Usable verification of fast cryptographic software

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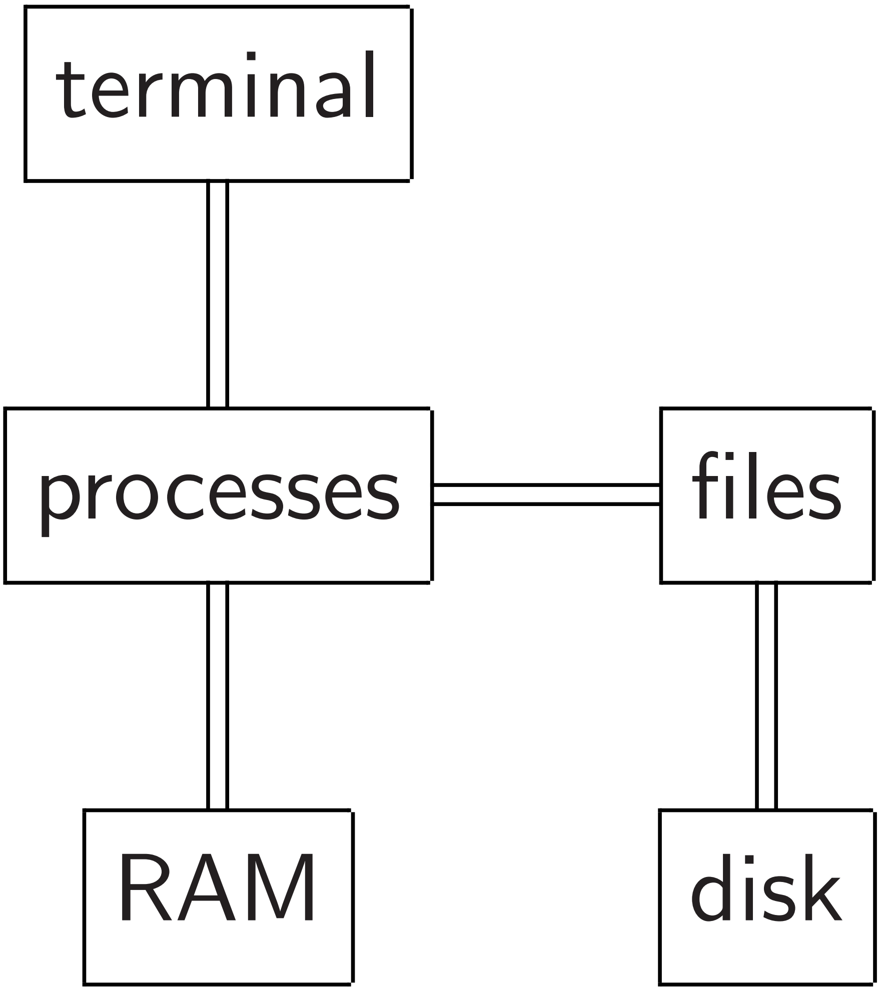
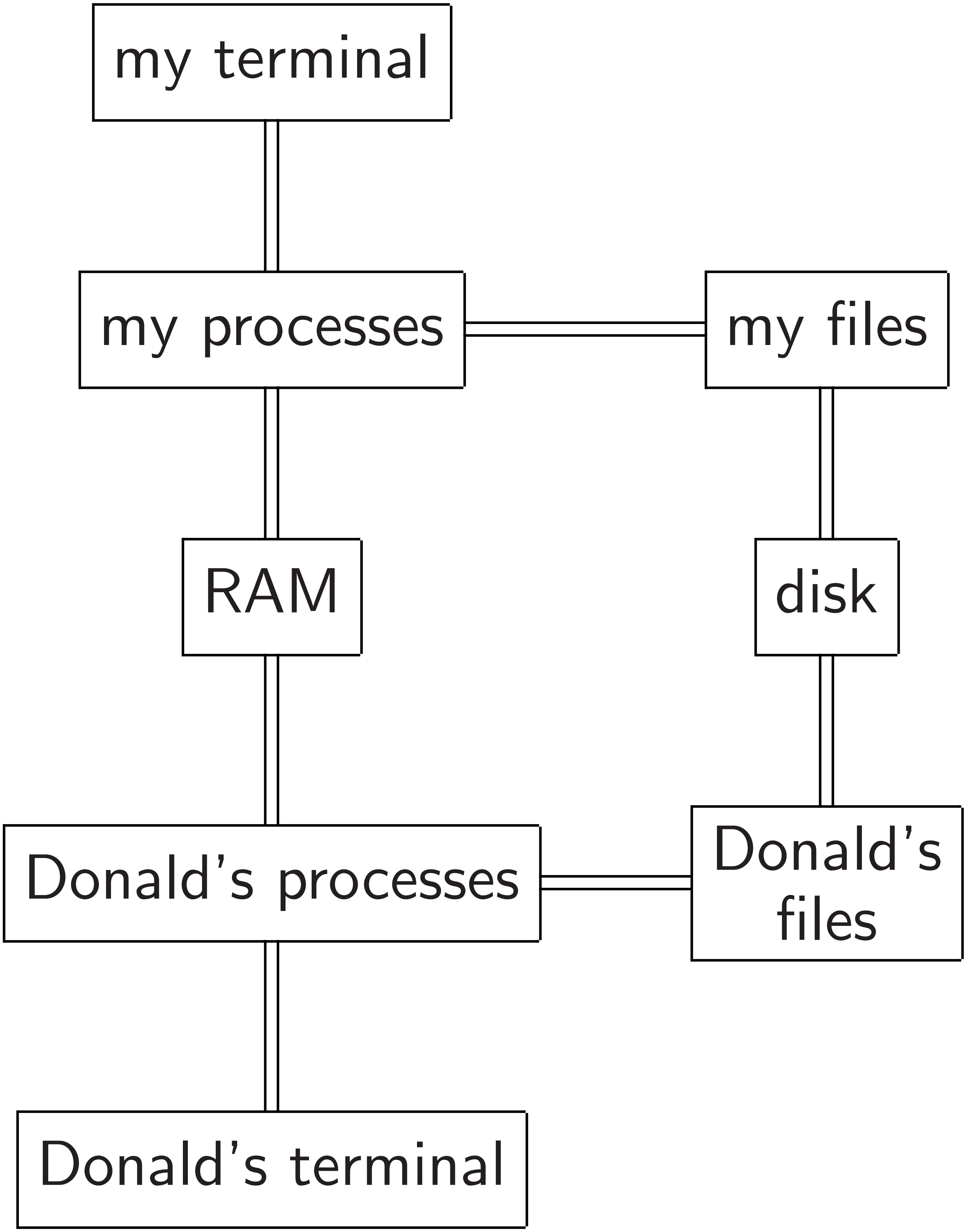


Operating-system kernel
divides RAM among processes,
divides disk among files.
Provides convenient functions
for processes to access files,
start new processes, etc.


my terminal
my processes
my files
RAM
disk
Donald's processes
Donald's files
Donald's terminal

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Defense: secure attention key.

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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.

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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!

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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... ×

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

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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Fix: rearchitect entire system
so that a **small** TCB
tracks sources of all data.
Eliminate all bugs in TCB.

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.

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All of this is in the TCB.
Many devastating security bugs.

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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.)

e.g. Variable-length-big-integer arithmetic library inside OpenSSL consumes 50000 lines of code. Includes 38 asm implementations optimized for various CPUs.

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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.

$>$1000000000 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?

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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": computer-aided proof of correctness of main loops in two high-speed asm Curve25519 implementations.

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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 `gfverif` annotation language. Should be able to reduce below 100 annotations per implementation.