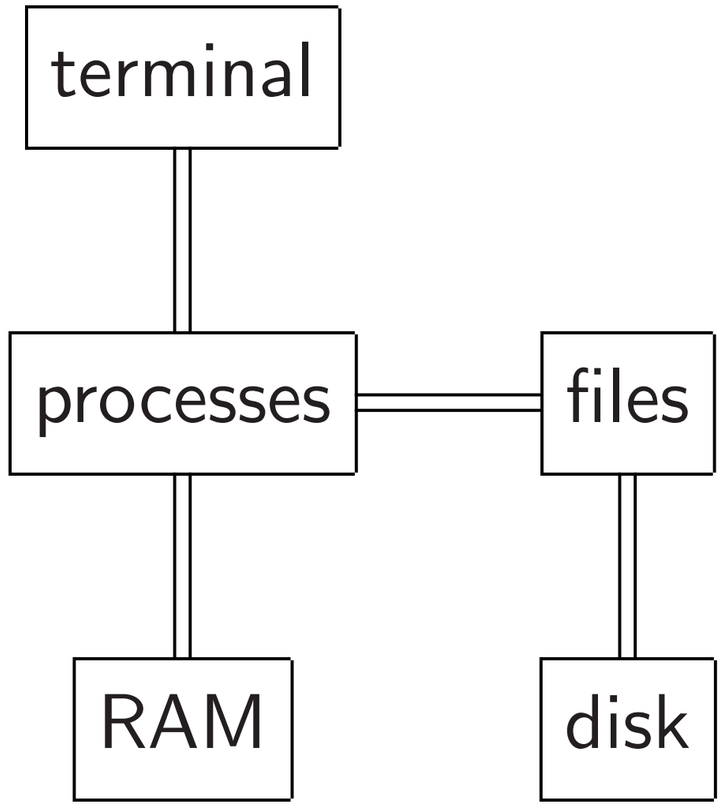
Usable verification of fast cryptographic software

Daniel J. Bernstein

University of Illinois at Chicago &
Technische Universiteit Eindhoven



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Provides convenient functions
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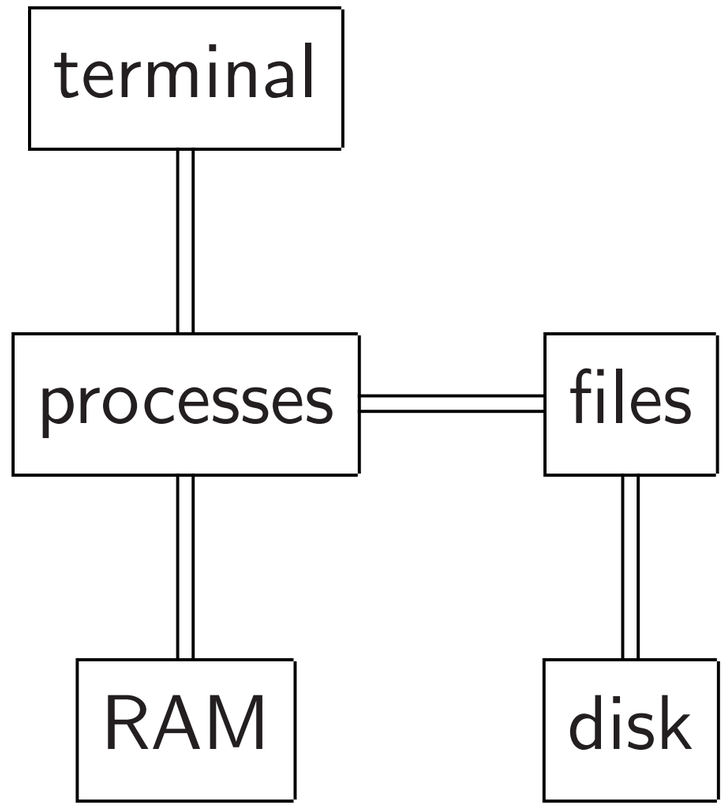

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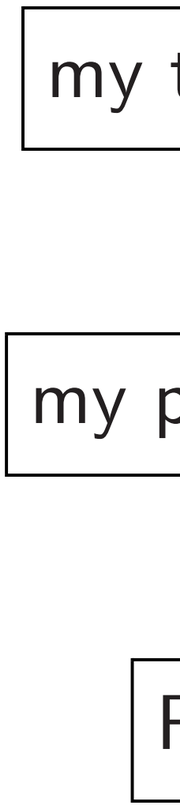

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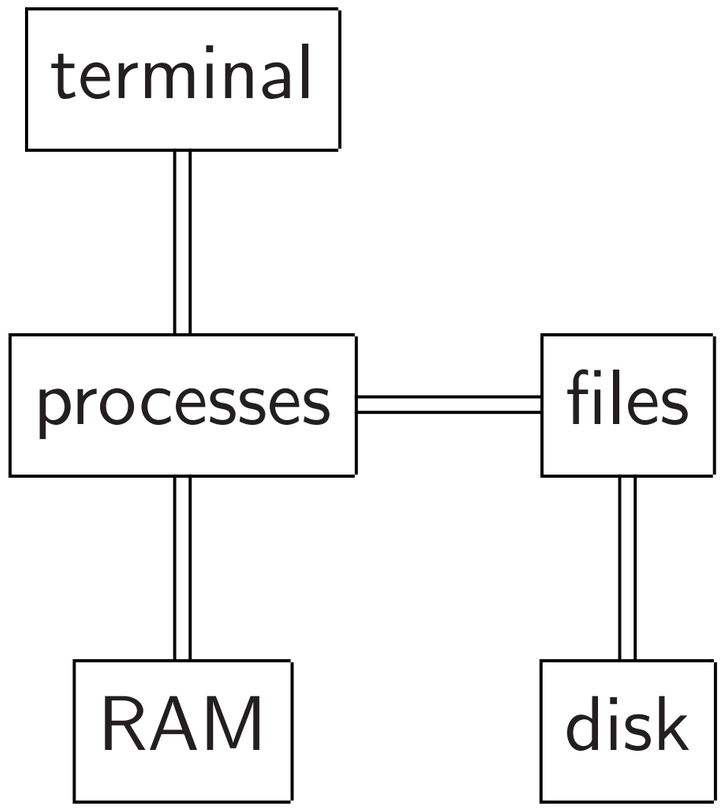

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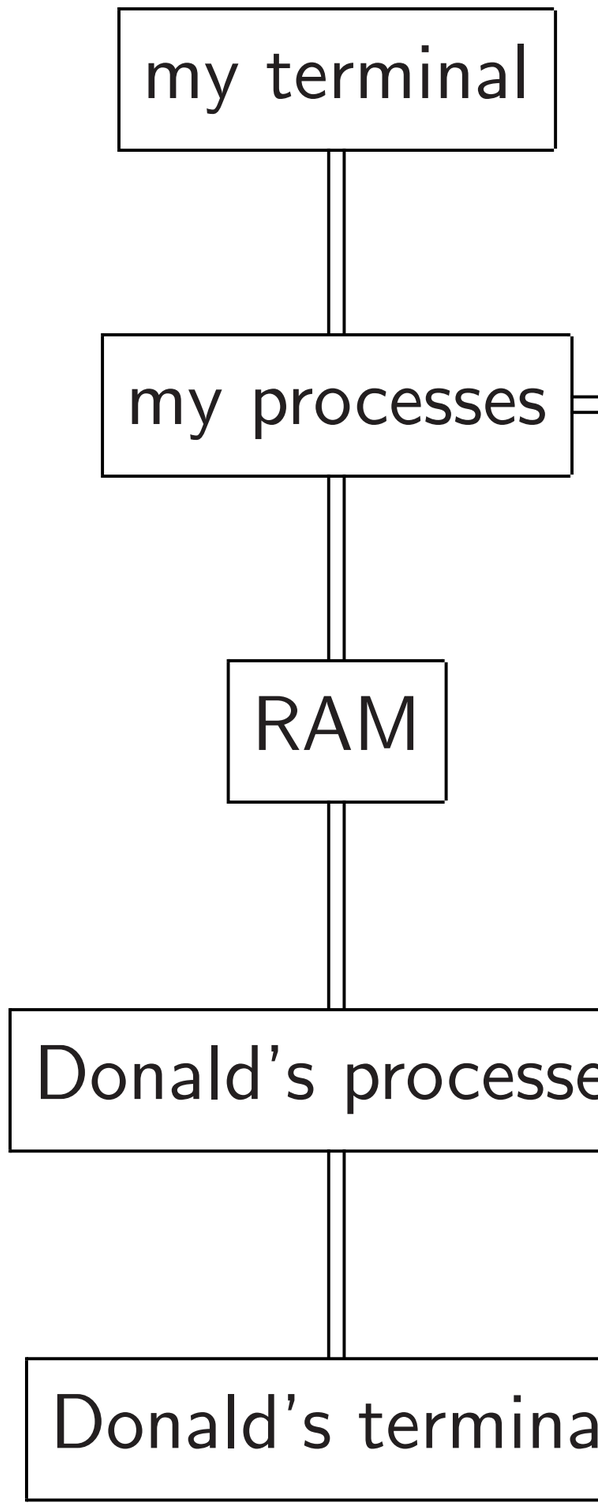

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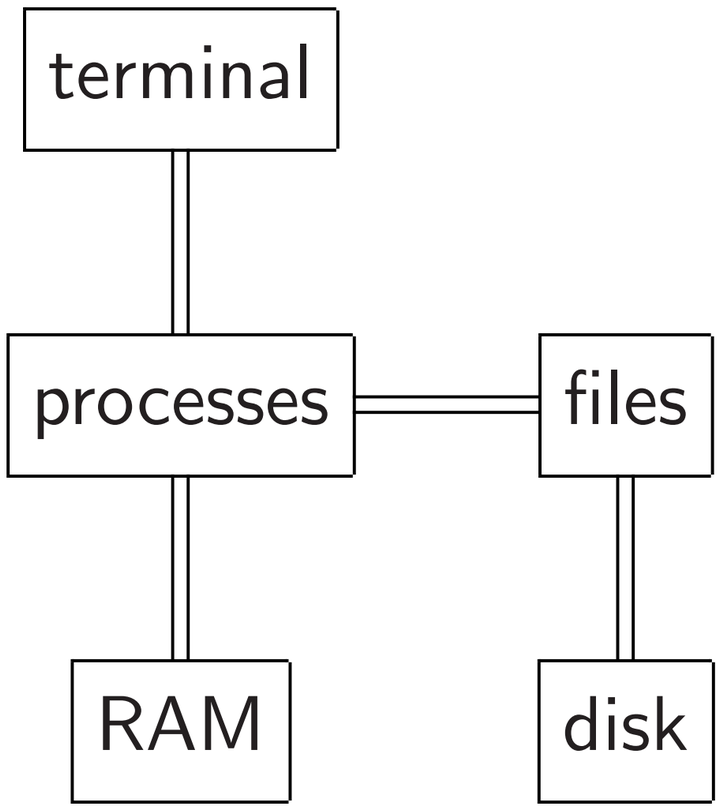

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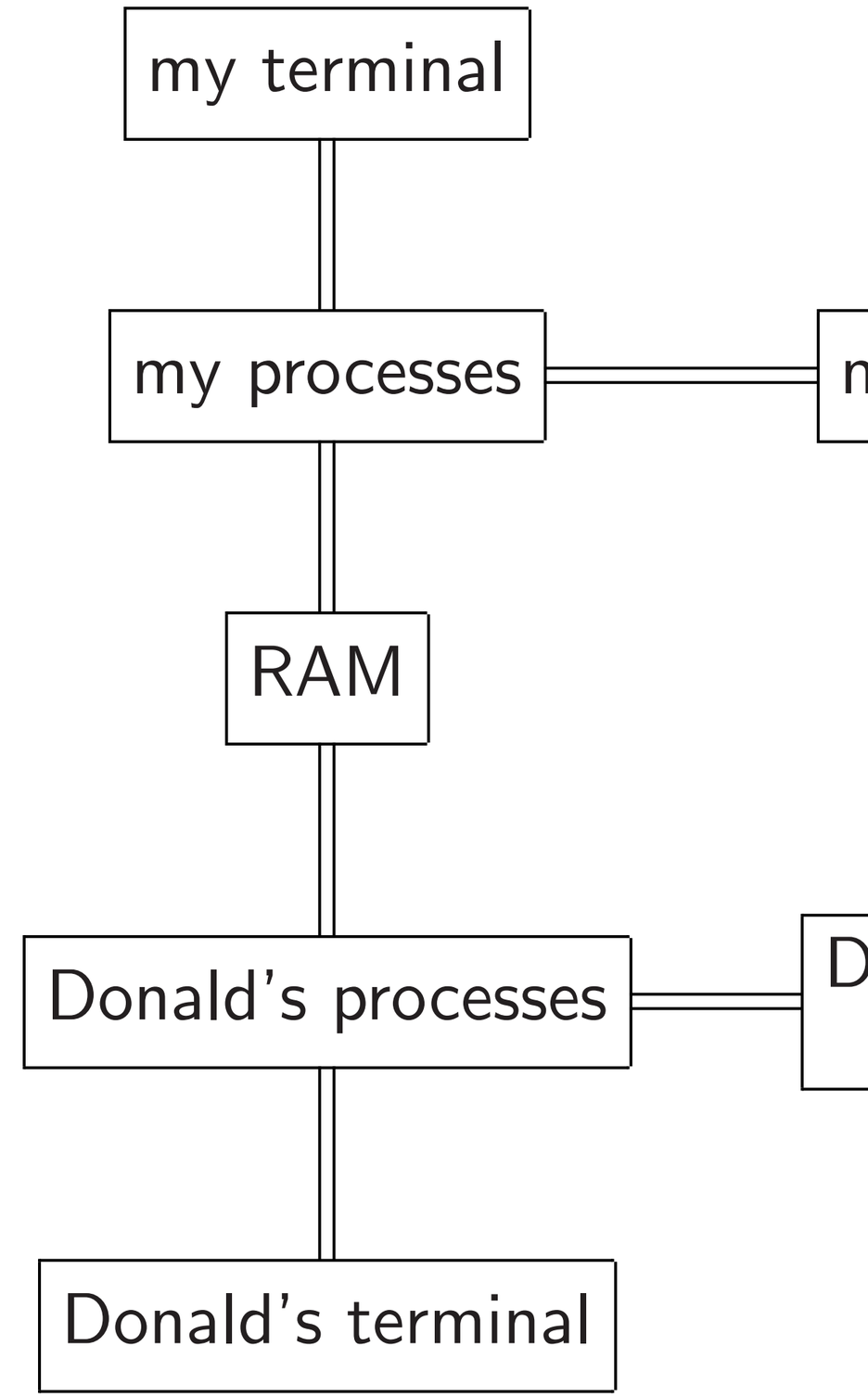

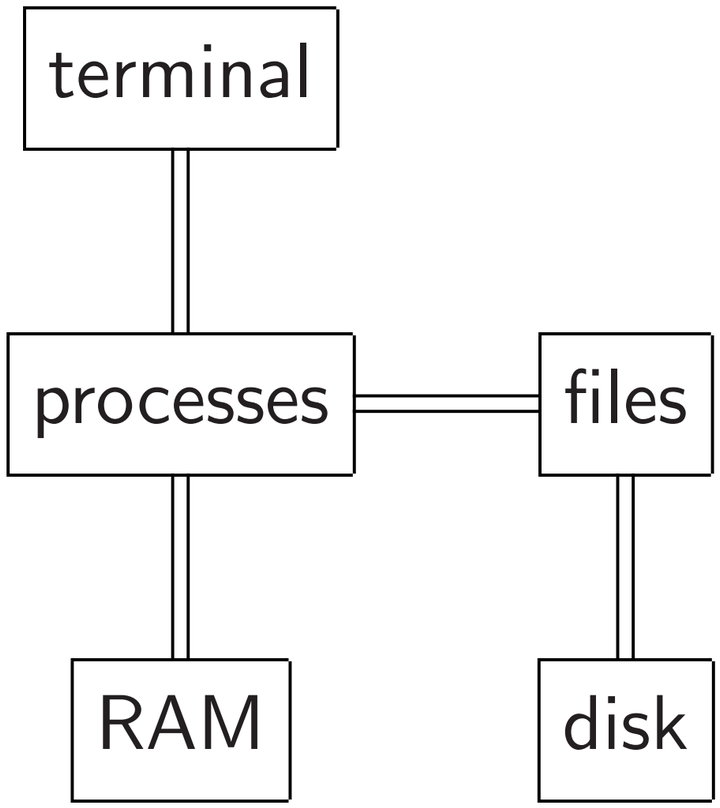

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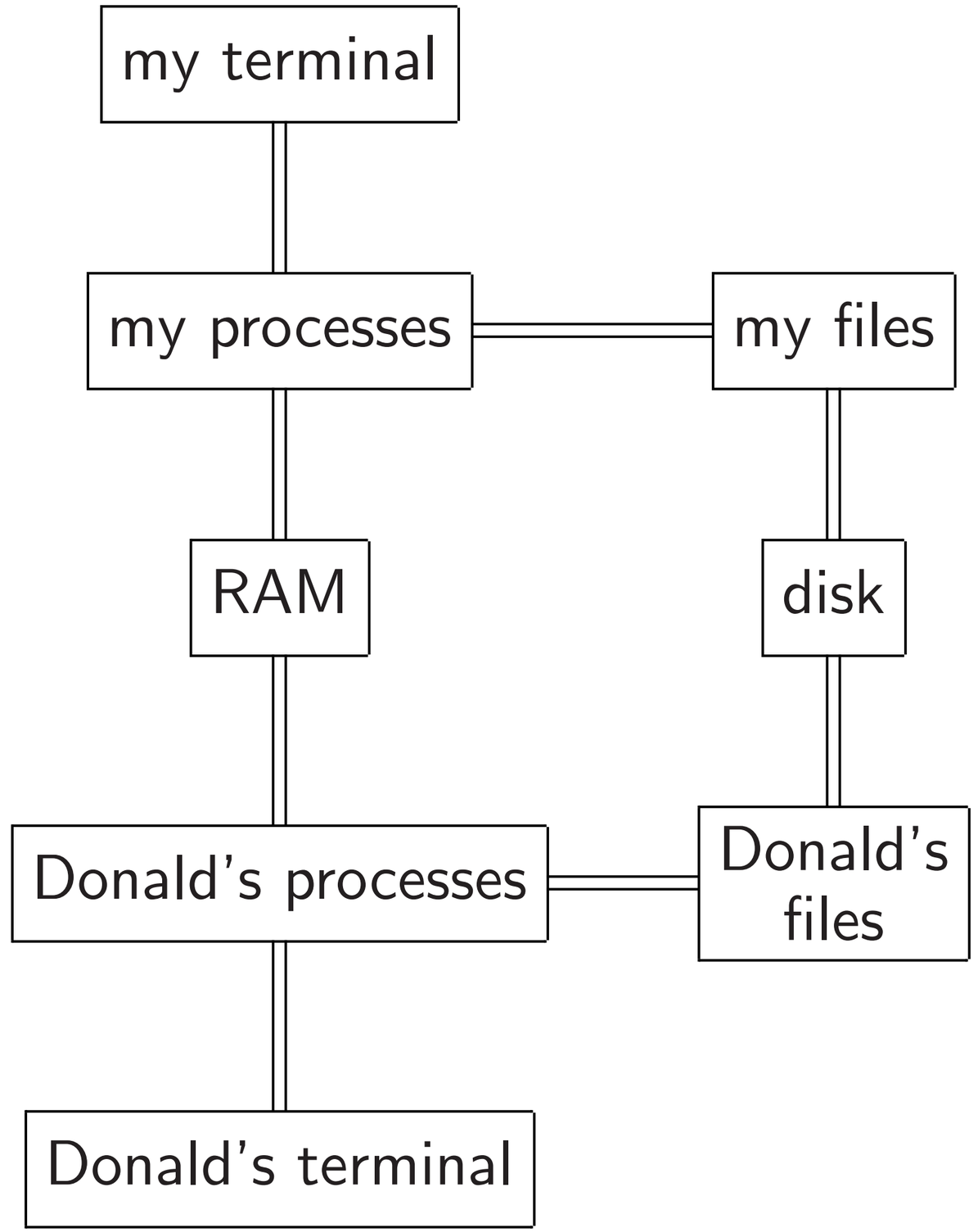

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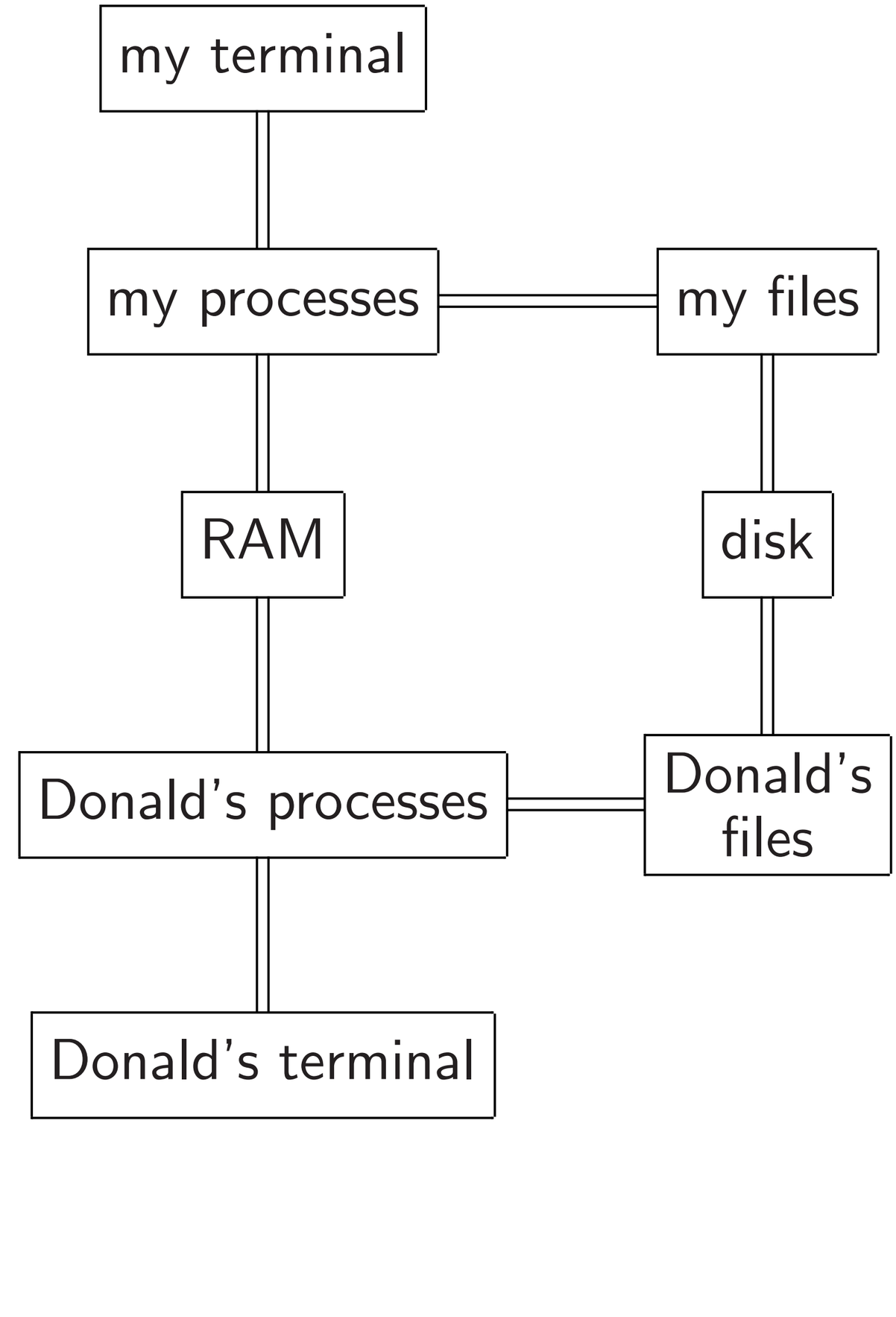

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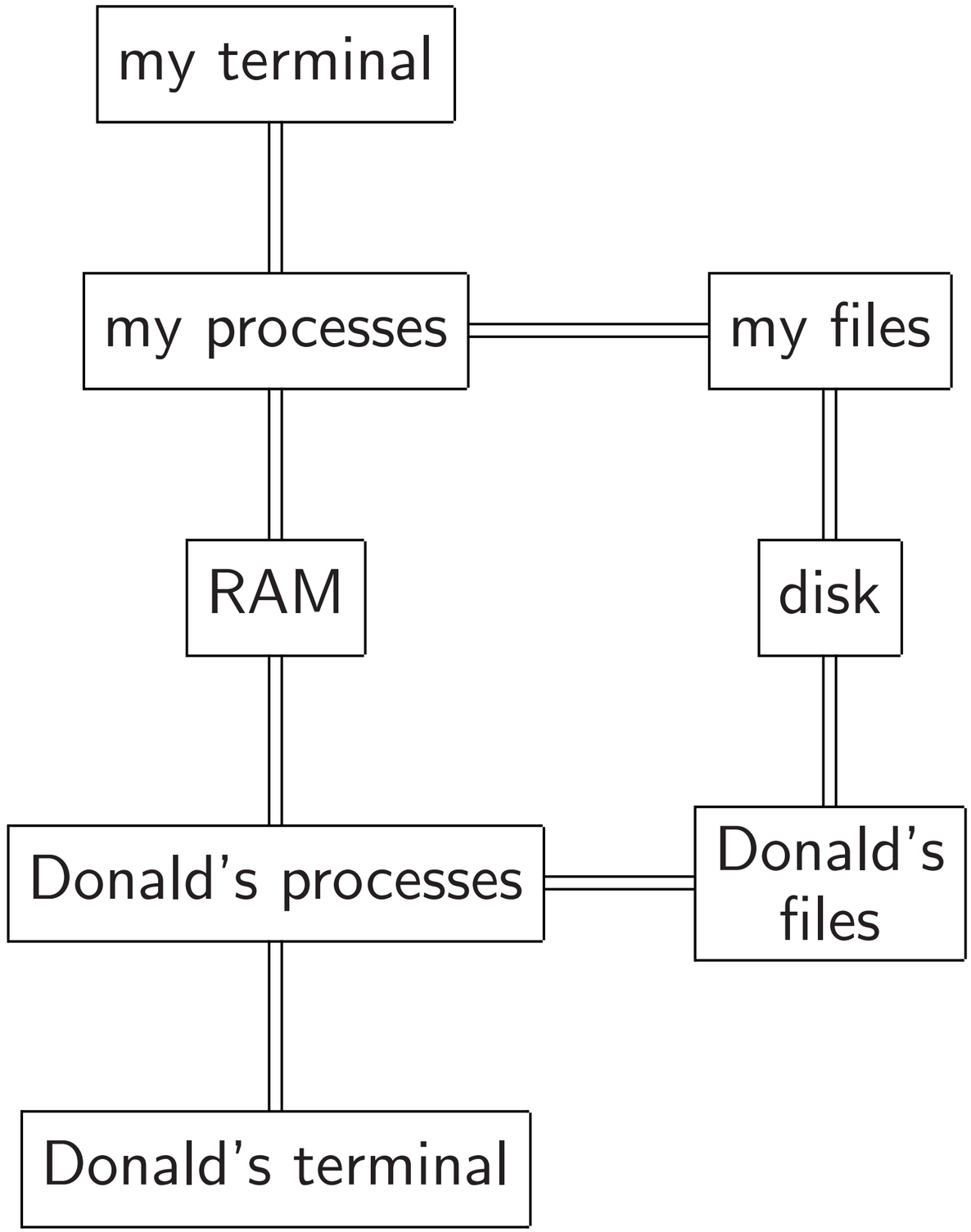

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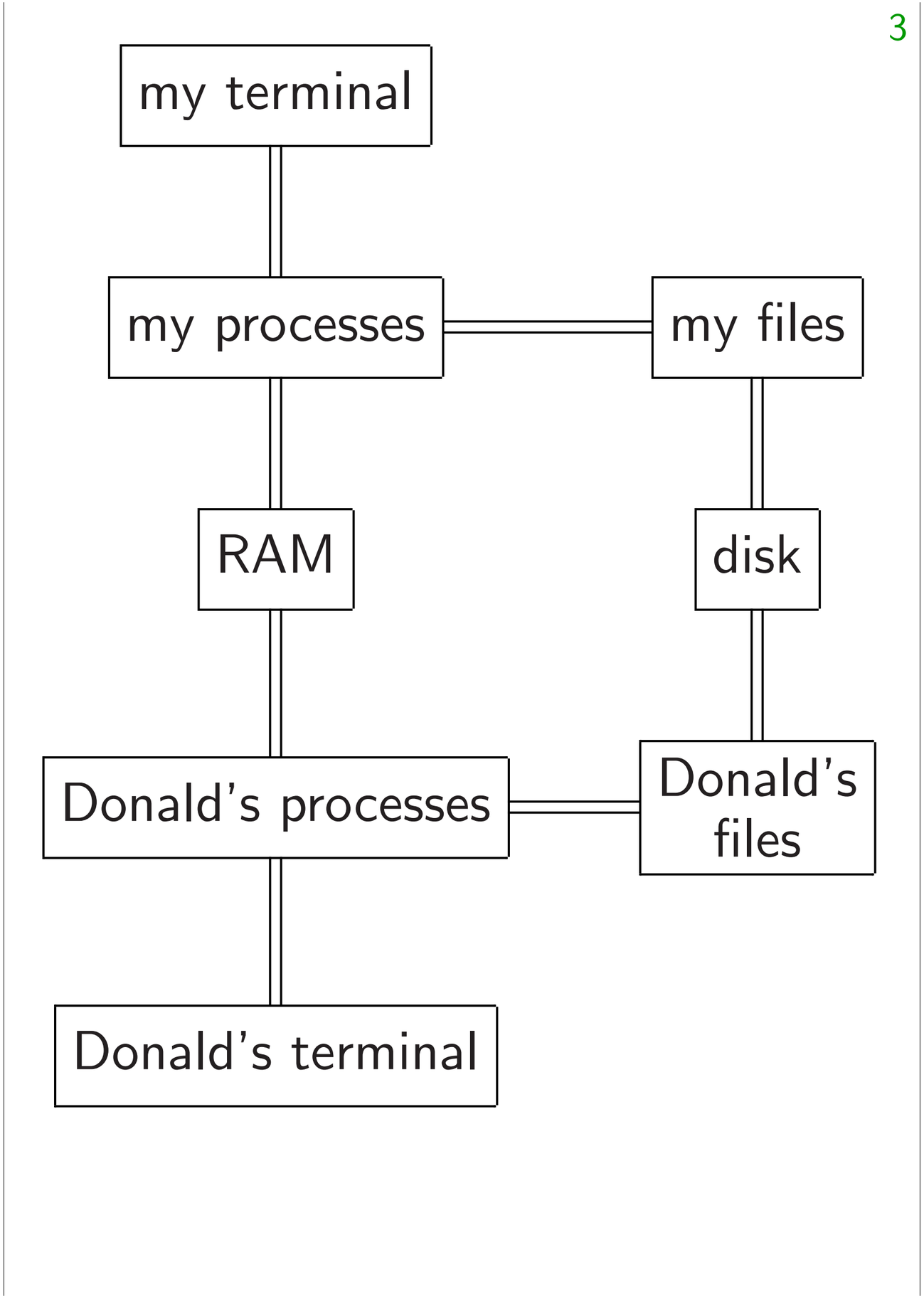

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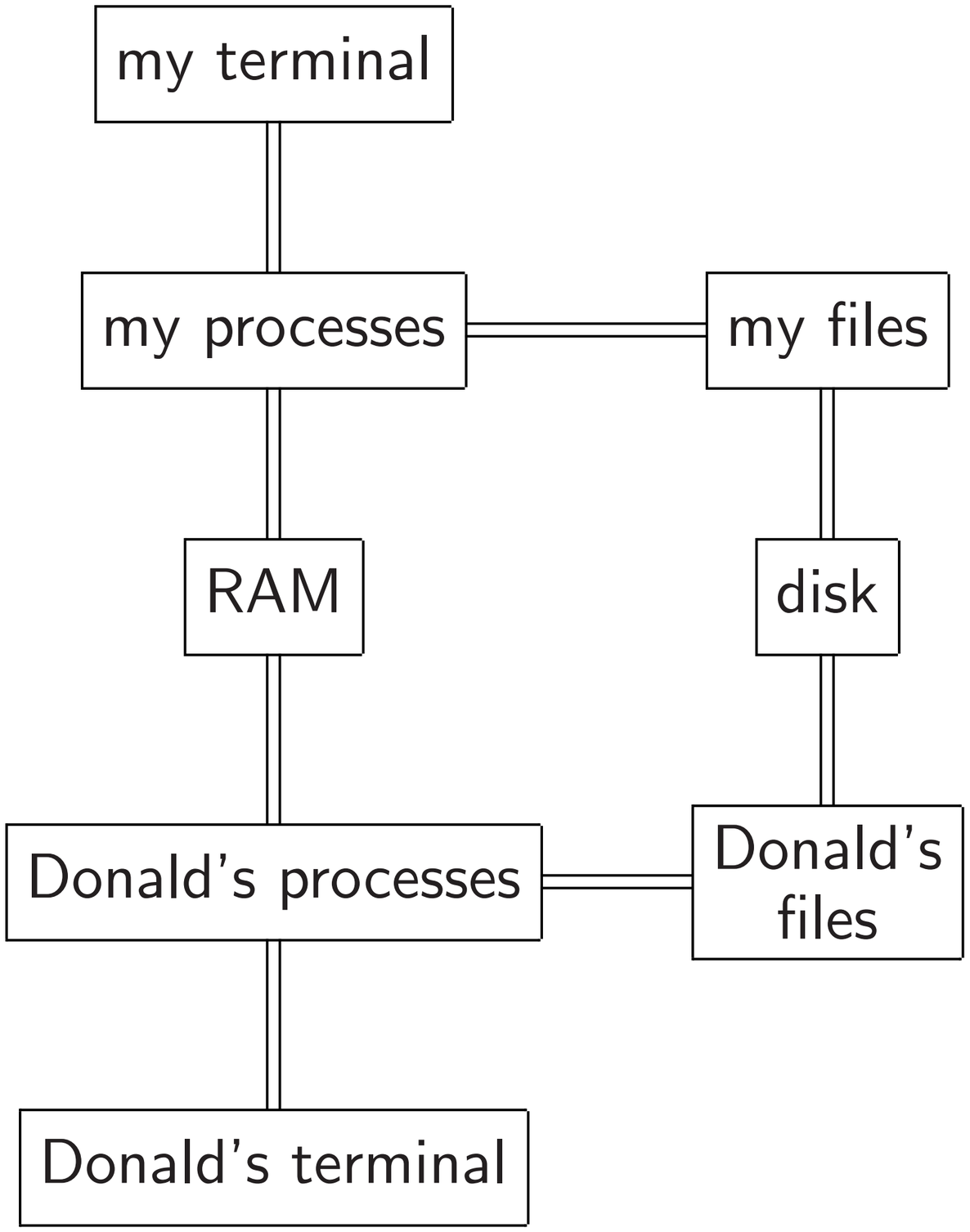

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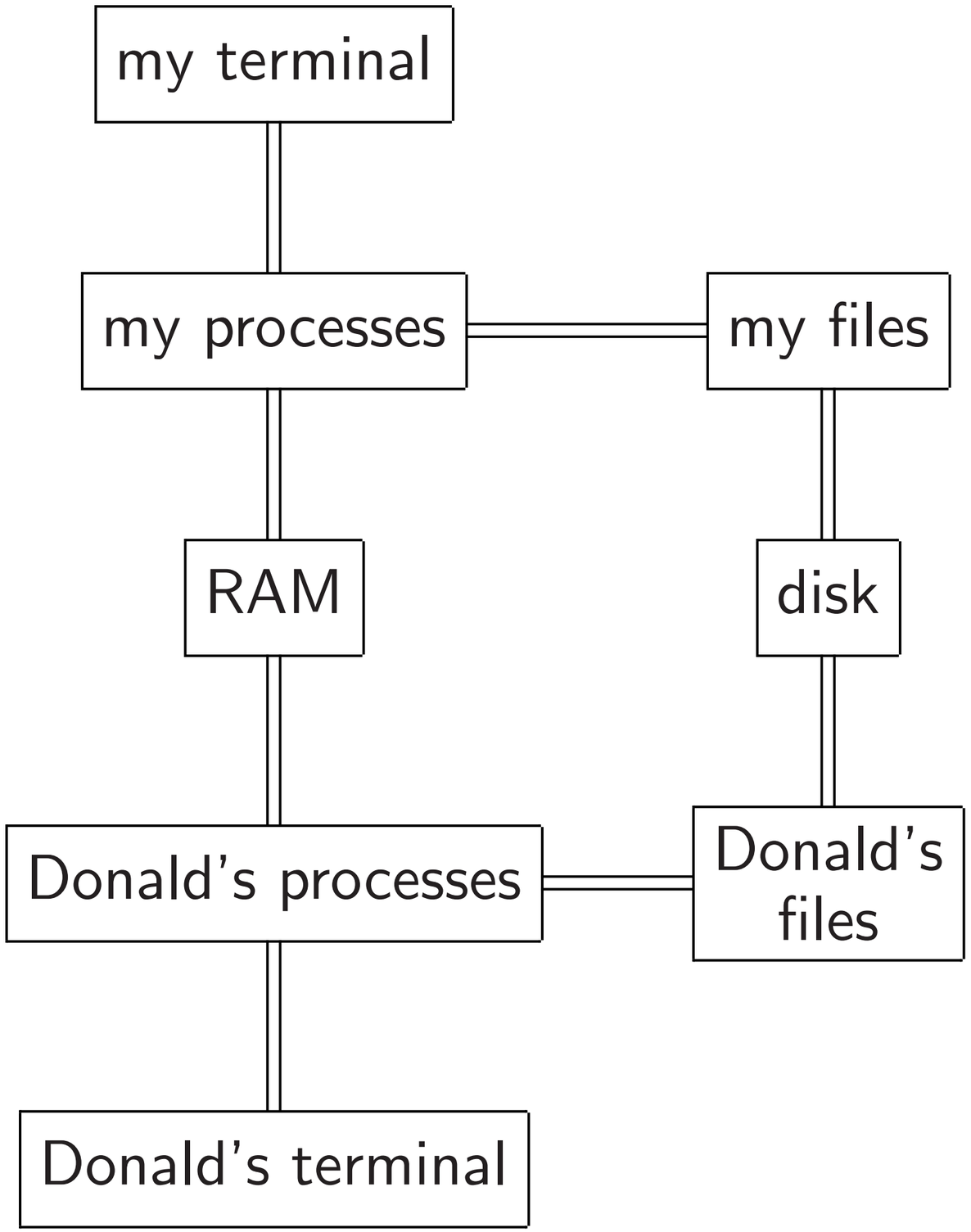

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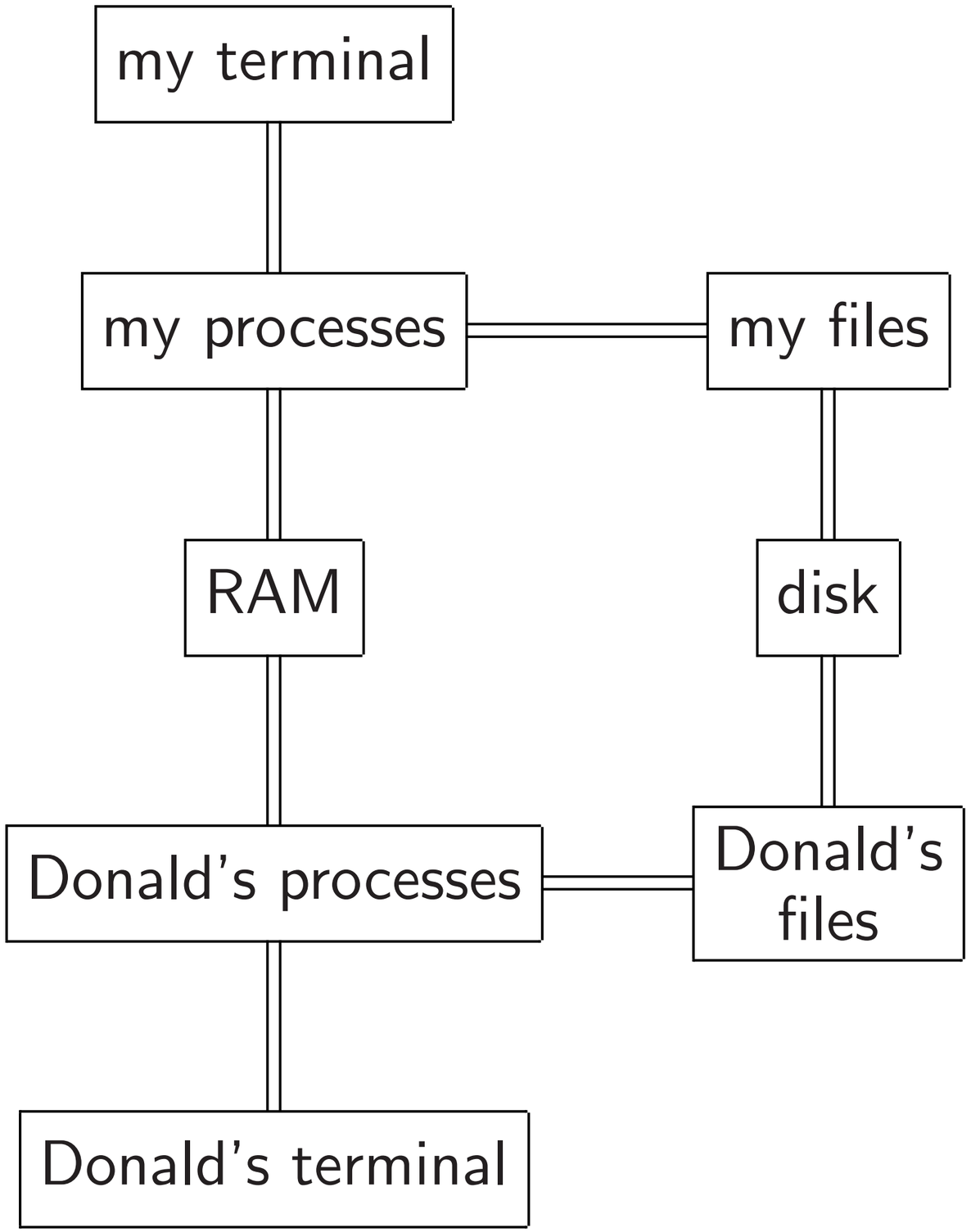

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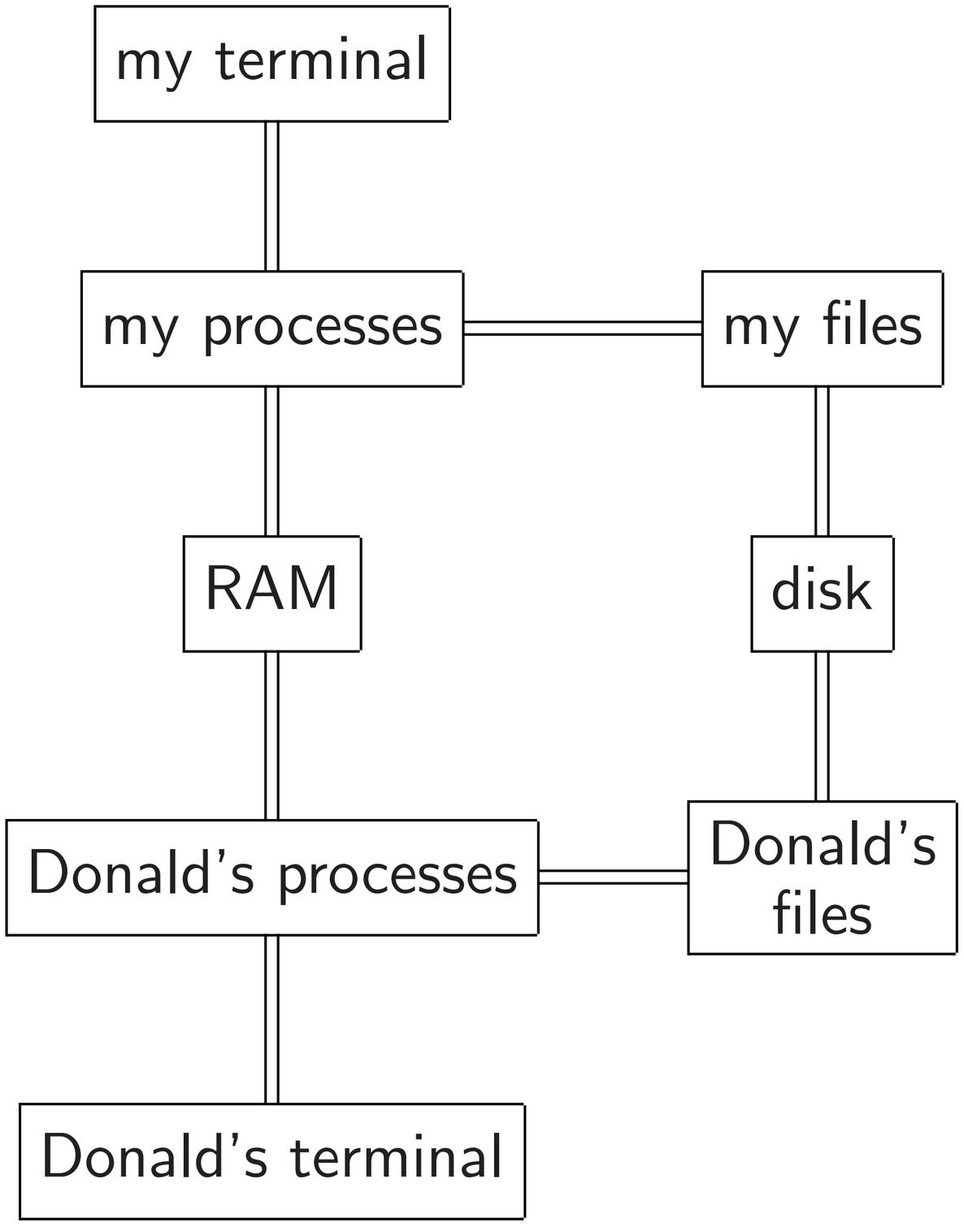

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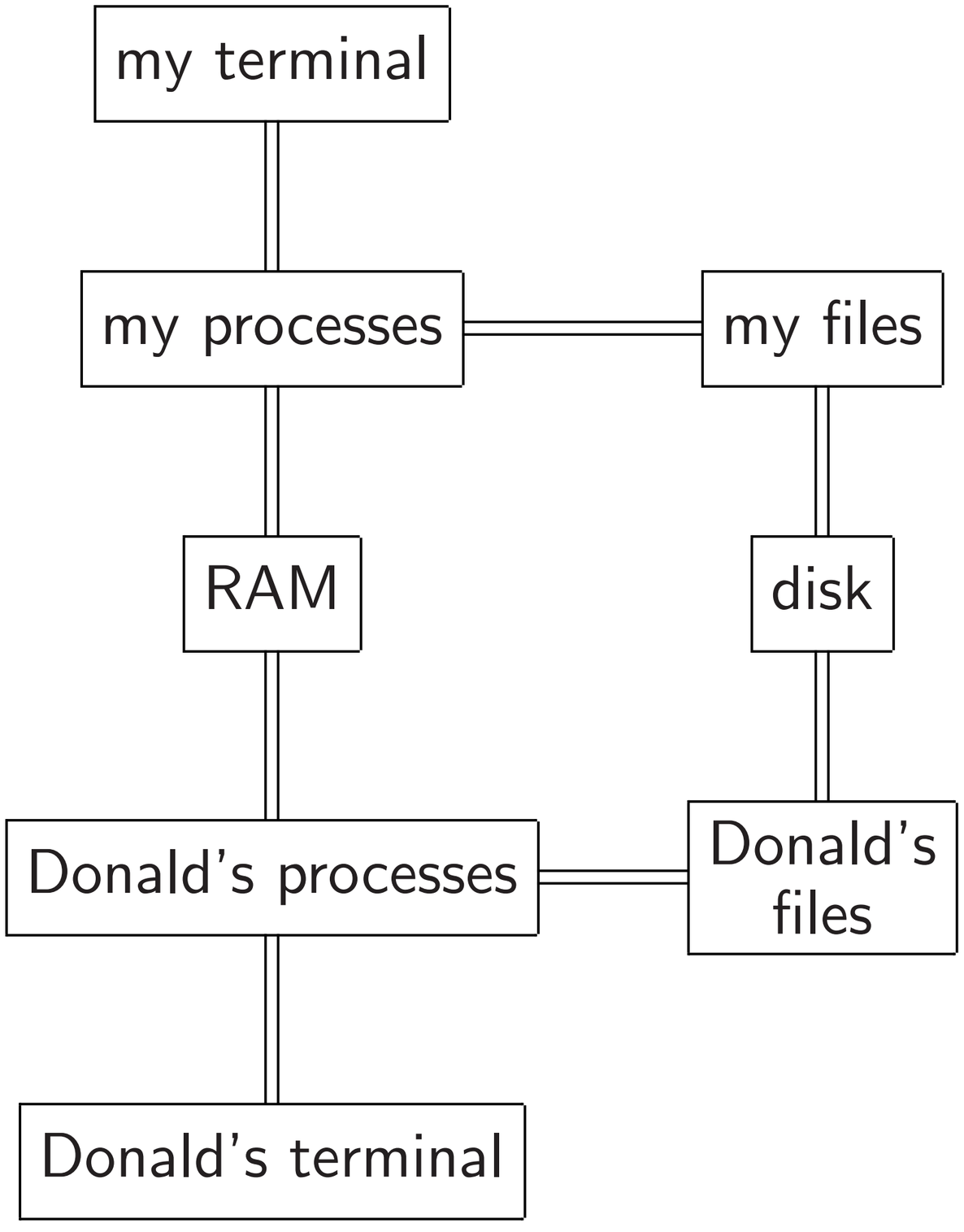

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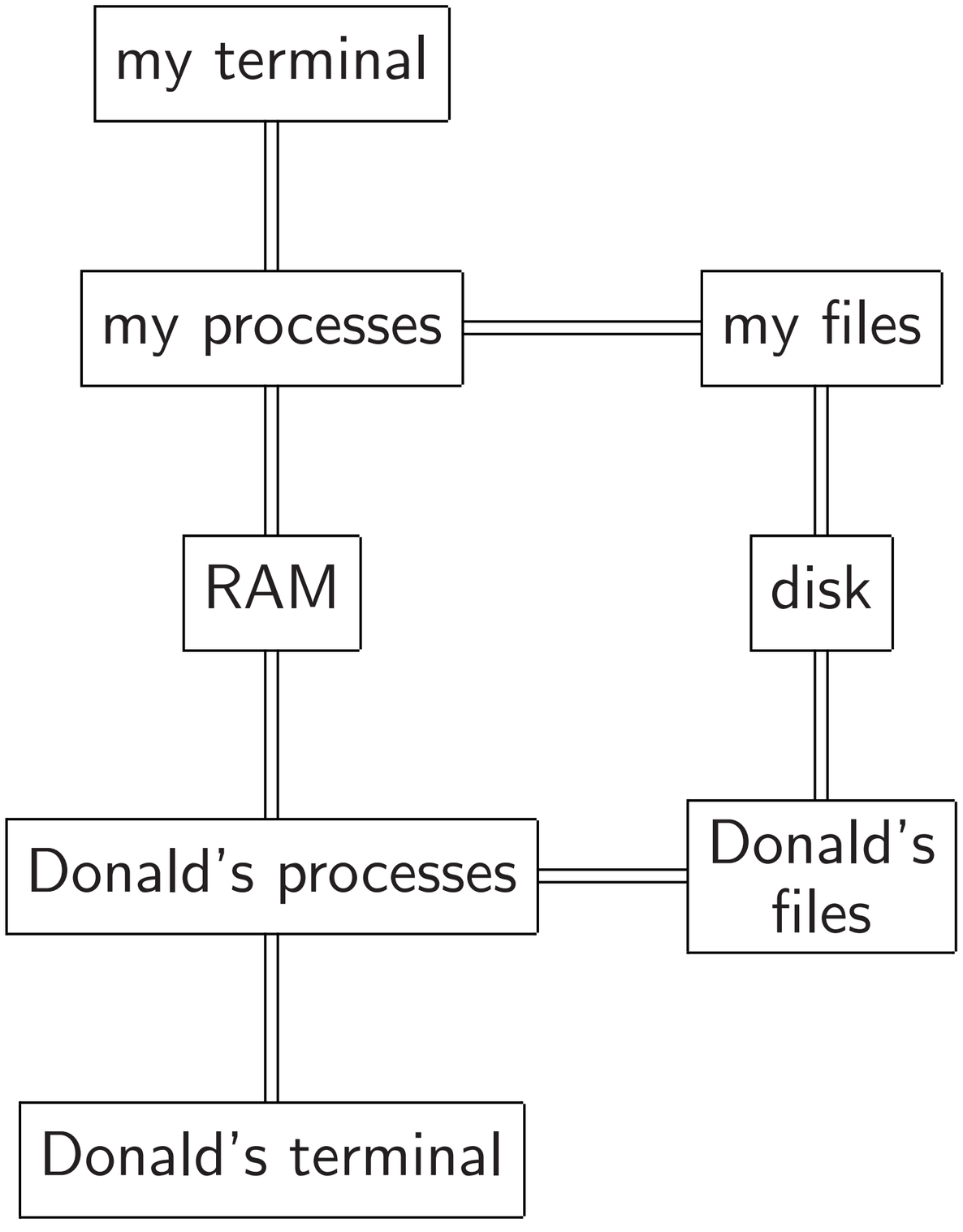

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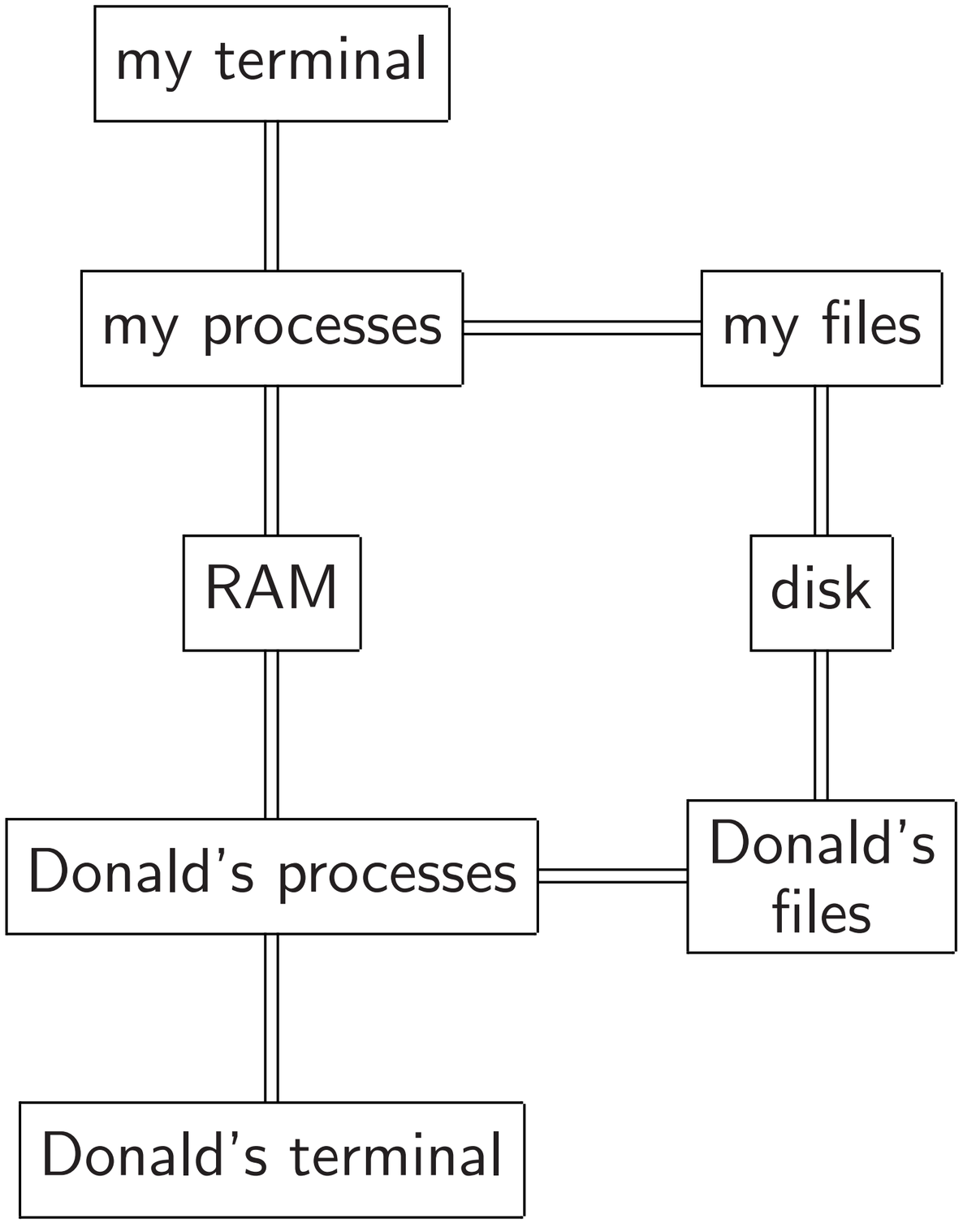

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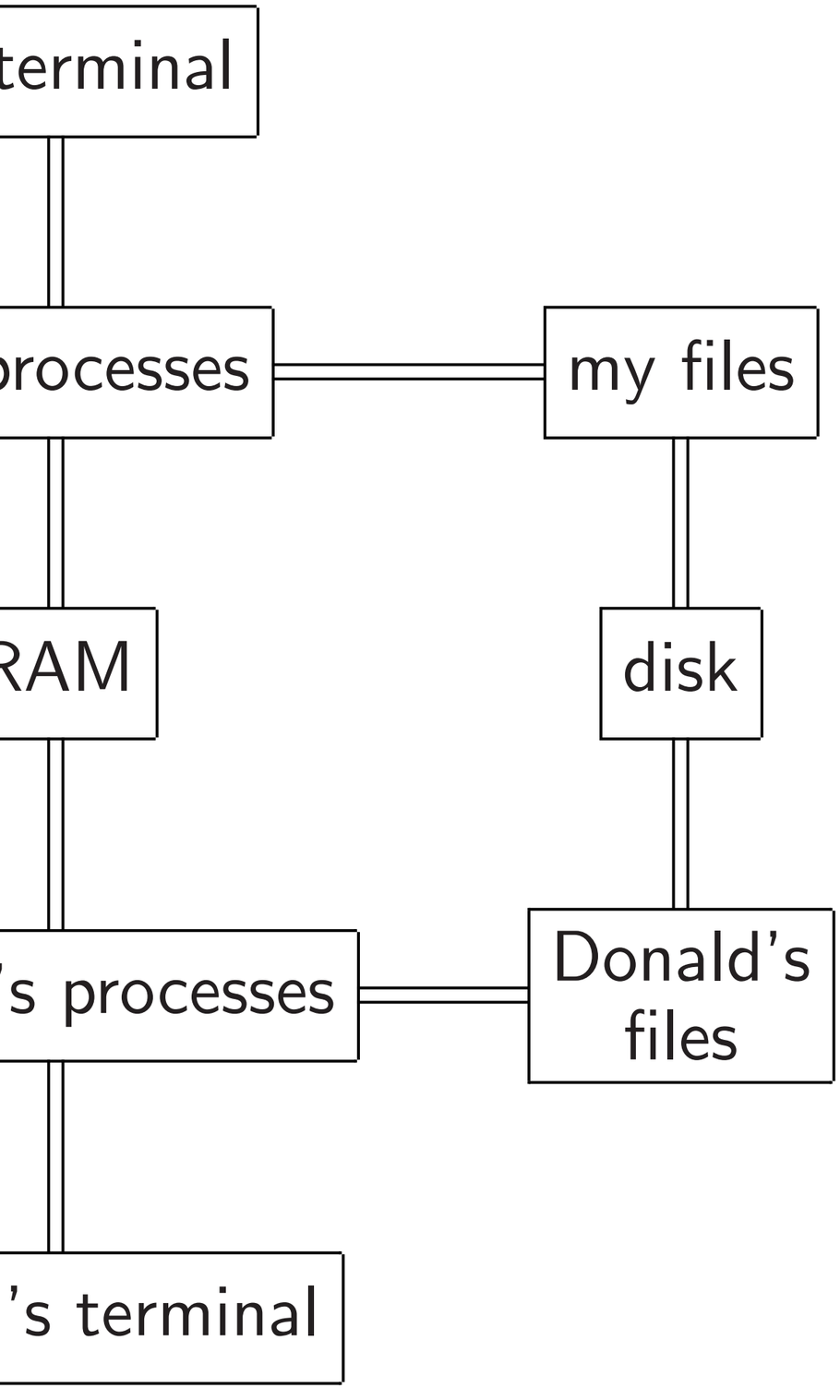

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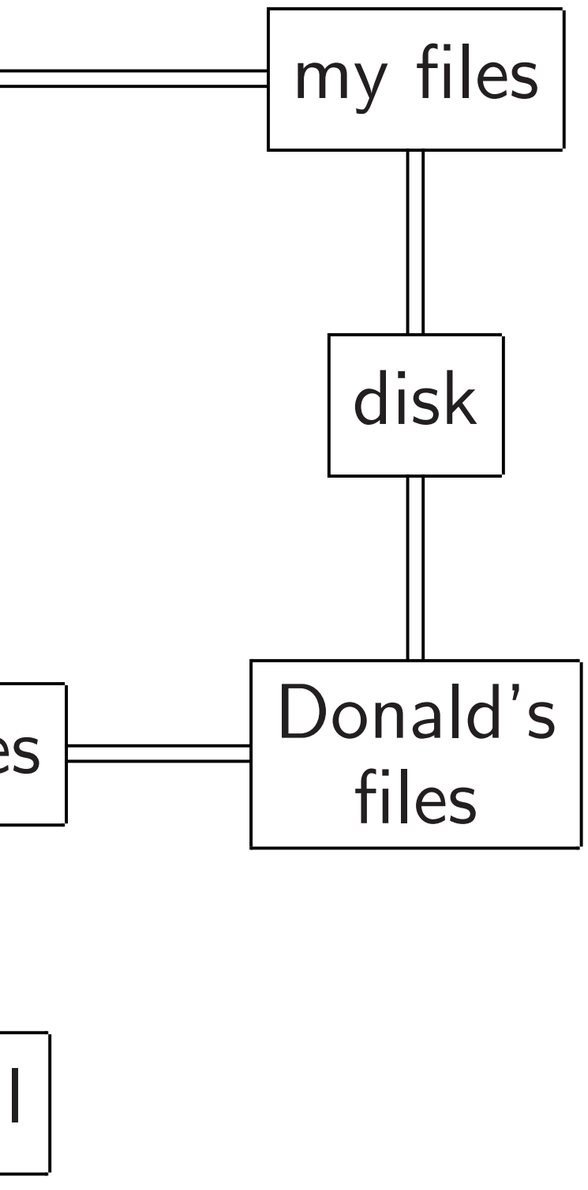

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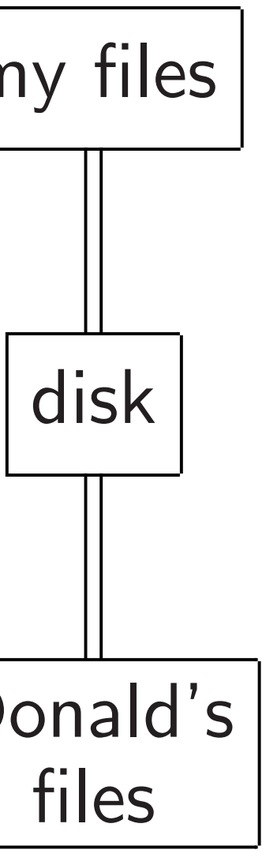

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1. "Memory protection". Hardware does not allow processes to access data outside areas marked by kernel.

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
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Successful example:
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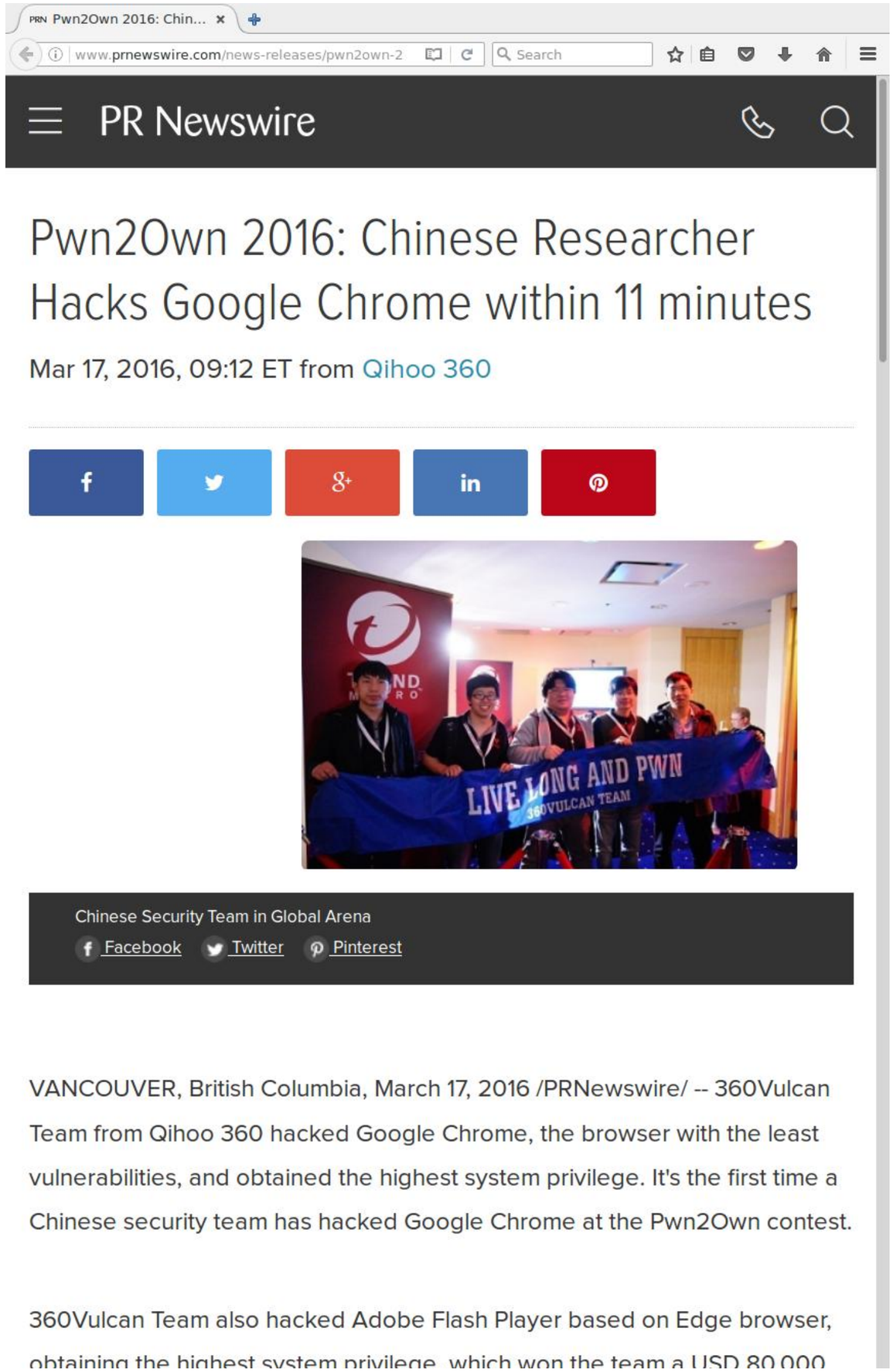

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Pwn2Own 2016: Chinese Researcher Hacks Google Chrome within 11 minutes

Mar 17, 2016, 09:12 ET from Qihoo 360

Chinese Security Team in Global Arena

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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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Alice sends me email.

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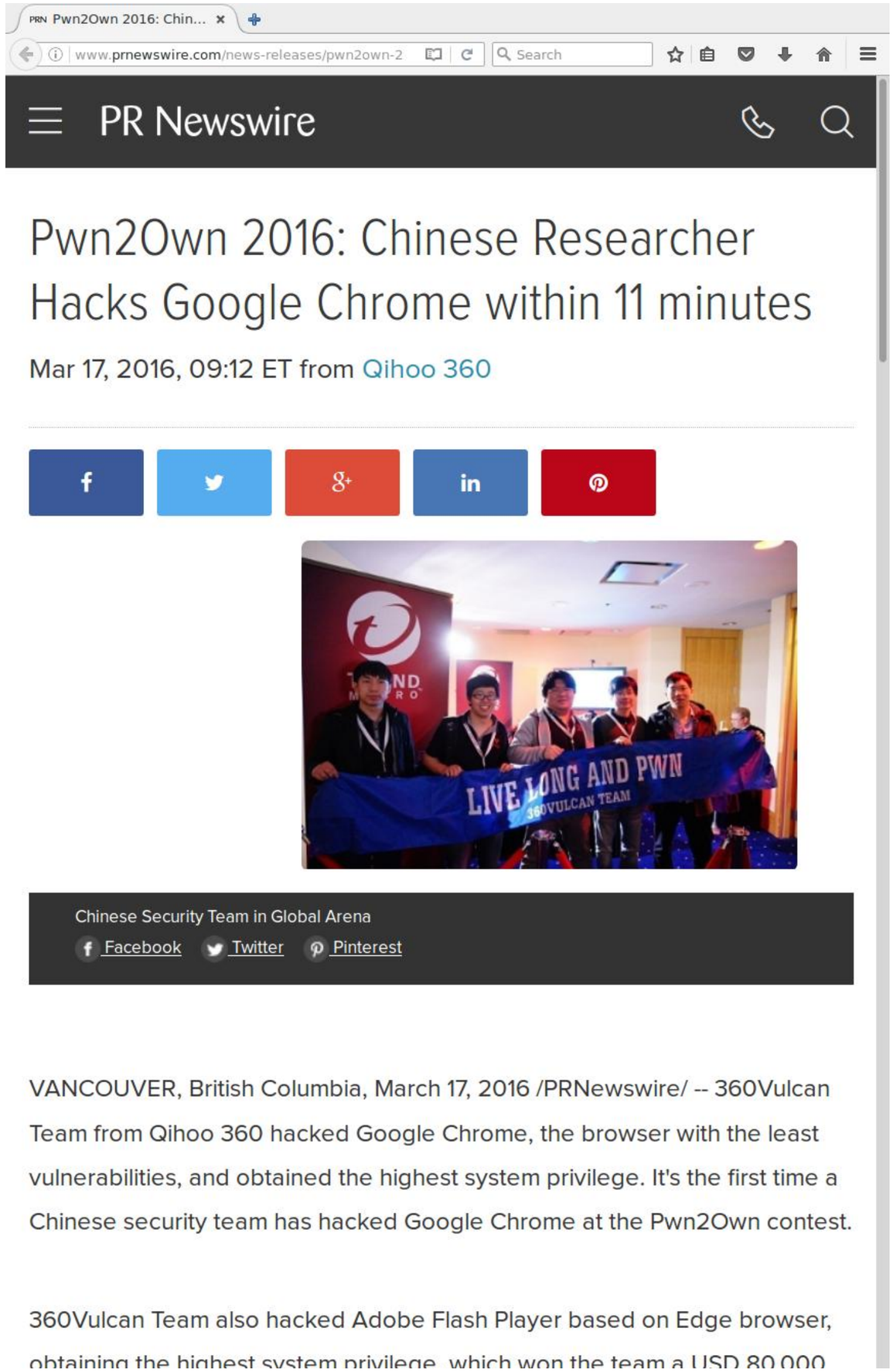

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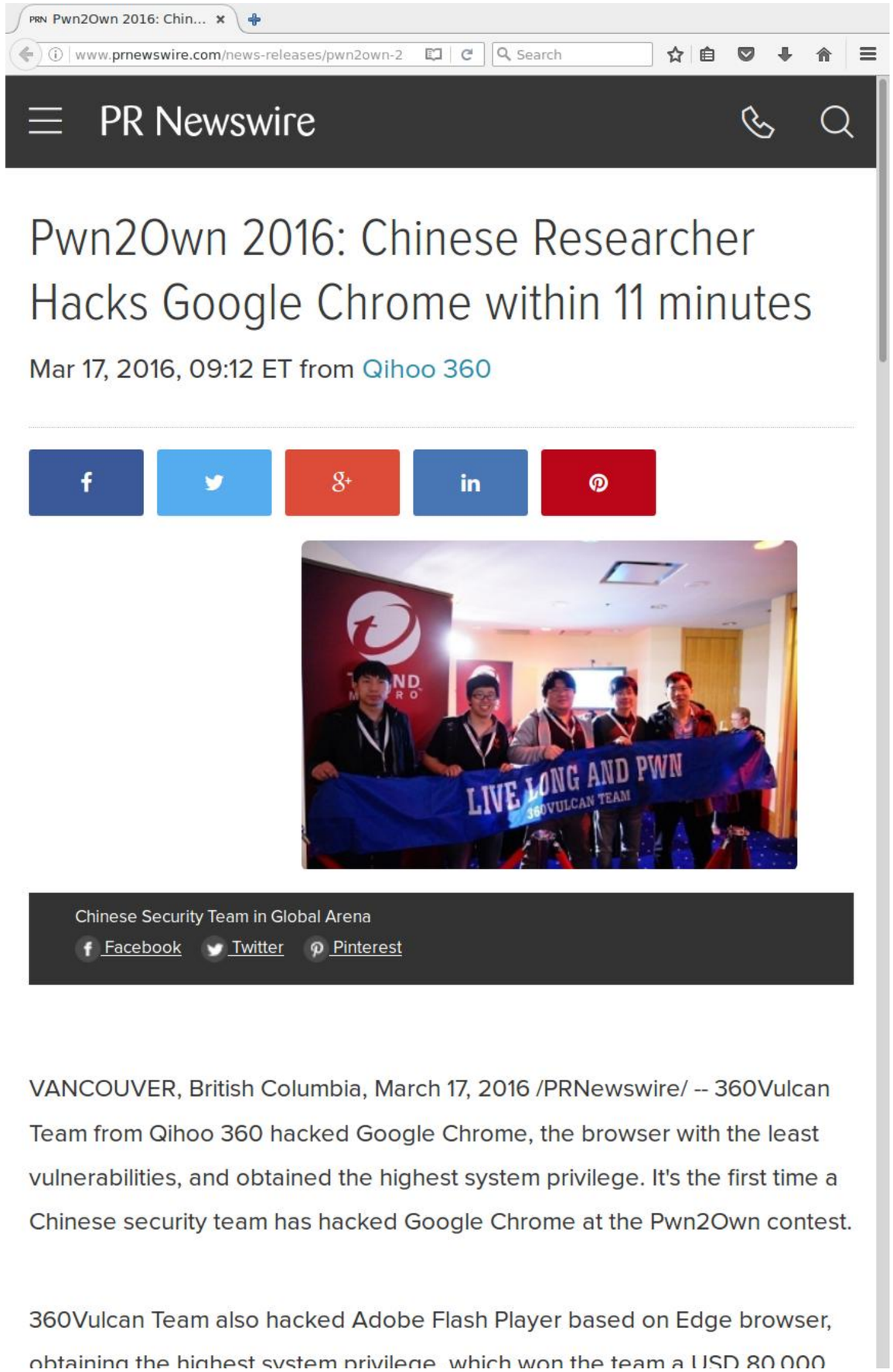

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Pwn2Own 2016: Chinese Researcher Hacks Google Chrome within 11 minutes

Mar 17, 2016, 09:12 ET from Qihoo 360

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

There is some “security” code inside kernel and browser.
But bugs in other code can and do compromise security.
TCB has >30000000 lines.

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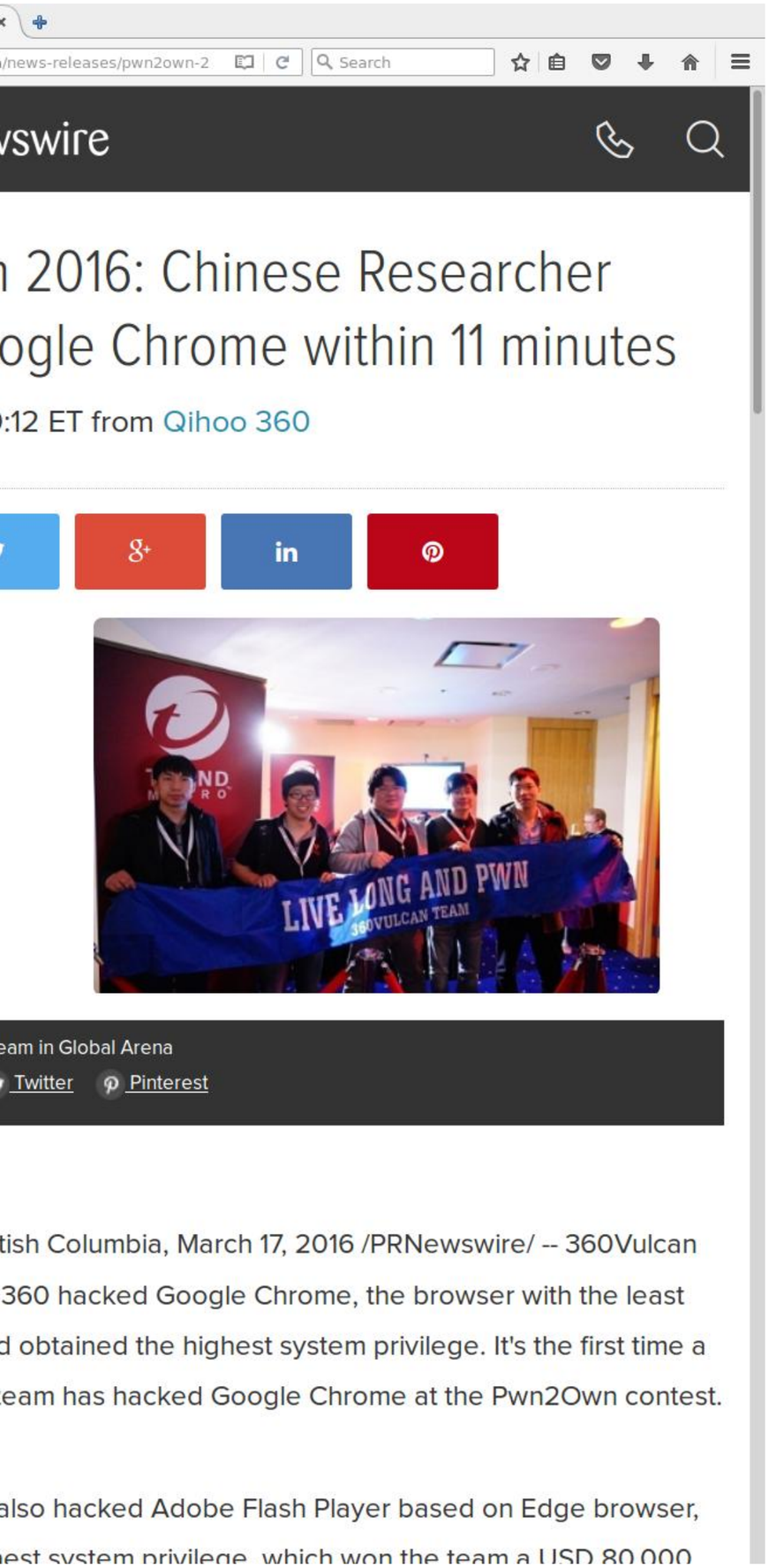

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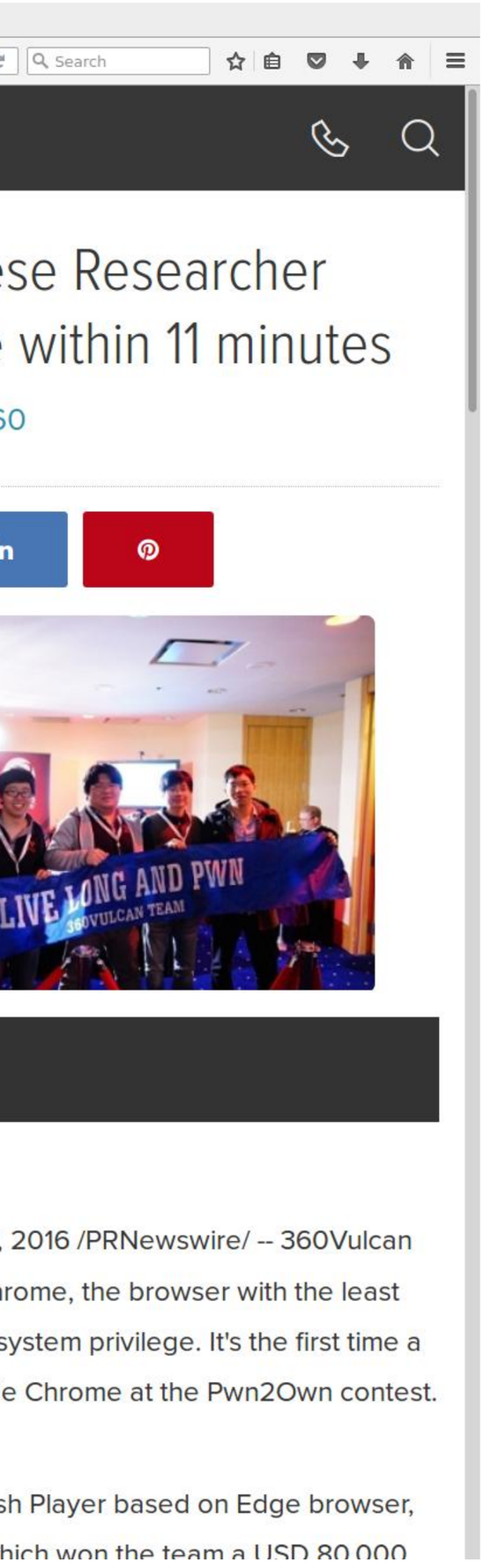

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Most important answer:
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(Same issue elsewhere in TCB, but most blatant for crypto.
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e.g. ECDSA signature verification:
$(H(M)/S)B + (x(R)/S)A = R$,
with S checked to be nonzero.

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

Checking $H(M)B + x(R)A = SR$
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Write A as
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ECDSA standard specifies reduction procedure given an integer "A less than p^2":

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

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$(A_7, A_6,$
$(A_{15}, A_1$
$(0, A_{15},$
$(A_{15}, A_1$
$(A_8, A_{13}$
$(A_{10}, A_8$
$(A_{11}, A_9$
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$(A_8, A_{13}, A_{15}, A_{14},$
$(A_{10}, A_8, 0, 0, 0, A_1$
$(A_{11}, A_9, 0, 0, A_{15},$
$(A_{12}, 0, A_{10}, A_9, A_8$
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Compute $T + 2S_1$
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Compute $T + 2S_1 + 2S_2 +$
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Reduce modulo p "by addin
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$(A_{15}, A_{14}, 0, 0, 0, A_{10}, A_9, A_8)$;
$(A_8, A_{13}, A_{15}, A_{14}, A_{13}, A_{11}, A_{10}, A_9)$;
$(A_{10}, A_8, 0, 0, 0, A_{13}, A_{12}, A_{11})$;
$(A_{11}, A_9, 0, 0, A_{15}, A_{14}, A_{13}, A_{12})$;
$(A_{12}, 0, A_{10}, A_9, A_8, A_{15}, A_{14}, A_{13})$;
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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.

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$_2; S_3; S_4; D_1; D_2; D_3; D_4$

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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.

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One of my favorite
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$(0, A_{15}, A_{14}, A_{13}, A_{12}, 0, 0, 0)$;
$(A_{15}, A_{14}, 0, 0, 0, A_{10}, A_9, A_8)$;
$(A_8, A_{13}, A_{15}, A_{14}, A_{13}, A_{11}, A_{10}, A_9)$;
$(A_{10}, A_8, 0, 0, 0, A_{13}, A_{12}, A_{11})$;
$(A_{11}, A_9, 0, 0, A_{15}, A_{14}, A_{13}, A_{12})$;
$(A_{12}, 0, A_{10}, A_9, A_8, A_{15}, A_{14}, A_{13})$;
$(A_{13}, 0, A_{11}, A_{10}, A_9, 0, A_{15}, A_{14})$.

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 "Curve2
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Tor, QUIC, WhatsApp, more

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>1000000000 Curve25519 users today: iOS, Signal, OpenSSH, Tor, QUIC, WhatsApp, more.

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Biggest challenge: the gap between big-integer operatio such as $a, b \mapsto ab \bmod 2^{255}$ and (e.g.) 32-bit operations.

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Timing can leak secret keys.

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Automatically build computation graph from original code.

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

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