Randomness of random in Cisco ASA

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Real World Crypto – March 28th 2023

*Work performed while at ANSSI.

The beginning of the story ...

Work on development projects

- X-509 parser [x509-parser]
- Elliptic Curve Cryptography library libecc [libecc]

Tests on a $>$250 millions X.509 certificates set led to ...

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X.509 Certs (TLS campaign)

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82k dup. ECDSA nonces

113k dup. ECDSA keys

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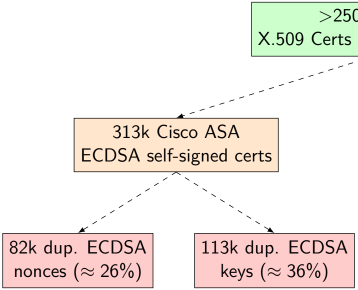

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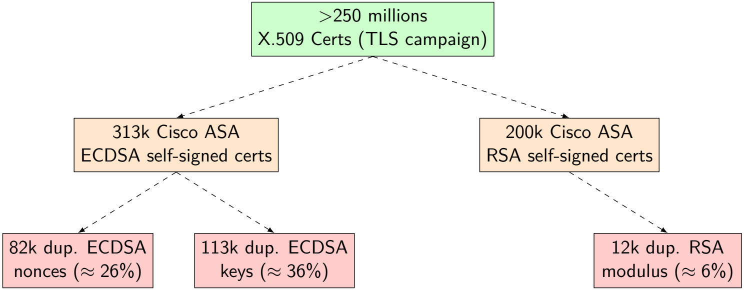

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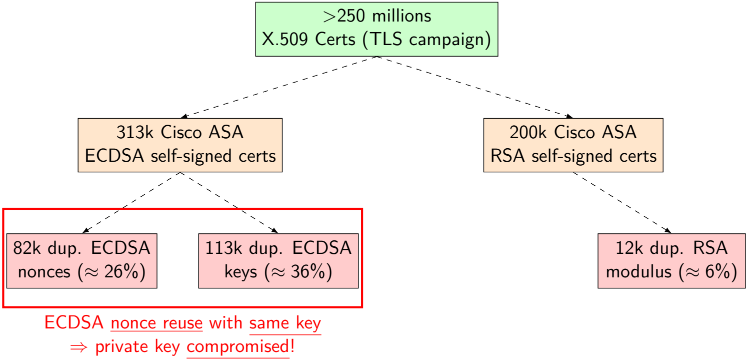
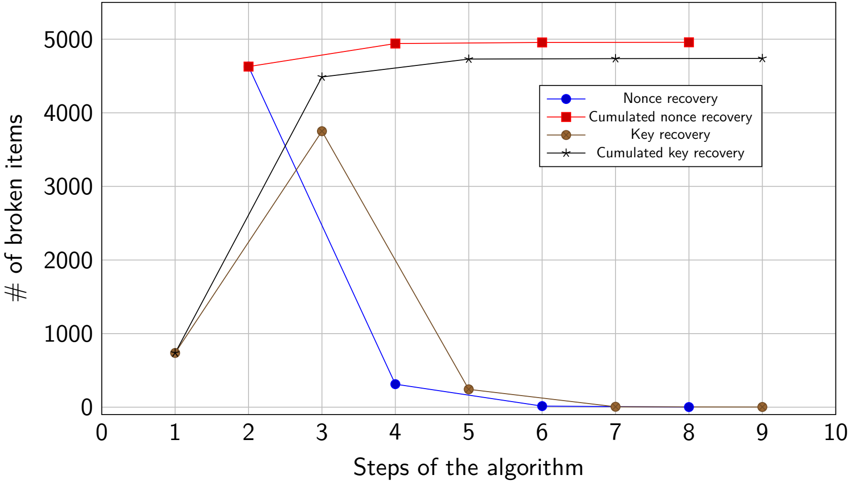


Iterative key recovery

Over 313k X.509 ASA ECDSA self-signed certificates with 216k unique keys



Some background on RNG fails ...

History

[CVE-2008-0166] 05/2008: predictible Debian OpenSSL RNG

⇒ Broken SSH/SSL RSA/DSA keys

[PS3EPICFAIL] 12/2010: Epic Fail ECDSA on the Sony PS3

⇒ Nonce reuse, compromission of the firmware signature key

[PSANDQS] 08/2012: Mining your Ps and Qs (modulus GCD)

⇒ Compromised RSA keys on many embedded devices

[NSBTCFAIL] 01/2013: Recovering BTC private keys

⇒ Nonce reuse, crypto-wallet ECDSA key compromission

[CVE-2019-1715, RWC-2019] Cisco ASA low entropy keys

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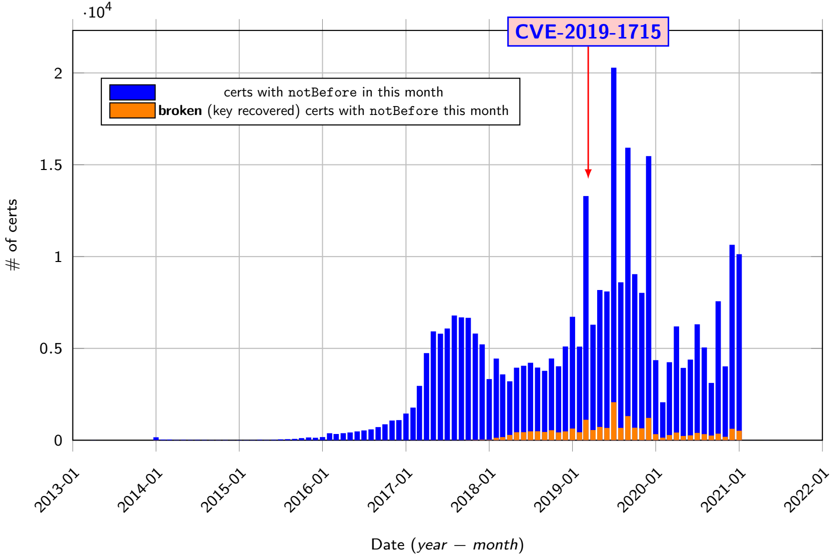
[CVE-2019-1715, RWC-2019] Cisco ASA low entropy keys 🤔

What about understanding and fixing last one for real? 😋 😇

[CVE-2023-20107] Cisco ASA low entropy keys

Distribution per month, broken / total

Over 313k certs ECDSA ASA



Cisco Adaptative Security Appliance (ASA)

- Firewall
- VPN (IPsec / TLS)
- IDS/IPS
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- Virtual applicances ASAv
- Firmware shared with HW
- Difference: no Cavium

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Virtual appliances ASAv images available

Cisco Adaptative Security Appliance (ASA)

- Firewall
- VPN (IPsec / TLS)
- IDS/IPS

- Instrumentation details not provided here (lack of time)
- Full length article with this to appear soon

Cisco ASA 5506
40 € Livraison : à partir de 6,50 €

- Virtual applicances ASAv
  - Firmware shared with HW
  - Difference: no Cavium

Hardware devices: easily available for a decent price!

Virtual appliances ASAv images available

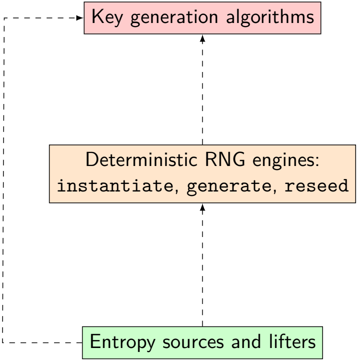
5506-X stats

Black box approach (through scripting)

Firmware	RSA modulus	ECDSA r nonce	ECDSA x key	#generated
9.6.2-23				45
9.6.3-20				15
9.6.4-34	● (red)		● (blue)	15
9.6.4-36	● (red)		● (blue)	15
9.6.4-40	● (red)		● (blue)	15
9.6.4-41	● (red)		● (blue)	15
9.6.4-42	● (red)		● (blue)	15
9.6.4-45	● (red)		● (blue)	45
9.7.1-4				160
9.8.1				60
9.8.2	● (olive)	◗ (orange)	■ (cyan)	60
9.8.3		● (yellow)		60
9.8.4-10		● (yellow)		10
9.8.4-41		● (yellow)		30
9.9.1	● (olive)	● (yellow)	■ (cyan)	30
9.9.2-85		● (yellow)		30
9.10.1-44		◗ (crimson)		30
9.12.4				30
9.12.4-35				30
9.13.1-12				30
9.14.3-18				30
9.15.1-15				30
9.16.2-14				30
9.16.2				45

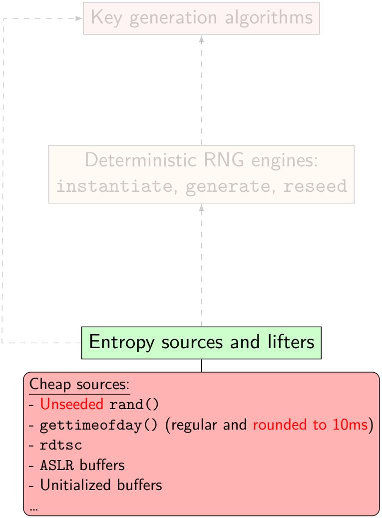
● collisions shared between firmware versions | Same color = collision values shared across versions
◗ = isolated collisions | Empty box = no observable collisions, inconclusive
■ = collisions emerging with same certificate time | Versions highlighted are vulnerable and NOT concerned by CVE-2019-1715

The RNG players in Cisco ASA



- Many primitives per layer
- Many combinations of these! (depending on ASA(v) version)
- Disclaimer: focus on important parts (not exhaustive)

Entropy sources and lifters



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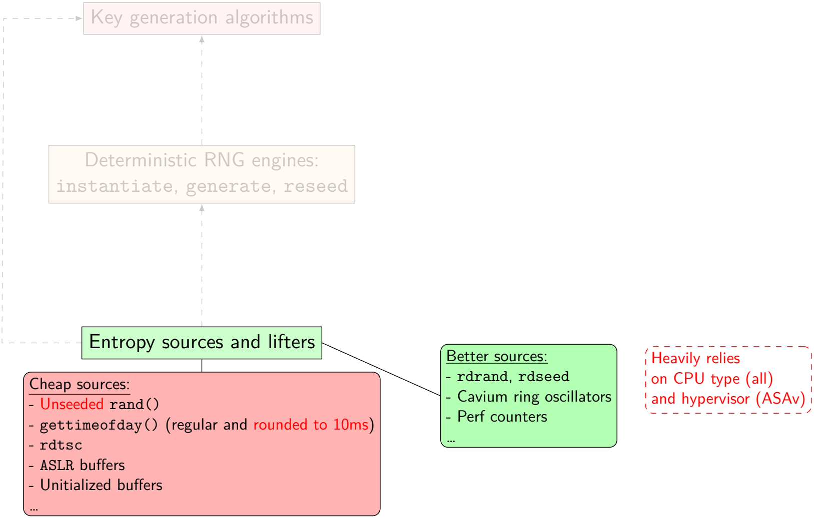

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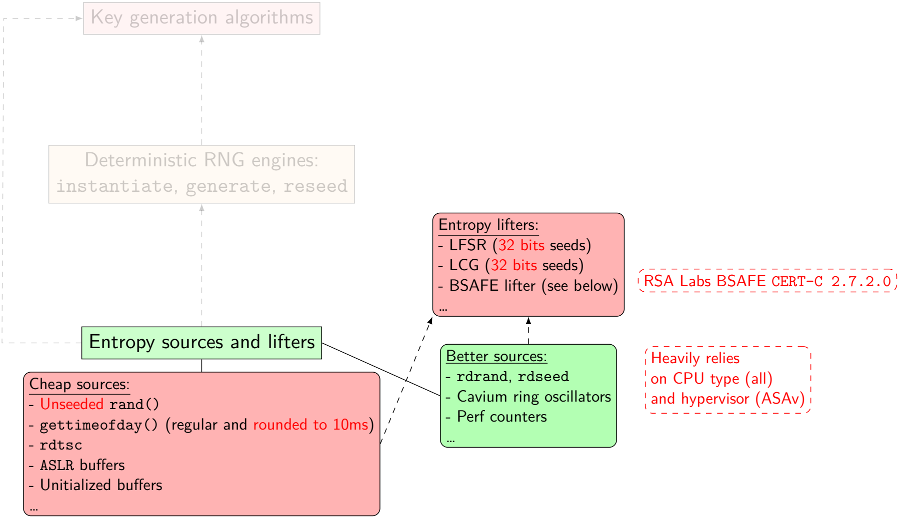
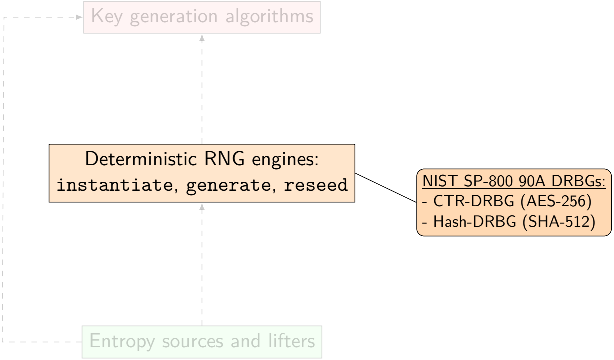


Deterministic generators



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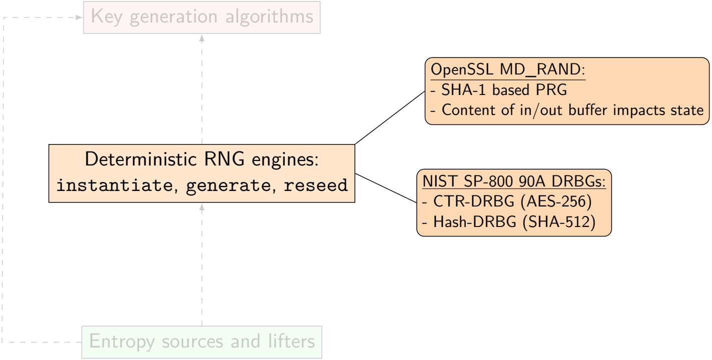

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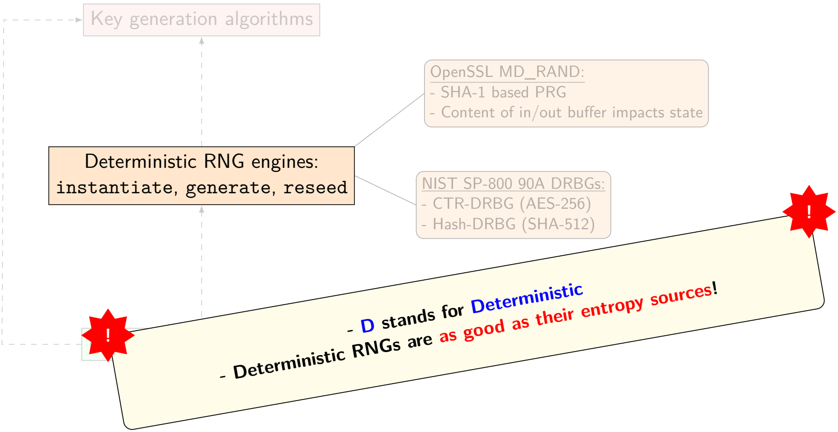
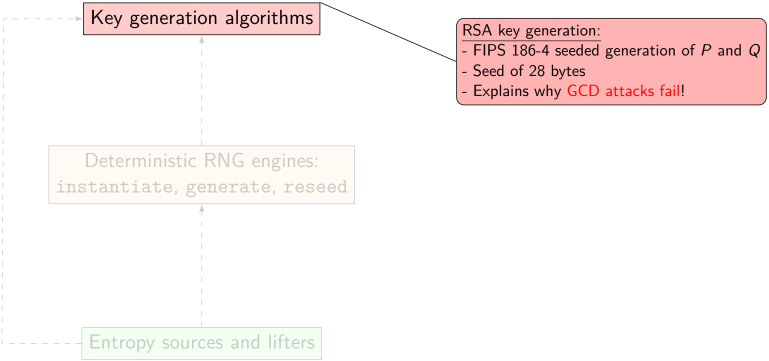


Key generation details



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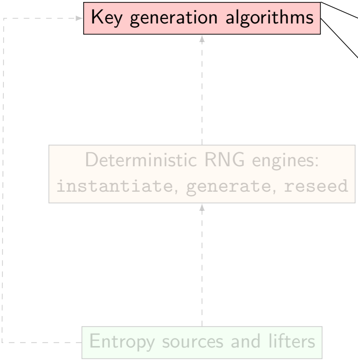
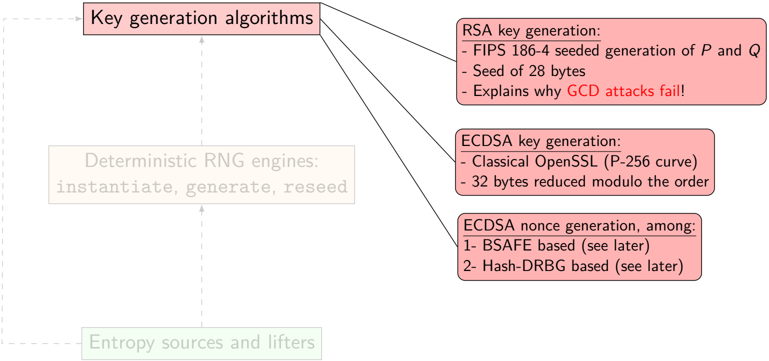


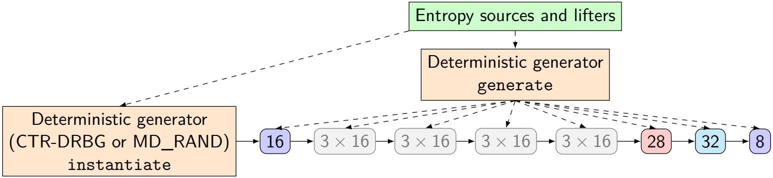
RSA key generation:
- FIPS 186-4 seeded generation of P and Q
- Seed of 28 bytes
- Explains why GCD attacks fail!

ECDSA key generation:
- Classical OpenSSL (P-256 curve)
- 32 bytes reduced modulo the order

Key generation details



Calls to the DRBG and random generate



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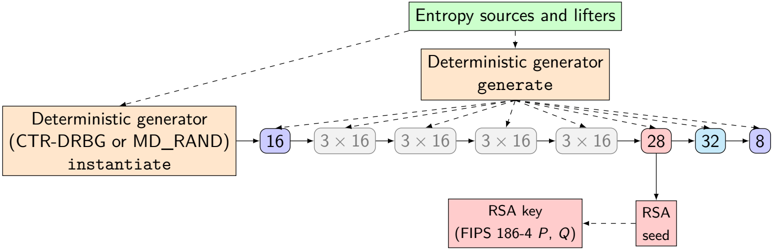

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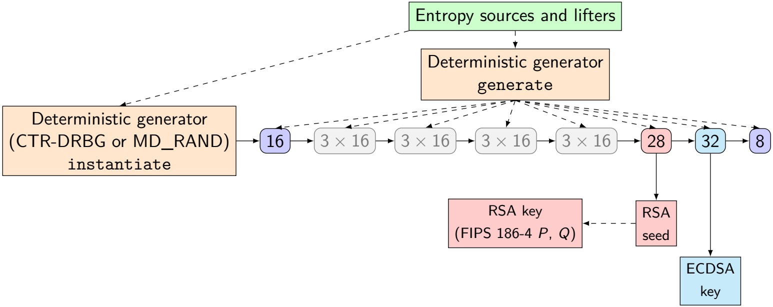

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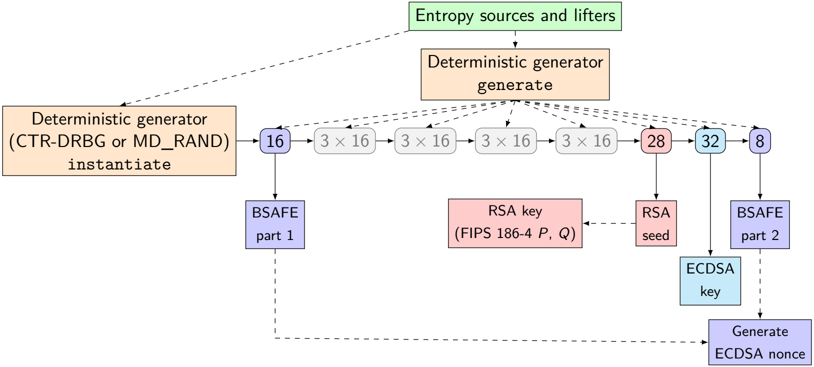
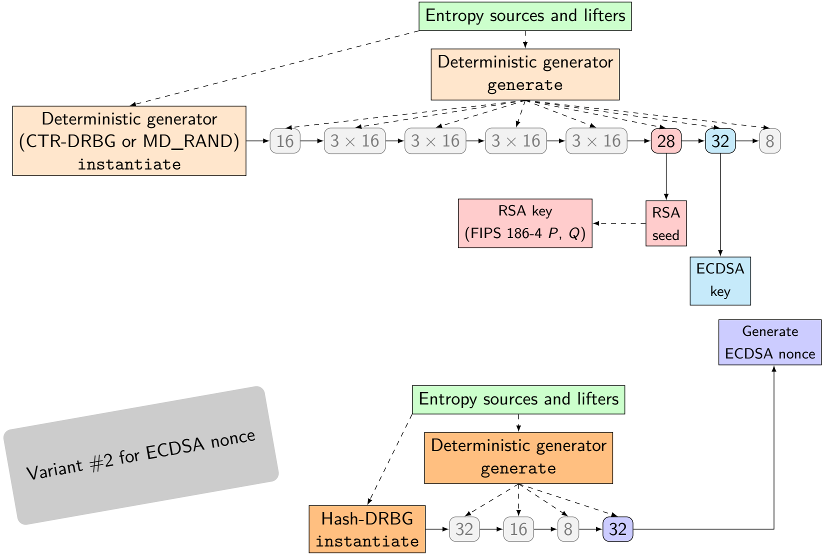
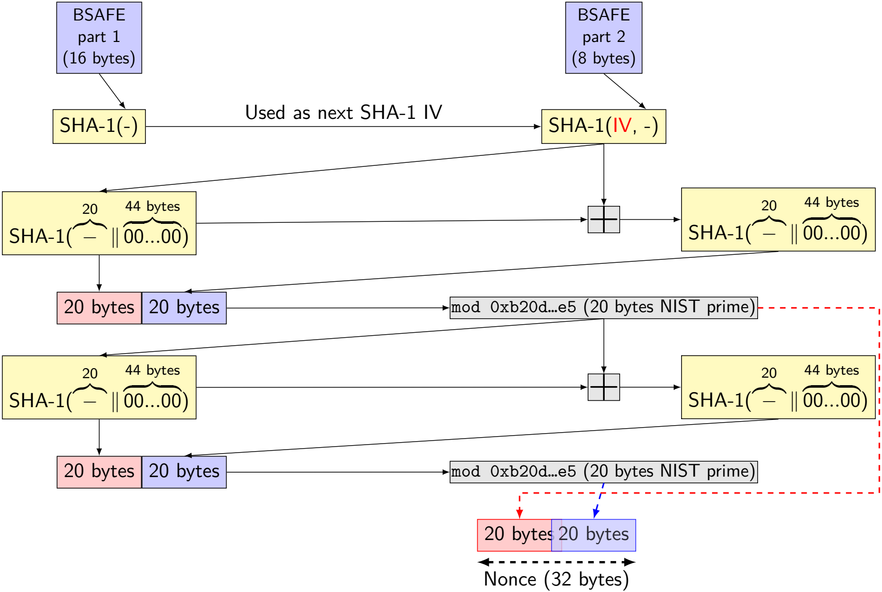


Variant #1 for ECDSA nonce

Calls to the DRBG and random generate



BSAFE lifter for ECDSA nonce



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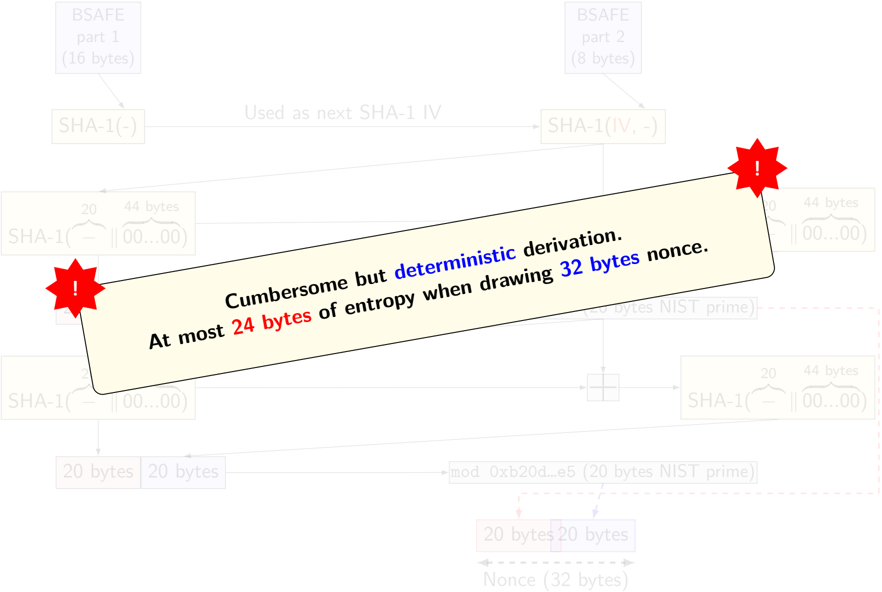


Cumbersome but deterministic derivation.
At most 24 bytes of entropy when drawing 32 bytes nonce.

ASAv v9.10.1.44

Overview of instantiated mechanisms

Used mechanisms

- CTR-DRBG used for RSA seed, ECDSA key
- ECDSA nonce using BSAFE with seeds from CTR-DRBG

CTR-DRBG Instantiate

- DRBG Personalization string:
  - Fixed `"CiscoSSL DRBG60"`
  - time from boot rounded to 10ms
- Entropy/nonce:
  - 40/20 bytes from MD_RAND ...
  - ... seeded by LFSR ...
  - ... seeded by 32 bits RDTSC.

CTR-DRBG Generate calls

- Addin: counter + time from boot rounded to 10ms

ASAv v9.10.1.44

Key aspects of a tricky keygenning

Estimated complexity

- 2^{32} possible LFSR seeds
- $\approx 2^{13}$ possible tuples for the 15 rounded time values

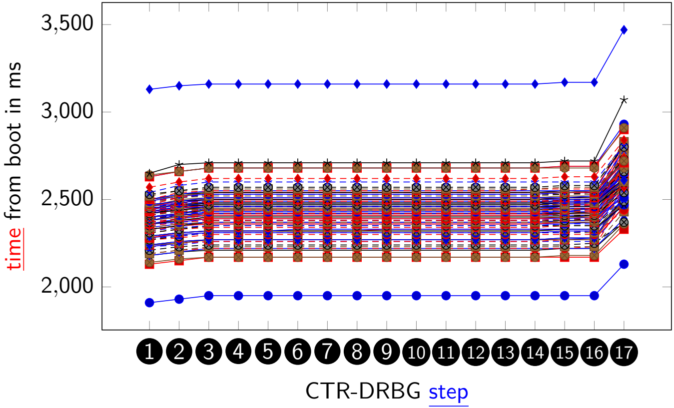
$\Rightarrow$ Exhaustive search for $\approx 2^{45}$ (w/ heavy DRBG calls)

Meet in the middle solution

- Patch the binary with a known fixed seed, do some stats on the timings as independent variables (valid approach)
- Take the most probable paths to reduce complexity, generate enough target certs and validate approach

ASAv v9.10.1.44

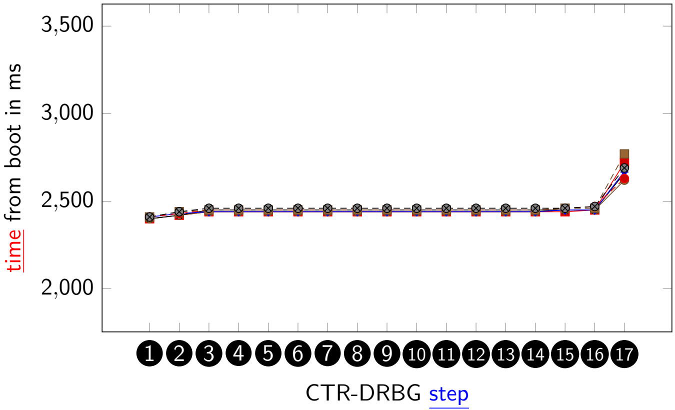
Timing statistics using patched binary (fixed seed)



- Pros: complexity reduced to $\approx 2^{13}$ for stats gathering

ASAv v9.10.1.44

Timing statistics using patched binary (fixed seed) + envelope reduction



- Pros: complexity reduced to $\approx 2^{37.5}$ for validation PoC on **unpatched** binary by reusing these envelope stats
- Cons: only 1.7% of possible certs remains accessible

ASAv v9.10.1.44

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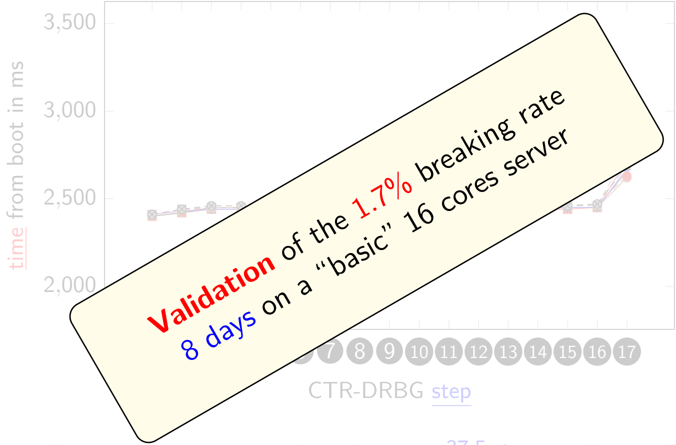

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ASAv firmware analysis: overview of results

Firmware	RSA modulus	ECDSA nonce	ECDSA key	Comment	Keygen time complexity
ASAv9.6.4-36	◗	●	◗ ▲	HASH-DRBG seeded by LFSR seeded by 32 bits `rdtsc`, used for nonce. CTR-DRBG is seeded by `MD_RAND`, itself seeded by HASH-DRBG itself seeded by a LFSR, itself seeded by `rdtsc` rounded to 32 bits	2^{32} (nonce)
ASAv9.8.1		●	▲	CTR-DRBG "saved" by addin with true `gettimeofday()`, HASH-DRBG seeded by a LFSR itself seeded by `rdtsc` rounded to 32 bits	2^{32} (nonce)
ASAv9.8.2	●	●	●	`MD_RAND` seeded by `rand()`, ASLR in input buffers for `MD_RAND` (nonce), BSAFE seeded by `MD_RAND`	$\approx 2^{33}$
ASAv9.8.3	●	●	●	CTR-DRBG seeded by `rand()` BSAFE seeded by `CTR_DRBG`	$\approx 2^{16}$
ASAv9.9.1	●	●	●	`MD_RAND` seeded by `rand()`, ASLR in input buffers for `MD_RAND` (nonce), BSAFE seeded by `MD_RAND`	$\approx 2^{33}$
ASAv9.10.1-44	🔴	🔴	🔴	CTR-DRBG seeded by `MD_RAND` seeded by LFSR seeded by 32 bits `rdtsc`. Bad `gettimeofday` is also used.	Full: $\approx 2^{45}$ PoC: $\approx 2^{37.5}$

Legend:
- ● Fully broken with a PoC **keygen**
- 🔴 Broken with a PoC **keygen** with higher time complexity
- ◗ **Fragile** entropy sources, harder to exploit (but seems feasible)
- ▲ Broken as a side effect of nonce breaking

Versions highlighted are vulnerable and NOT concerned by previous CVE-2019-1715

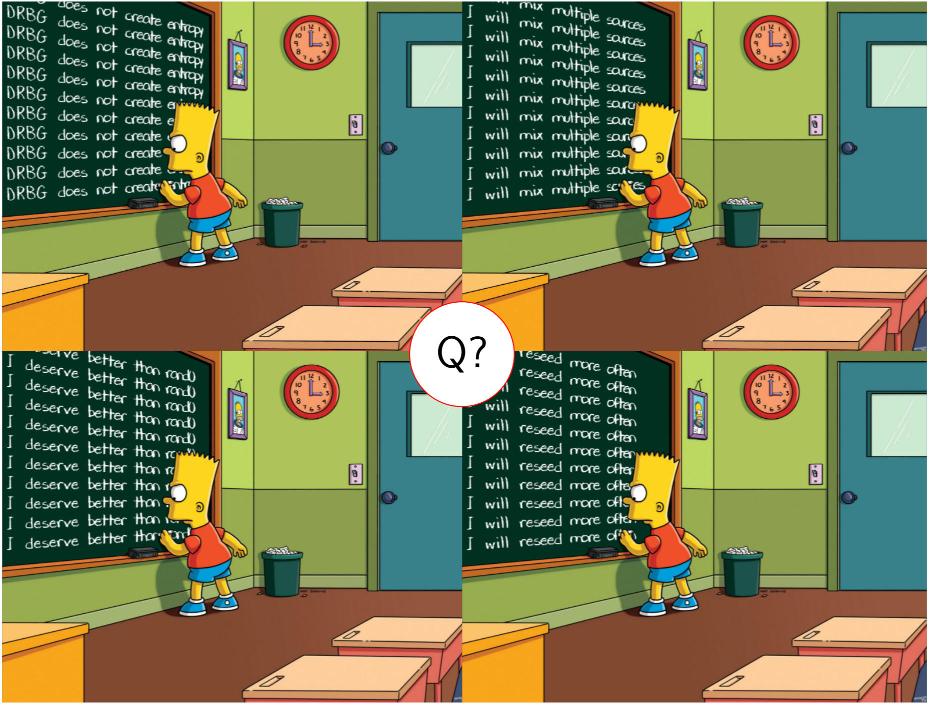
Conclusion

What we ~~learned~~ already knew.

- Fail instead of fallback to a bad entropy source
- Consider worst code path, remove if unacceptable/unsure
- Mix multiple sources instead of using a single one
- DRBG specific
  - DRBG security depends on `instantiate()` source
  - Poor addins for `DRBG generate()` calls is risky
  - Reseeding often is a requirement [DRBG-ANALYSIS]

Final thoughts

- Good looking keys, etc $\not\Rightarrow$ good random
- Good DRBG/PRNG $\not\Rightarrow$ good random
- Full 50 pages article to come for SSTIC 2023 in june


DRBG does not create entropy
DRBG does not create entropy
DRBG does not create entropy
DRBG does not create entropy
DRBG does not create entropy
I will mix multiple sources
I will mix multiple sources
I will mix multiple sources
I will mix multiple sources
I will mix multiple sources
Q?
I deserve better than rand()
I deserve better than rand()
I deserve better than rand()
I deserve better than rand()
I deserve better than rand()
I will reseed more often
I will reseed more often
I will reseed more often
I will reseed more often

- Ryad Benadjila, Arnaud Ebalard, Jean-Pierre Flori **“libecc: an ecc-based signature mechanisms library”**. Available at https://github.com/libecc/libecc.
- Arnaud Ebalard **“x509-parser: a RTE-free X.509 parser”**. Available at https://github.com/ANSSI-FR/x509-parser. More details at https://www.sstic.org/2019/presentation/journey-to-a-rte-free-x509-parser/
- Nils Schneider **“Recovering Bitcoin private keys using weak signatures from the blockchain”**, Blog entry, 28 January 2013, http://www.nilsschneider.net/2013/01/28/recovering-bitcoin-private-keys.html, broken link use https://archive.org.
- Nadia Heninger and Zakir Durumeric and Eric Wustrow and J. Alex Halderman **“Mining Your Ps and Qs: Detection of Widespread Weak Keys in Network Devices”**, https://www.usenix.org/system/files/conference/usenixsecurity12/sec12-final228.pdf.

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failoverflow, https://web.archive.org/web/20150627235425/https://events.ccc.de/congress/2010/Fahrplan/attachments/1780_27c3_console_hacking_2010.pdf, 29 December 2010

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Joanne Woodage and Dan Shumow **"An Analysis of the NIST SP 800-90A Standard"**, https://eprint.iacr.org/2018/349.pdf, 2018.

Greg Zaverucha and Dan Shumow **“Are Certificate Thumbprints Unique?”**, https://eprint.iacr.org/2019/130.pdf, 2019

Cisco Adaptive Security Appliance Software and Firepower Threat Defense Software Low-Entropy Keys Vulnerability, https://sec.cloudapps.cisco.com/security/center/content/CiscoSecurityAdvisory/cisco-sa-asa5500x-entropy-6v9bHVYP, March 2023