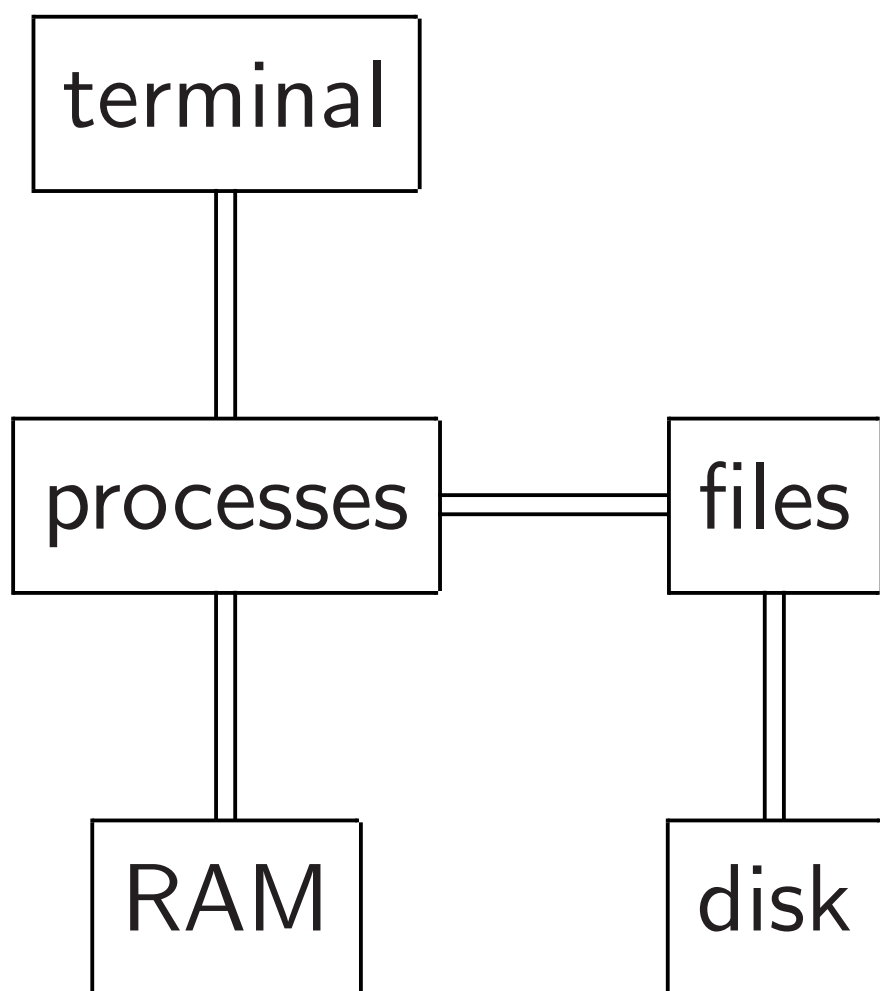


Usable verification of fast cryptographic software

Daniel J. Bernstein

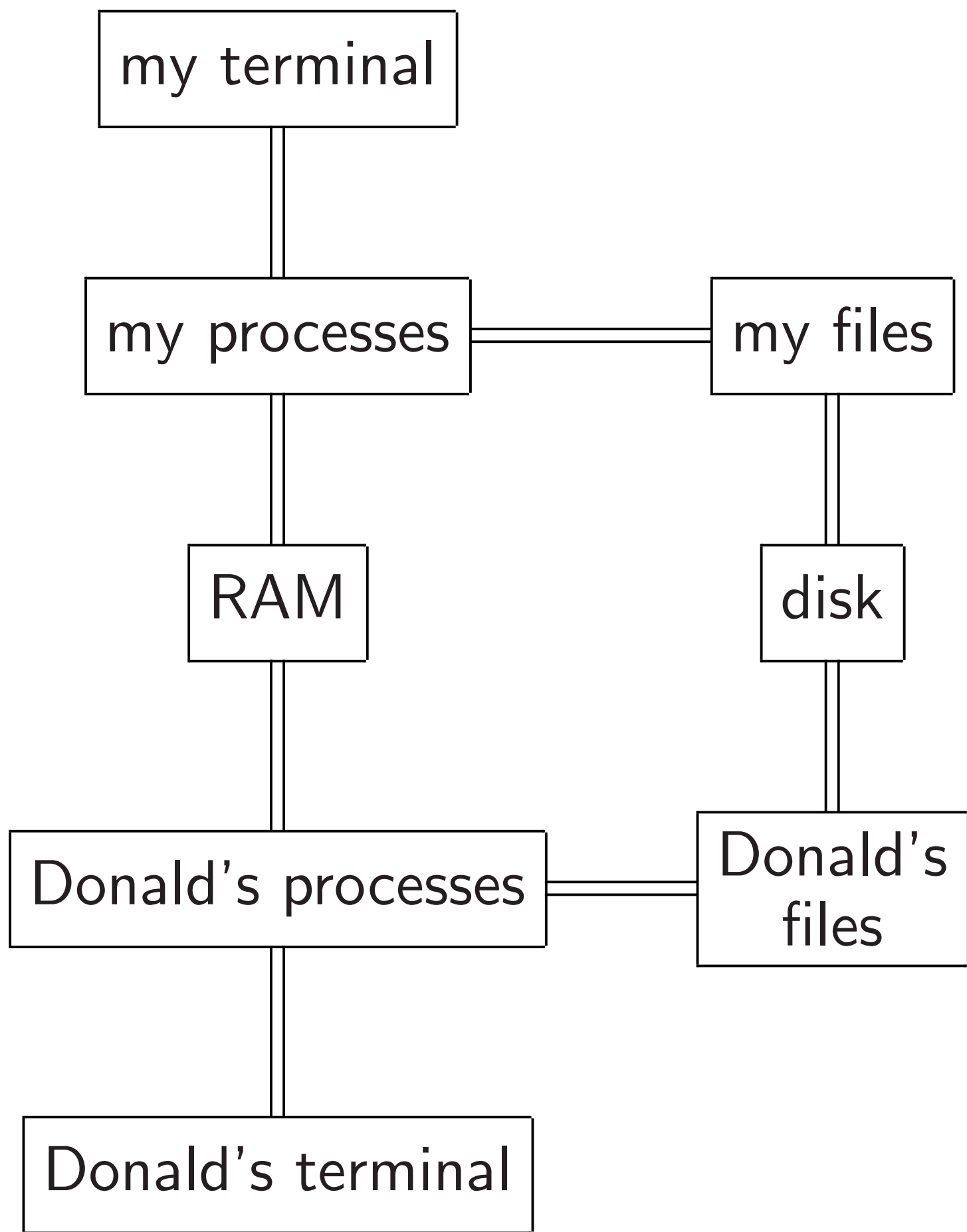
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Technische Universiteit Eindhoven





Operating-system kernel
divides RAM among processes,
divides disk among files.

Provides convenient functions
for processes to access files,
start new processes, etc.



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Defense: secure attention key.

Donald is authorized to store data on the same computer.

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Two-part defense:

1. “Memory protection” .

Hardware does not allow processes to access data outside areas marked by kernel.

2. Kernel keeps track of which parts of RAM and disk are mine, and which parts are Donald's.

Bugs in this kernel code
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Fix: Eliminate the bugs!

Bug-free code is expensive but not impossible when code volume is small enough.

Successful example:
computer-verified proof of seL4 microkernel correctness, including RAM partitioning etc.

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I can run a 10000000-line program filled with bugs, and still be confident that Donald is unable to corrupt the output of the program.

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The **trusted computing base** (TCB) is the part of the system that enforces security policy.

The 10000000-line program is not part of the TCB.

But we *want* communication!

Today: Alice sends me email.

I download Bob's web page.

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These users are authorized to put data on my screen.

Security policy: Whenever the computer shows me a file, it also tells me the source of the file.

If Donald creates a file and convinces the computer to show me the file as having source "Alice" then this policy is violated.

PRN Pwn2Own 2016: Chin... x +

www.prnewswire.com/news-releases/pwn2own-2 Search

PR Newswire

Pwn2Own 2016: Chinese Researcher Hacks Google Chrome within 11 minutes

Mar 17, 2016, 09:12 ET from [Qihoo 360](#)



Chinese Security Team in Global Arena

[Facebook](#) [Twitter](#) [Pinterest](#)

VANCOUVER, British Columbia, March 17, 2016 /PRNewswire/ -- 360Vulcan Team from Qihoo 360 hacked Google Chrome, the browser with the least vulnerabilities, and obtained the highest system privilege. It's the first time a Chinese security team has hacked Google Chrome at the Pwn2Own contest.

360Vulcan Team also hacked Adobe Flash Player based on Edge browser, obtaining the highest system privilege, which won the team a USD 80,000

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Widely deployed software systems make no real efforts to limit this.

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But bugs in other code can and do compromise security.

TCB has >300000000 lines.

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Fix: rearchitect entire system

so that a **small** TCB

tracks sources of all data.

Eliminate all bugs in TCB.

Cryptography in the TCB

What happens if data is sent through Donald's network?



Cryptography in the TCB

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Solution: Sender and receiver scramble communication in a way that Donald cannot understand and cannot silently corrupt.

OpenSSL crypto library has 500000 lines of code, and there are many other crypto libraries.

All of this is in the TCB.

Many devastating security bugs.

Why is crypto so big?

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Why is crypto so big?

Most important answer:
the pursuit of performance.

(Same issue elsewhere in TCB,
but most blatant for crypto.)

The rest of this talk
will focus on crypto.)

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e.g. ECDSA signature verification:
 $(H(M)/S)B + (x(R)/S)A = R$,
with S checked to be nonzero.

OpenSSL has complicated code for fast computation of $1/S$.

Checking $H(M)B + x(R)A = SR$ would be somewhat slower.

e.g. NIST P-256 prime p is
 $2^{256} - 2^{224} + 2^{192} + 2^{96} - 1$.

ECDSA standard specifies
reduction procedure given
an integer “ A less than p^2 ”:

Write A as

$(A_{15}, A_{14}, A_{13}, A_{12}, A_{11}, A_{10}, A_9,$
 $A_8, A_7, A_6, A_5, A_4, A_3, A_2, A_1, A_0)$,

meaning $\sum_i A_i 2^{32i}$.

Define

$T; S_1; S_2; S_3; S_4; D_1; D_2; D_3; D_4$

as

$(A_7, A_6, A_5, A_4, A_3, A_2, A_1, A_0);$
 $(A_{15}, A_{14}, A_{13}, A_{12}, A_{11}, 0, 0, 0);$
 $(0, A_{15}, A_{14}, A_{13}, A_{12}, 0, 0, 0);$
 $(A_{15}, A_{14}, 0, 0, 0, A_{10}, A_9, A_8);$
 $(A_8, A_{13}, A_{15}, A_{14}, A_{13}, A_{11}, A_{10}, A_9);$
 $(A_{10}, A_8, 0, 0, 0, A_{13}, A_{12}, A_{11});$
 $(A_{11}, A_9, 0, 0, A_{15}, A_{14}, A_{13}, A_{12});$
 $(A_{12}, 0, A_{10}, A_9, A_8, A_{15}, A_{14}, A_{13});$
 $(A_{13}, 0, A_{11}, A_{10}, A_9, 0, A_{15}, A_{14}).$

Compute $T + 2S_1 + 2S_2 + S_3 + S_4 - D_1 - D_2 - D_3 - D_4.$

Reduce modulo p “by adding or subtracting a few copies” of $p.$

Next-generation crypto

One of my favorite topics:
removing tensions between
security, simplicity, speed.

In particular, designing
simple high-security crypto
setting new speed records.

e.g. 2006 Bernstein “Curve25519”
is twice as fast as standard ECC
and much simpler to implement.

>10000000000 Curve25519 users
today: iOS, Signal, OpenSSH,
Tor, QUIC, WhatsApp, more.

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nacl.cr.yp.to

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**Can we guarantee zero bugs in
TweetNaCl? And in NaCl?**

Biggest challenge: the gap
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1. Not state-of-the-art speed.
Okay for TweetNaCl; not NaCl.

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1. Not state-of-the-art speed.
Okay for TweetNaCl; not NaCl.
2. Input-dependent timing.
Timing can leak secret keys.
Not okay even for TweetNaCl.

ACM CCS 2014 Chen–Hsu–Lin–
Schwabe–Tsai–Wang–Yang–Yang
“Verifying Curve25519 software” :
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Each proof also required
many hours of computer time.

Joint work with Schwabe:

new verifier `gfverif`

focusing on arithmetic mod p .

gfverif.cryptojedi.org

Automatically build computation graph from original code.

Automatically analyze ranges, convert ops into polynomials.

New peephole range optimizer.

Ask human for occasional annotations expressing high-level computations on integers mod p .

Have verified entire Curve25519 computation, not just main loop, for another implementation.

Only 1 minute of computer time.

Under 300 lines of easy annotations per implementation.

Usable by crypto developers.

Continuing to improve `gverif` annotation language. Should be able to reduce below 100 annotations per implementation.