Information is probably used to build linked list of free memory blocks
- Functionality of FREE NEXT and FREE PREV comparable to NEXT and PREV

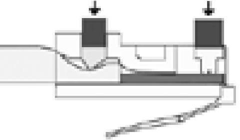
# Arbitrary Memory write

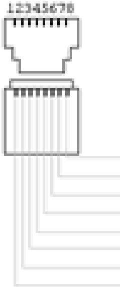

- FREE NEXT and FREE PREV are not checked
- Pointer exchange takes place
- Using 0x7FFFFFFF in the size field, we can mark the fake block „free“
- Both pointers have to point to writeable memory

```
*free_prev=*free_next;
*(free_next+20)=*free_prev;
```

# Places for pointers

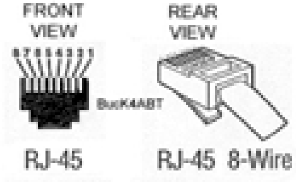
- ‚show mem proc alloc‘ shows a „Process Array“
- Array contains addresses of process information records indexed by PID
- Process information record‘s second field is current stack pointer
- All of these are static addresses per IOS image



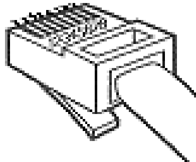


# Taking the Processor

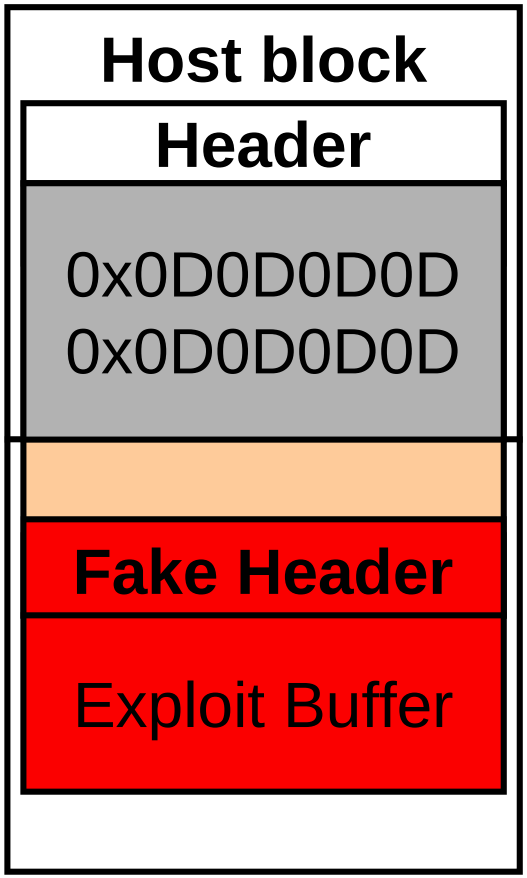
- The stack of any IOS process is writable by any code running on the system
- We can overwrite
  - Frame pointer
  - Return address
  - Process Array entry
  - Process Record stack entry
  - Process Record SP entry



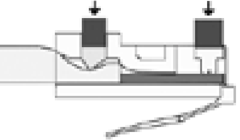


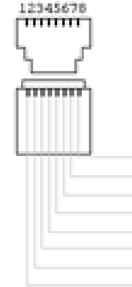



# The Buffer



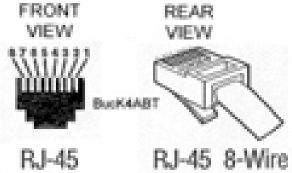

- A free() on IOS actually clears the memory (overwrites it with 0x0D)
- Buffer after fake block is considered already clean and can be used for exploitation
- Position of the buffer relative to PREV ptr is static per platform/IOS



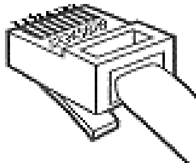


# The shell code – V1

- Example based on Cisco 1600
- Motorola 68360 QUICC CPU
- Memory protection is set in the registers at 0x0FF01000
- Disabling memory protection for NVRAM address by modifying the second bit of the appropriate QUICC BaseRegister (See MC68360UM, Page 6-70)
- Write invalid value to NVRAM
- Device reboots and asks for config



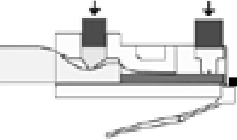
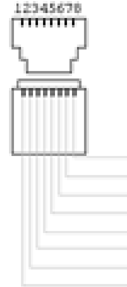


# The shell code – V1

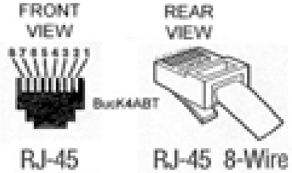
- Simple code to invalidate NVRAM (Sorry, we are not @home on 68k)
- Dummy move operation to d1, data part of OP code is overwritten on free()
- ADDA trick used to circumvent 0x00 bytes in code

```
\x22\x7C\x0F\xF0\x10\xC2    move.l #0x0FF010C2,%a1
\xE2\xD1                    lsr    (%a1)
\x22\x7C\x0D\xFF\xFF\xFF    move.l #0x0DFFFFFF,%a1
\xD2\xFC\x02\xD1            adda.w #0x02D1,%a1
\x22\x3C\x01\x01\x01\x01    move.l #0x01010101,%d1
\x22\xBC\xCA\xFE\xBA\xBE    move.l #0xCAFEBABE,(%a1)
```

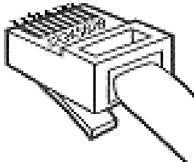



# The Cisco 1600 Exploit

- Overflow once to get predictable memory layout
- Overflow buffer with
  - Fake block and correct PREV ptr
  - Size of 0x7FFFFFFF
  - FREE NEXT points to code buffer
  - FREE PREV points to return address of process „Load Meter“ in stack
  - Code to unprotect memory and write into NVRAM



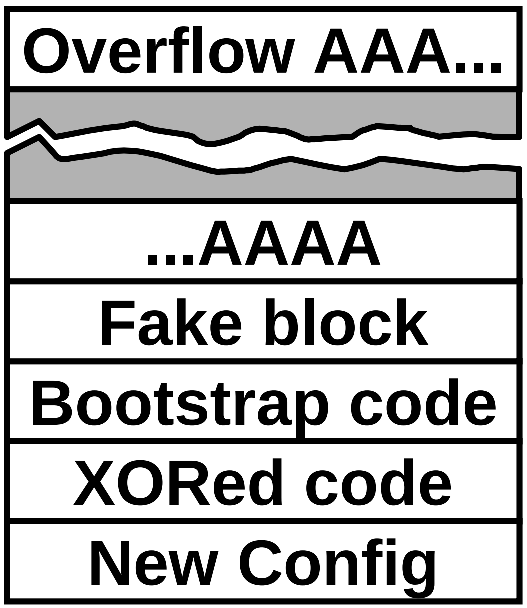


# The remote shell code

- Append new minimum config to the overflow
- Disable interrupts
- Unprotect NVRAM
- Calculate values for NVRAM header
  - Length
  - Checksum
- Write new header and config into NVRAM (**slowly!**)
- Perform clean hard reset

# The IOS Exploit Phenoelit Ultima Ratio

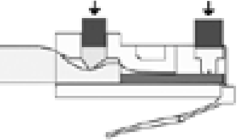


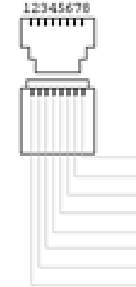

- Code size including fake block: 282 bytes
- New config can be specified in command line
- Adjustments available from command line
- Full source code available

**http://www.phenoelit.de/ultimaratio/**

# Phenoelit Ultima Ratio

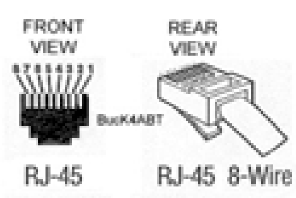
```
"\xFD\x01\x10\xDF" // RED
"\xAB\x12\x34\xCD" // MAGIC
"\xFF\xFF\xFF\xFF" // PID
"\x80\x81\x82\x83" // AL chk
"\x08\x0C\xBB\x76" // NAME
"\x80\x8a\x8b\x8c" // Al PC
"\x02\x0F\x2A\x04" // NEXT
"\x02\x0F\x16\x94" // PREV
"\x7F\xFF\xFF\xFF" // SIZE
"\x01\x01\x01\x01" // ref cnt
"\xA0\xA0\xA0\xA0" // De Al
"\xDE\xAD\xBE\xEF" // MAGIC2
"\x81\x82\x83\x84" // De PC
"\xFe\xFe\x0B\xAD" // CCC greets
"\xFe\xFe\xBA\xBE" // CCC greets
"\x02\x0F\x2A\x24" // Fnext
"\x02\x05\x7E\xCC" // Fprev
```



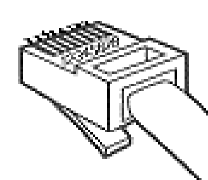


# OoopSPF

- Cisco IOS 11.2, 11.3, 12.0 crash with more than 255 OSPF neighbors
- Cisco Bug ID: **CSCdp58462**
- Overwrites memory structures – but different:
  - Overflow is not single packet
  - Overflow is in IO memory buffers
  - Overflow is not at the end of memory block chain

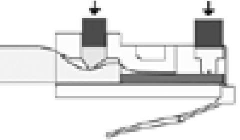


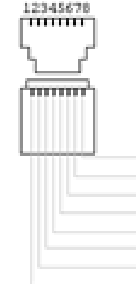


# OoopSPF Exploitability

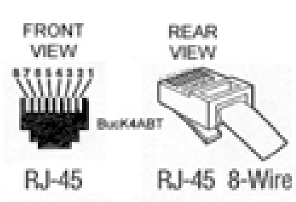
- Creation of a list entry depends on the source address of the IP OSPF HELO packet
  - Source IP address has to be expected on this interface (network statement)
  - Netmask smaller than 0xFFFFFF00 required (more than 255 neighbors)
- List entry is the OSPF header Router ID
  - Not checked against the source network
  - No plausibility checks at all



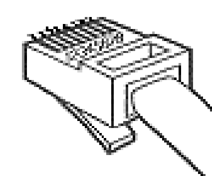


# IO memory and buffers

- IOS uses dynamically scaled lists of fixed size buffers for packet forwarding and other traffic related operations
- **Public buffer pools**
  (small, middle, big, very big, hug)
- **Private interface pools**
  (size depends on MTU)
- Allocation/Deallocation depends on thresholds (perm, min, max, free)

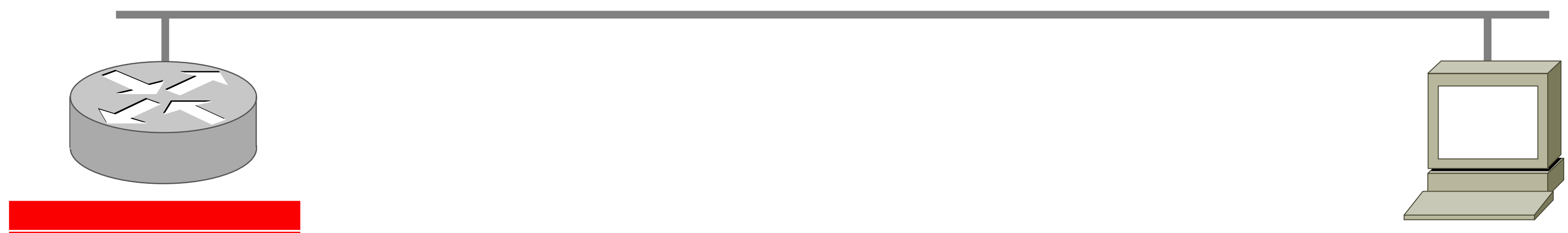


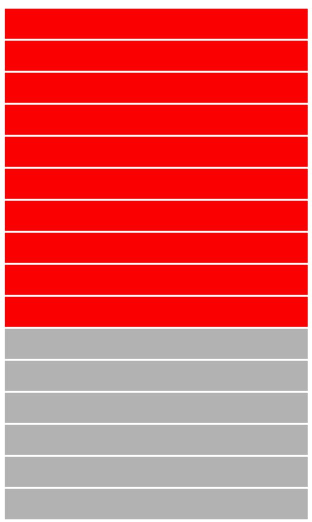


# OoopSPF Exploit

## Hey Cisco, piece this together for me!



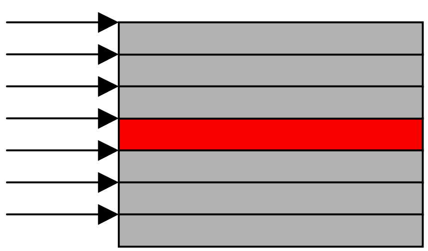



- Every packet can deliver 4 bytes to the buffer
- Overflow happens buttom to top (copy action)
- 256 IP addresses gives a buffer of 1024 bytes
- Larger buffers possible

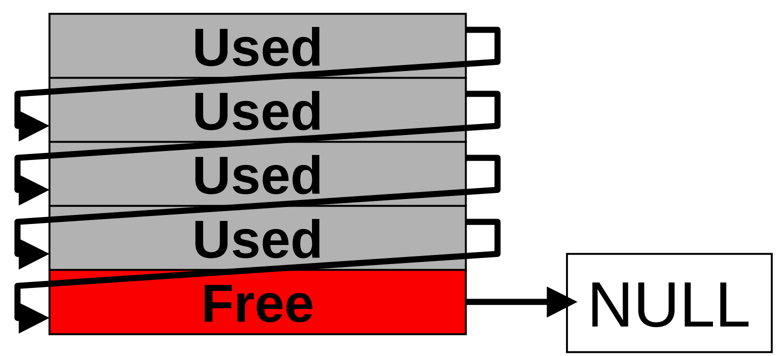
# Memory Mgmt Tricks

- Overflowed block header is in the middle of a memory block chain
- Free() exploit depends on memory being coalesced
- Solution: make a free used block ;-)

Buffer list view



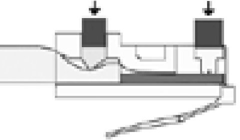
Memory merger view

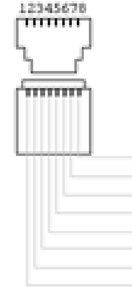


# Memory Mgmt Tricks [2]

- Requires
  - Correct PREV Pointer
  - Correct Size up to the end of the memory pool
- System stays stable after successful overflow – ***exploit dormant***

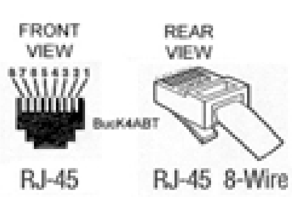
| Address | Bytes | Prev. | Next | Ref | PrevF | NextF | Alloc PC | What |
|---|---|---|---|---|---|---|---|---|
| .... | | | | | | | | |
| E2F5F8 | 1680 | E2EF3C | E2FCB4 | 1 | | | 3172EF0 | *Packet Data* |
| E2FCB4 | 1680 | E2F5F8 | E30370 | 1 | | | 3172EF0 | *Packet Data* |
| E30370 | 1680 | E2FCB4 | E30A2C | 1 | | | 3172EF0 | *Packet Data* |
| E30A2C | 260 | E30370 | E30B5C | 1 | | | 3172EF0 | *Packet Data* |
| E30B5C | 1897592 | E30A2C | 0 | 0 | 0 | E30B80 | 808A8B8C | [PHENOELIT] |



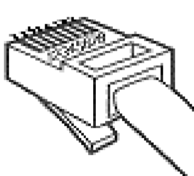


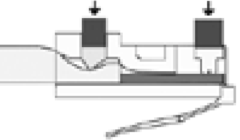
# Activating the Exploit

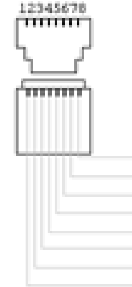
- The box has to need more small (or medium) buffers than set as „permanent“
  - Heavy traffic load
  - Complex routing updates
- After „trimming“ the buffers (deallocation), the box comes back with a new config
- Alternative (social engineering):
  **`buffers small permanent 0`**





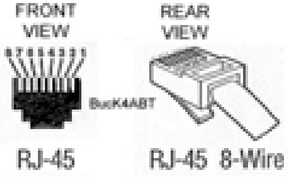





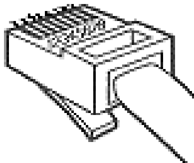


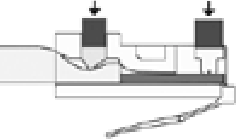
# A minimum IOS config

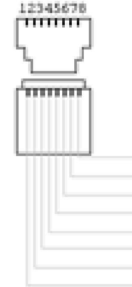
```
ena p c
in e0
 ip ad 62.1.2.3 255.255.255.0
ip route 0.0.0.0 0.0.0.0 62.1.2.1
li v 0 4
 pas c
 logi
```





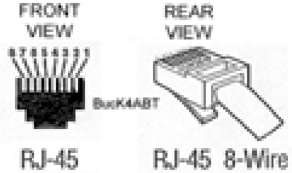





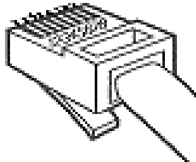


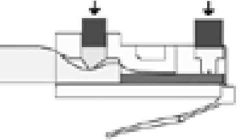
# Work to do

- PREV ptr addresses and all the other guesswork
  - Mapping commonly used addresses
  - Stabilizing the PREV ptr address
  - Produce „stable“ exploits ;-)
- NVRAM and Config
  - Writing to FLASH instead of NVRAM
  - Anti-Forensics shell codes
  - Real time config modification code

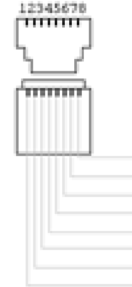




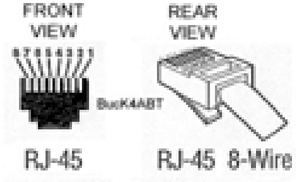





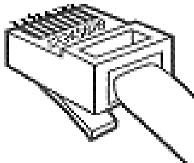
# IOS Exploit - so what?

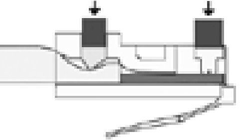


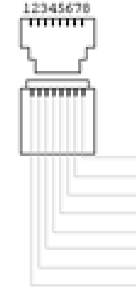
- Most IOS heap overflows seem to be exploitable
  - Protocol based exploitation
  - Debug based exploitation
  - Network infrastructure still mostly unprotected
- NVRAM still contains former config after local network exploitation
  - Password decryption
  - Network structure and routing protocol authentication disclosed





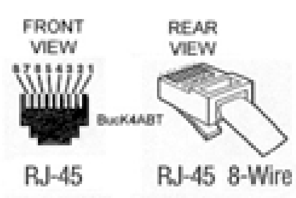





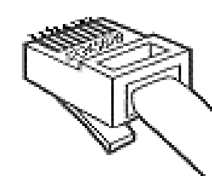


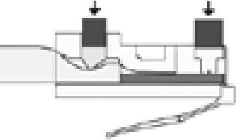
# How to protect

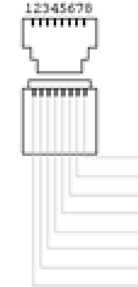
- Do not rely on one type of device for protection
- Consider all your networked equipment vulnerable to the fullest extent
- Employ all possible protection mechanisms a device provides
- Do not ignore equipment because it is small, simple, or has not been exploited in the past.
- Plan your device management as you plan root logins to UNIX systems





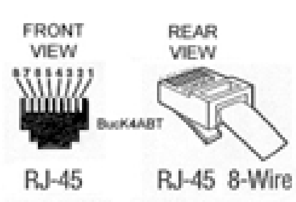





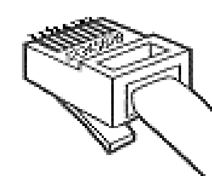


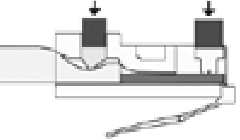
# How to protect - HP

- Assign passwords
  - Admin password
  - SNMP *read and write* community
  - PJL protection (gives you time)
- Allow access to port 9100 on printer only from print servers
- Remove this.loader from the printer (edit /default/csconfig and restart)
- Consider putting your printers behind an IP filter device

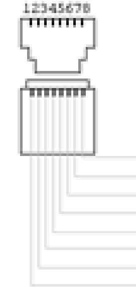




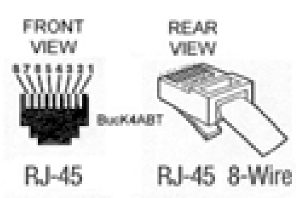





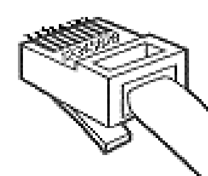
# How to protect - Cisco



- Have no overflows in IOS
- Keep your IOS up to date
- Do not run unneeded services (TFTP)
- Tell your IDS about it. Signature: \xFD\x01\x10\xDF\xAB\x12\x34\xCD
- **`debug sanity`** might stop less experienced attackers
- The hard way: **`config-register 0x00`**
- Perform logging on a separate segment
- Protect your syslog host





**Thanks and greets to...**
**Jeff and Ping,**
**Halvar, Johnny,**
**Nico, Riley, Scusi,**
**the Phenoelit Members,**
**the Members of c0d3&b33r,**
**and the audience !**

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**FX of Phenoelit, Blackhat Amsterdam 2003**