What hacker research taught me

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What this is about

- A personal rant / ”quest”
- The fun and huge presumpion of defining ”**hacking**” :-)
- An excuse for citing Phrack, Uninformed, Defcon/Recon/Shmoocon/Toorcon/...
- Realization that ”hacking” goes to the **heart** of fundamental Computer Science problems

”Hackers!”

- The Adversary
- Harbingers of Future Technologies
- Engineers / researchers of a unique specialization (not yet formally defined)
  - ”What kind of engines?”

”Hackers!”

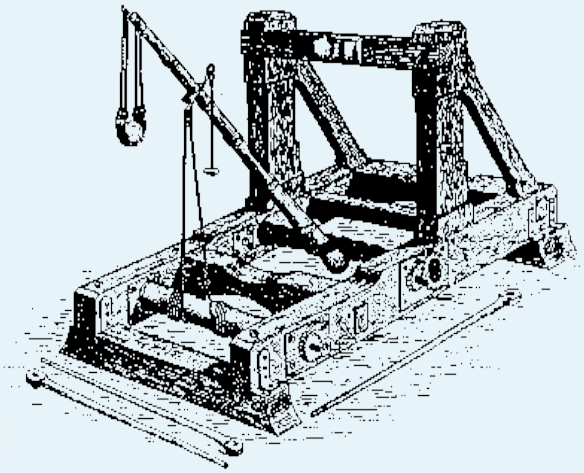
- The Adversary
  - Media + politicians
    Notice how they are always selflessly saving us from something or other?
  - ”We may need to forego certain freedoms to make the Internet a safer place”
    John Markoff, NYT, 2009
  - Enough said :-(

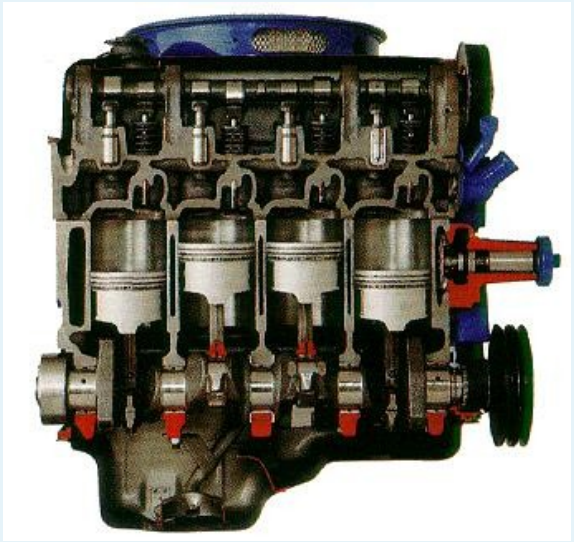
”Hackers!”

- Harbingers of the Future
  - Hackers realized the potential of universal, ubiquitous, cheap connectivity long before actual technology owners
    Emmanuel Goldstein, Toorcamp '09
  - Phone companies initially expected their revenues to come from ”customers” connecting to (for-pay) ”services”, not subscribers talking with other subscribers
    Andrew Odlyzko (AT&T Research)
    ”*Why content is not King*”

”Hackers!”

- Engineers of a unique kind / not yet formally defined discipline of engineering
- ”*What kind of engines?*”





”Hackers!”

- Engineers of a unique kind / not yet formally defined discipline of engineering
- ”*What kind of engines?*”
  - What kind of fundamental, hard problems are they up against?
    - E.g.: energy to motion is hard, storing energy is hard, etc.
  - What laws of nature are involved?
    - E.g.: Newtonian conservation laws, laws of thermodynamics, P != NP (?), ...

The defining challenges

- Something really, provably hard (as in ”NP”, RSA, other ”God's own math”)
- Something really human, what we must do every day

The defining challenges

- Something really, provably hard (as in ”NP”, RSA, other ”God's own math”)

Composition

- Something really human, what we must do every day

The defining challenges of Hacking as a discipline

- Something really, provably hard (as in ”NP”, RSA, other ”God's own math”)

Composition

- Something really human, what we must do every day

Trust

Composition is hard

- Informally: even if non-trivial properties of parts are known, the same properties of the combined system **cannot** be deduced by any general formal algorithm
- A.k.a. ”**Security is not composable**”
- Kind of formally:

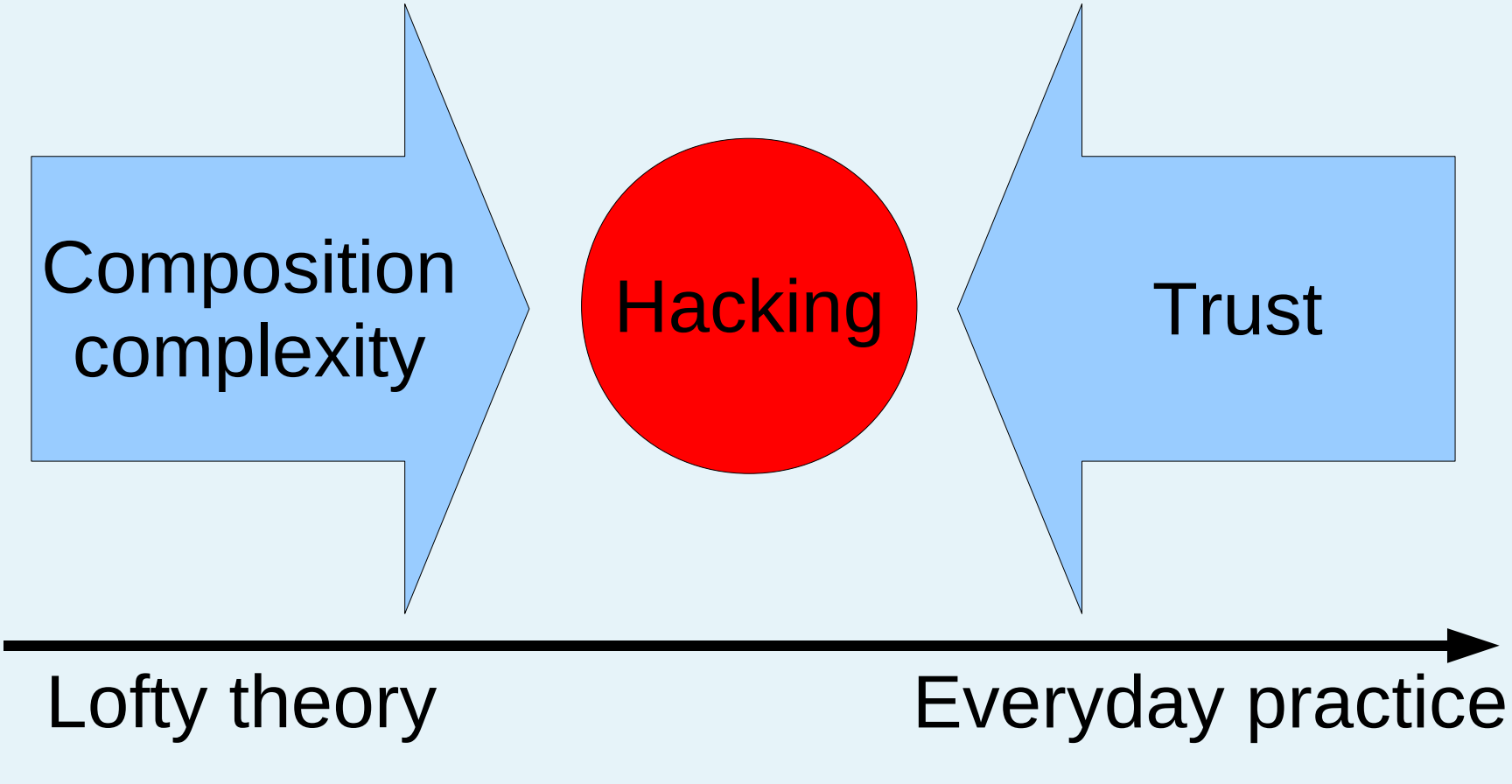
  Rice's Theorem ~ Halting problem

- There is a reason why humans don't deal well with complexity

Trust is crucial to human activities

- Economies and ways of life are defined by levels of trust
  - ”High Trust” vs ”Low Trust” societies theory
  - Personal experience :-)
- FX, Bratzke @ SiS '07: Pragmatically, InfoSec is about ”working towards computer systems we can finally trust”

The discipline of hacking at a glance



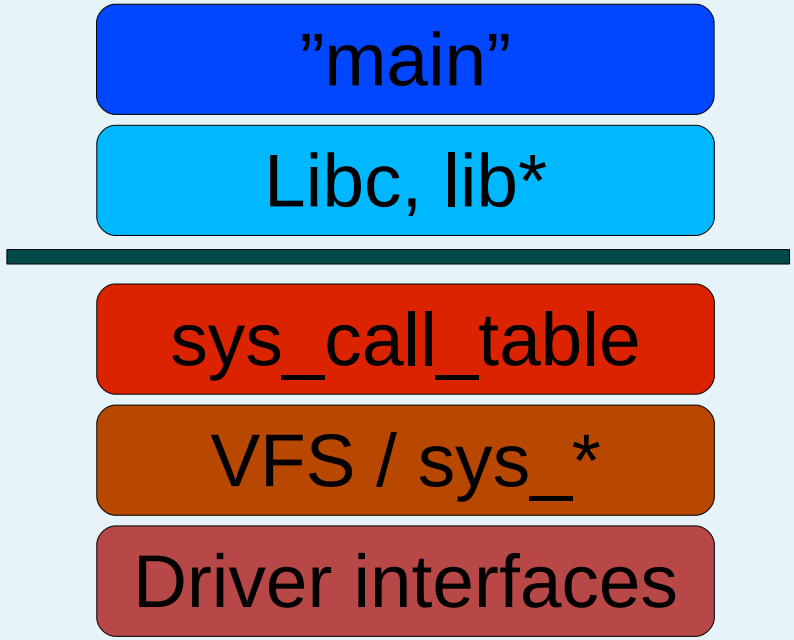
Hacking as R&D

Hacking (n.):

the capability/skill set to question and verify trust (security, control) assumptions expressed in complex software and hardware (as well as in human-in-the-loop processes that use them)

Lesson 1: **Look across layers**

- Humans aren't good at handling complexity
- Engineers fight it by layered designs:



Layers are magical

- They just work, especially the ones below
- One layer has proper security =>
  the whose system is trustworthy

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NOT! ;-)

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- *”They just work, especially ones below”*
- *”One layer has proper security =>*
  the whose system is trustworthy”
- **In real life, layer boundaries become <u>boundaries of competence</u>**

Layers are magical

- *”They just work, especially ones below”*
- *”One layer has proper security =>*
  the whose system is trustworthy”
- In real life, layer boundaries become boundaries of competence
- Hacker methodology in a word:

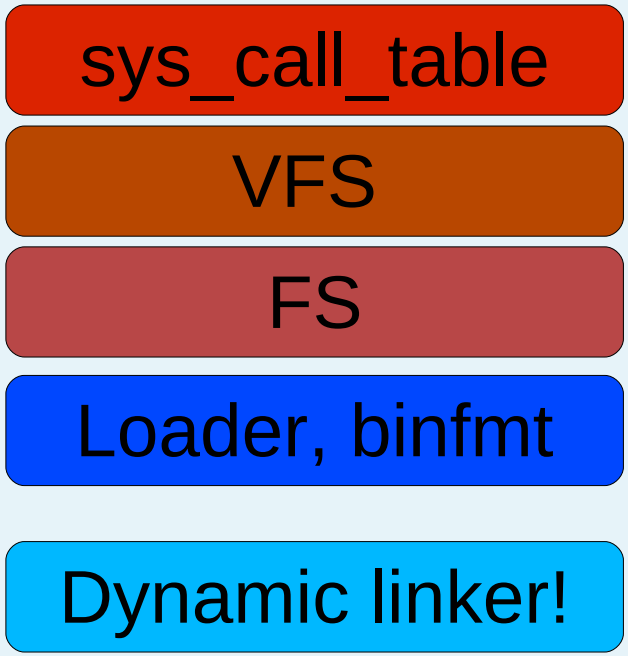
cross-layer approach

Best OS course reading ever :-)

- Phrack 59:5, palmers@team-teso

  ”5 Short Stories about execve”,

  *”**Deception in depth**”*



sys_execve, ”The Classic”

do_execve, ”The Obvious”

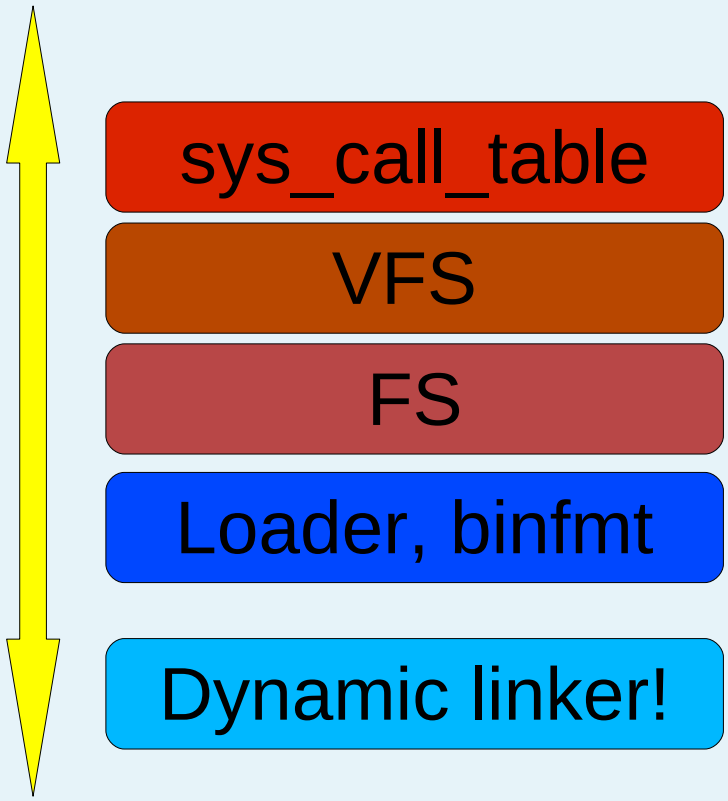
open_exec, ”The Waiter”

load_binary, ”The Nexus”

mmap/mprotect, ”The Lord”

”Cross-layer approach” in action

- Phrack 59:5, palmers@team-teso
  ”5 Short Stories about execve”,
  *”**Deception in depth**”*



sys_execve, ”The Classic”

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Lesson 2: **Composition is Weird**

Any complex execution environment is actually **many:**

One intended machine, endless **weird machines**

Exploit is ”code” that runs on a ”weird machine”, in its ”weird instructions”

Exploitation is ...

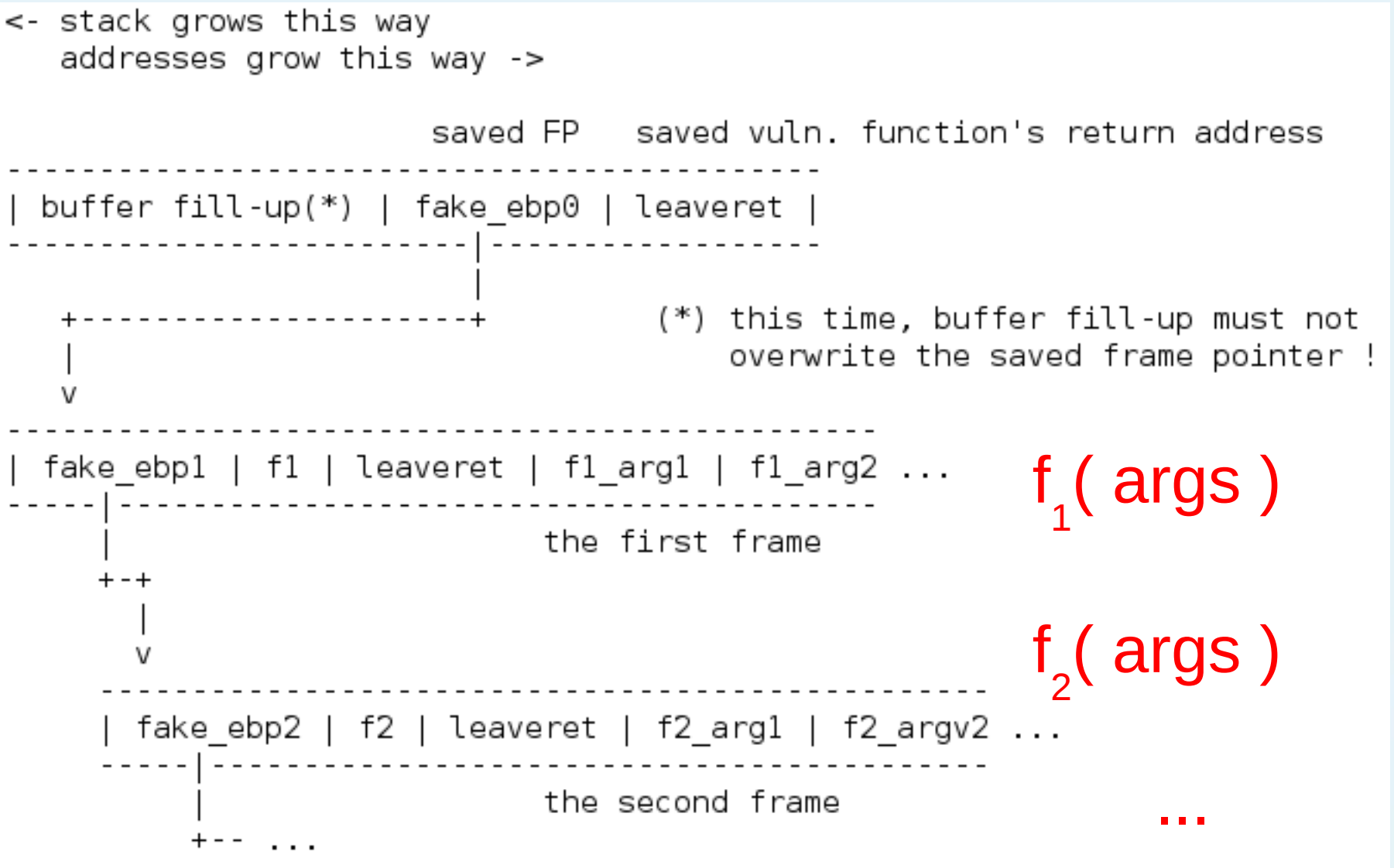
- Programming the ”weird machine” inside your machine (via crafted input)
- One case study:

  from return-into-libc (1997?) to
  ”return-oriented programming” (2008)

Exploitation is ...

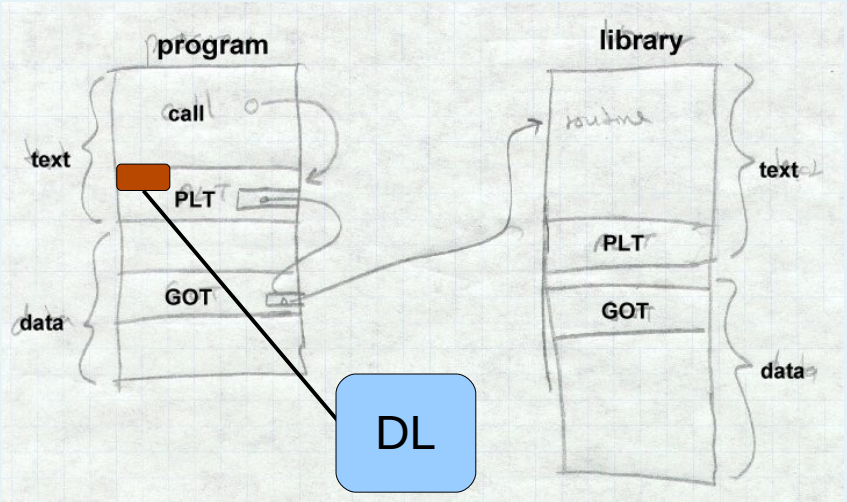
- Programming the ”weird machine” inside your machine (via crafted input)
- In 2008, academia calls this threat ”malicious computation” vs ”malicious code”
  - Hacker publications and countermeasures: 1997-- (Solar Designer, Wojtczuk, …)
  - Phrack 58 #4 (Nergal, 2001) spells it out
  - CCS 2008, it gets the cool name *”return-oriented programming”*

Phrack 58 #4


<- stack grows this way
addresses grow this way ->
saved FP
saved vuln. function's return address
| buffer fill-up(*) | fake_ebp0 | leaveret |
(*) this time, buffer fill-up must not overwrite the saved frame pointer !
| fake_ebp1 | f1 | leaveret | f1_arg1 | f1_arg2 ...
the first frame
f1(args)
f2(args)
| fake_ebp2 | f2 | leaveret | f2_arg1 | f2_argv2 ...
the second frame
...

Phrack 58 #4

- Sequence stack frames (pointers & args) just so that existing code fragments are chained into programs of any length
  - Just like TCL or FORTH programs
  - Pointers to functions can be provided by OS's dynamic linker itself



Another elementary instruction of the ”weird machine”, called through PLT: ”return-into-DL”

Case study timeline

- Solar Designer, "Getting around non-executable stack (and fix)", 1997
- Rafal Wojtczuk, "Defeating Solar Designer non-executable stack patch", 1998
- Phrack 58:4 (Nergal), 59:5 (Durden)
- Shacham et al., 2007-2008
  - ”The geomerty of innocent flesh on the bone”, 2007
  - ”Return-Oriented Programming: Exploits Without Code Injection”, 2008
- Hund, Holz, Freiling, ”Return-oriented rootkits”, 2009
  - Actual ”compiler” to locate and assemble return-target code snippets into programs

”PaX case study”
ASLR activity

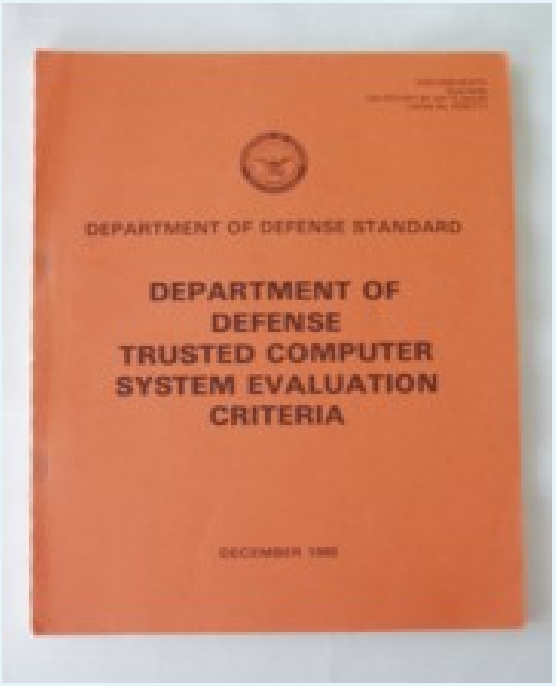
So we are waiting for...

- Double-free –oriented programming? :-)
- DL-malloc –oriented programming? :-)
- In each case, the original code contains snippets usable as ”instructions” of a ”weird machine” that can be composed together

”OMG, it's Turing-complete!”

Hacking and Multi-level Security DoD idea of Trusted Systems

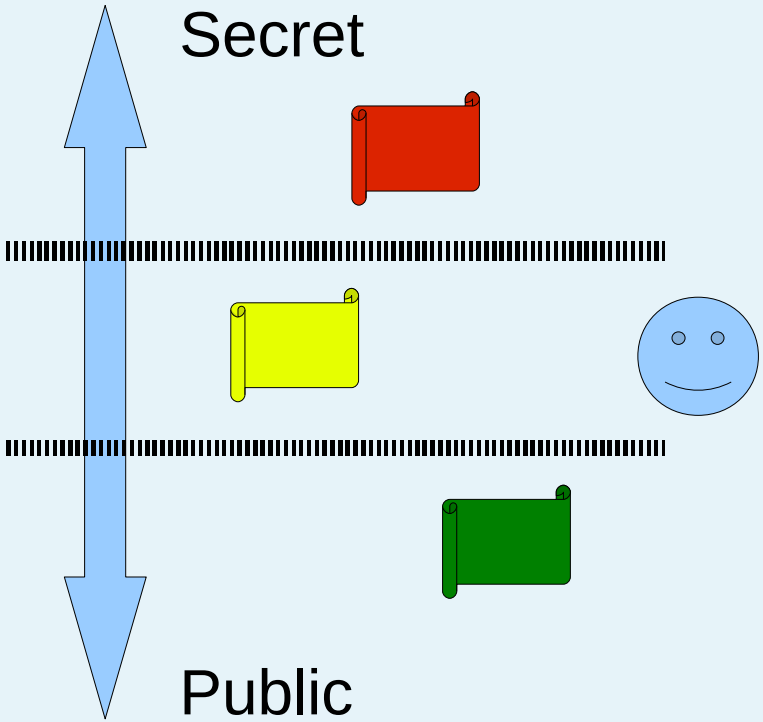
- Mandatory access control
  - Each principal is labeled
- All data is labeled
  - ”Everything is a file”
- Labels are checked at each operation by a *reference monitor*
  - Most trusted part of OS, ”trusted code base”



The ”Orange Book”

Bell-LaPadula Formalism (1973)

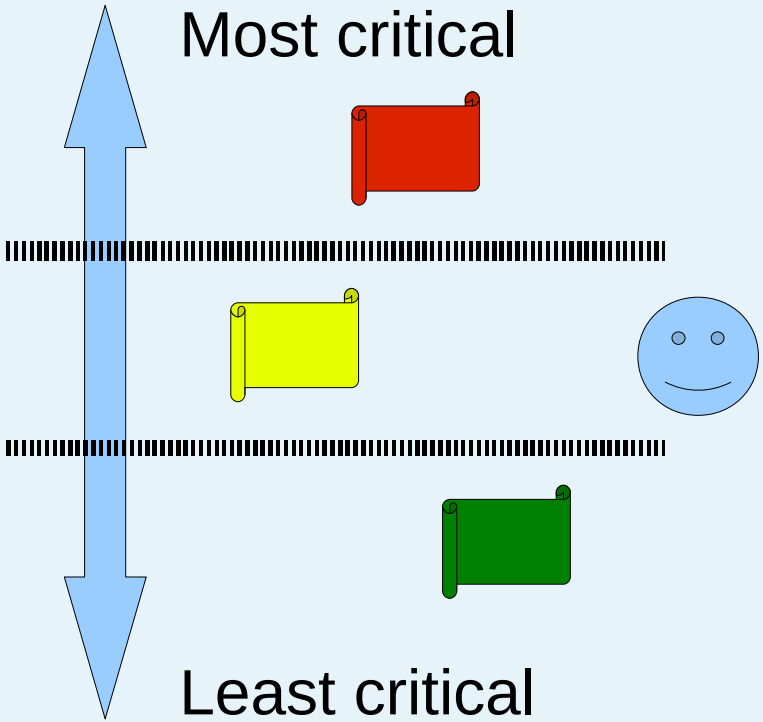
Goal: coltrol information flow, protect secrets from colluding malicious users



- ”No read up” (can't read higher privs' data)
- ”No write down” (can't willfully downgrade data)

Biba integrity model (1977)

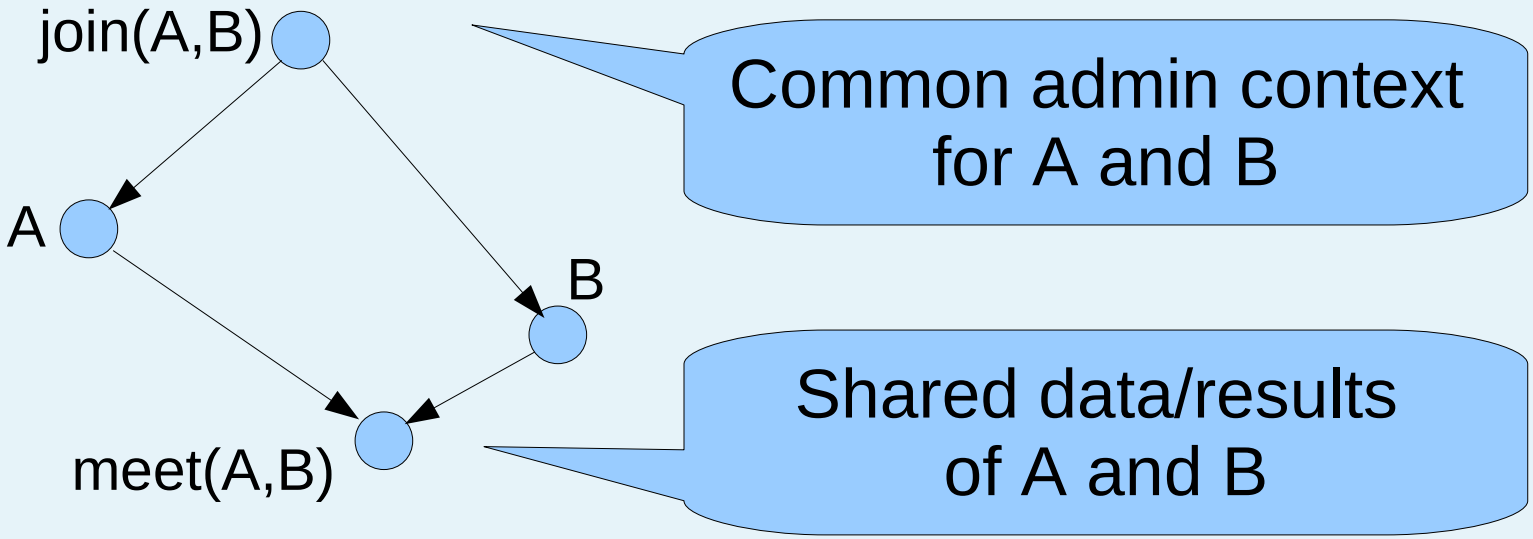
Goal: prevent integrity violations by and through lower level users



- ”No read down” (let untrusted stuff alone)
- ”No write up” (can't clobber higher layers)

”It's a lattice out there!”

- Partial order on all labels
  - Some are not comparable and will not interact directly
- Every pair has a unique ”join” and ”meet”



Once there was hardware...

- The general ”Orange Book” approach:
  - System objects get labeled according to parts they play security-wise
  - Labeling enforced by OS and/or HW

- Tagged architectures
- MMU memory segmentation

...time passes...

- The general ”Orange Book” approach:
  - System objects get labeled according to parts they play security-wise
  - Labeling enforced by OS and/or HW
- Being **executable** – ”code” vs ”data” – is a most fundamental trust-wise distinction between ”bunches of bytes” in RAM
  - Code runs, does stuff
  - Data kind of sits there

...epic fail...

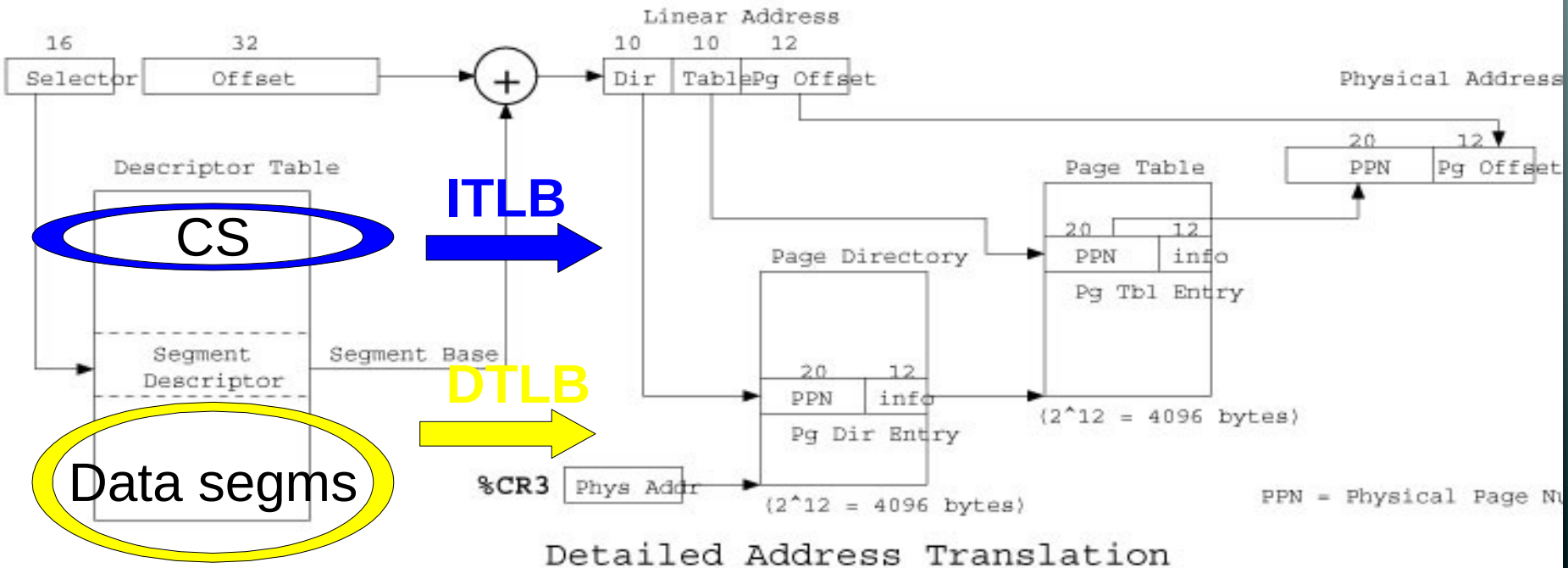
- Being **executable** – ”code” vs ”data” – is a most fundamental trust-wise distinction between ”bunches of bytes” in RAM...

  ...and yet commodity systems ignored it!

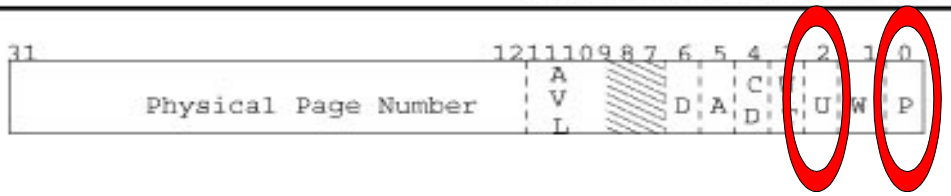
Enter hacker patches

- Label x86 pages as non-executable
- Emulate absent NX trapping bits to enforce
  - PAGEEXEC
    - Overload PTE's Supervisor bit, in conjunction with split TLB
  - SEGMEXEC
    - Map code and data twice, via different x86 segments
    - Instruction fetches from data-only segment will trap

Protected-mode address translation



Detailed Address Translation



Page Table Entry

P -- Present
W -- Writable
U -- User
WT -- Write-Through (1), Write-Back (0)
CD -- Cache Disabled
A -- Accessed
D -- Dirty
AVL -- Available for system use

Page Directory Entries are identical except that bit 6 (the Dirty bit) is unused.

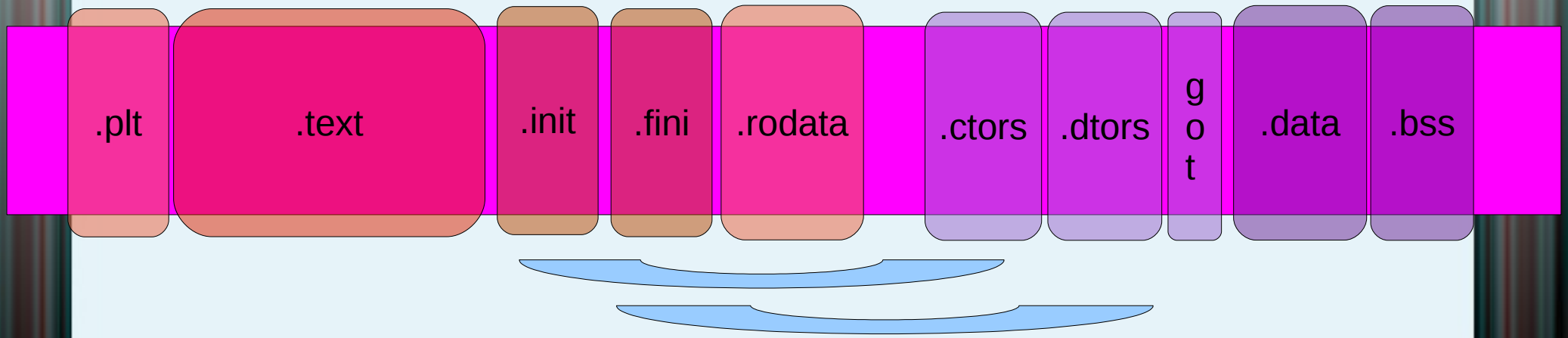
This is Beautiful

- ”Like Xmas for trust engineering”
- ”Hackers keep the dream alive!”

- Labels (NX) are kept as close to their objects as possible – right where they belong!
- Enforcement is by trapping – as efficient as it gets
- Page fault handler is a part of the ”reference monitor”

Why stop at pages?

- We want to label objects not pages !
- ELF describes many objects, inter-related



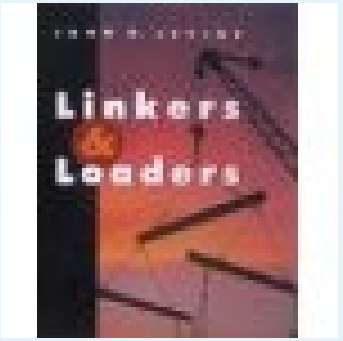
- Objects have intimate & exclusive code–data relationships

What I hope to see:

- The **Return of the Lattice**, on **ELF objects**
- Why shoudn't the loader know what the linker knows?
- ELF *Sections* table already describes trees of datastructures (e.g., _DYNAMIC)
- We could enforce granular code–data ”ownership” through the MMU trapping!
  - Like Biba MLS for code and data units within a process virtual address space

Learning about ABI? Rant.

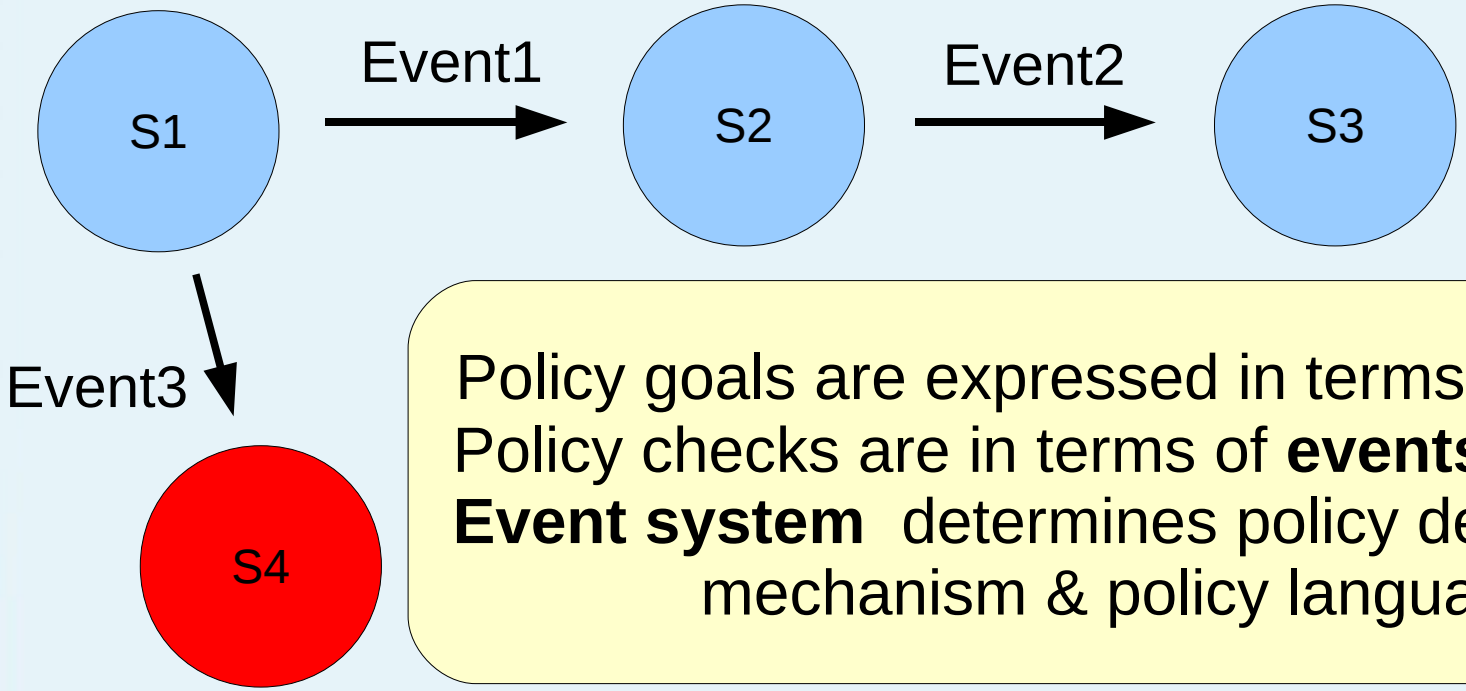
- **One** (!) accesible ”non-hacker” book on ABI:
  - John Levine, *”Linkers & Loaders”*



- Everything else worth reading and available is hacker sources.
  - Silvio Cesare (Phrack 56:7, etc.)
  - Phrack 61–63 (including Elfsh > ERESI)
  - ”Cheating the ELF”, the grugq
  - ”ELF virus writing HOWTO”
  - Uninformed.org (”Locreate”, ...)

Lesson 3: **Trapping is King**

- Traps shape enforcable policies
- A policy must prevent reaching ”untrusted states” from ”trusted states”



Policy goals are expressed in terms of **states.**
Policy checks are in terms of **events/**transitions.
Event system determines policy design, mechanism & policy language.

Trapping is overloaded

- It makes paging-based security work
  - Page Fault handler isn't just for swapping :-)
  - PaX, OpenWall, KnoX, ...
- It makes virtualization work
  - Multiplexes physical devices, IO, ...
- It makes OS-level isolation work
  - ”Virtual machines, VMMs for security”
- It makes debuggers work

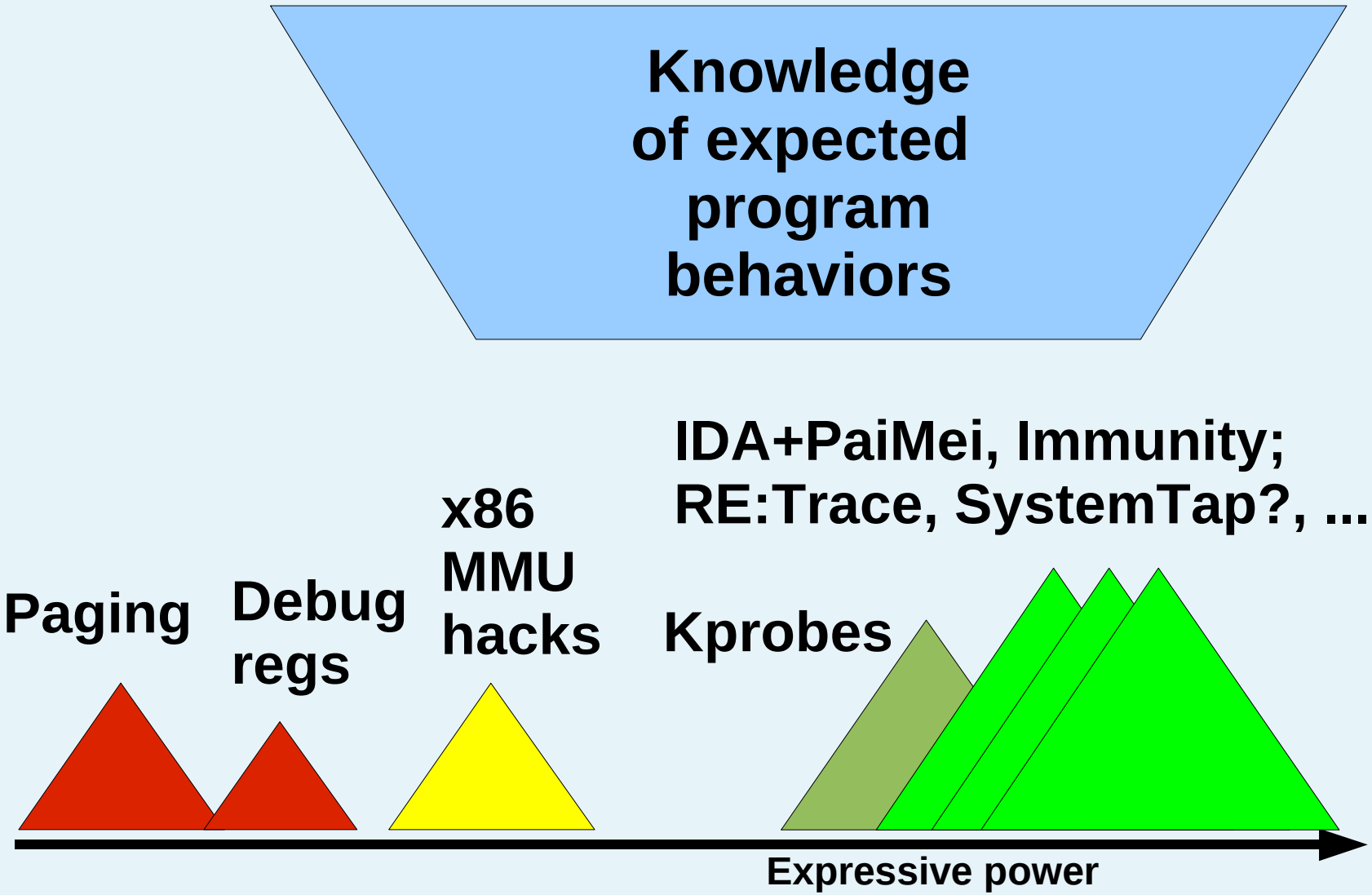
Thou shalt know how thy debugger works

- Hackers are leading makers of debuggers
- ”Unconventional” debugging
  - Dum(b)ug
  - Rr0d Rasta debugger
  - RE:Trace, RE:Dbg
    - Uses DTrace
  - OllyBone (”special trap” case)
    - Traps on ”instr fetch from a page jsut written”

Debugging ~ Trust ~ Security

- Trust is ”*relying on an entity to behave as expected*”
- Debugging is an activity that links expected behavior with actual behavior
- **So does security policy enforcement!**
- Hacker debugger use is like a full-fledged programmable, scriptable environment
  - ”An interpreter for C and kernel”

”The march of debuggers”



Lesson 4: **Follow trust relations**

Trust (-relationship) mapping of networks: industry created by hacker tools.

Thank you!

- I think I learned more about the real challenges of CS from hacker research than from any other source
- **”Hackers are a national resource”**
  Angus Blitter
- **Security does not get better until hacker tools establish a practical attack surface**
  Joshua Wright