Application Security (apsi)

Lecture at FHNW

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Agenda

Use of Cryptography

- Key generation and handling, entropy gathering
- Some comments on passwords
- Password storage
- Storing and handling private data
- Disk encryption: Full-disk encryption, file encryption
- Encryption in the cloud
- Encryption in the browser

Note: This is very incomplete...

Generating Cryptographic Keys

Requires high-quality random data (actually: "unpredictable" data)

Usual approach:

- CPRNG (Cryptographic Pseudo Random Number Generator)
- Needs seeding, usually 256 bits of entropy or more (generator dependent)
- After seeding, practically unlimited amount of key-grade data available

Where to get entropy ?

- Physical processes (disk access, network events, user input, etc.)
- Store some between reboots (save on shutdown, load on start)
- Initial seeds from outside (VMs!)

→ Many errors are made here! (looks very easy – is pretty hard)

Lit: "Mining Your Ps and Qs", https://factorable.net/weakkeys12.extended.pdf

Information-Theoretical Entropy

Measures the "uncertainty" of a value produced "randomly"

Unit (one symbol): "bit"

Unit (stream of symbols): "bit/symbol"

Unit (Entropy-density, i.e. Entropy per bit): "bit/bit" or none

Definition: $$E = -\sum_{i=0}^{n-1} p_i * \log_2(p_i) \quad [bit]$$

for n symbols with probabilities $p_{0,} \cdots, p_{(n-1)}$

Example:

A source can emit 128 different symbols, all equally probable
→ Entropy per symbol: 7 bit
→ Stream-Entropy: 7 bit/symbol

Estimating Entropy is Tricky

Yet estimation is needed to make sure a CPRNG seeding is good!

→ The key is to generously over-estimate the seeding entropy

Example: User input timing on the keyboard

> Question: How much entropy is there in the time-stamp of one key-press of a sequence of keys? Assume there is a 0.1sec random variation per key.
>
> Answer: ???

Seeding a CPRNG

Example: /dev/(u)random (Linux standard kernel CPRNG)

- /dev/random: Only gives data until estimated seeding entropy reached
  → may block a long time (not good)
- /dev/urandom: Gives unlimited CPRNG output (even if badly seeded)
  → Good seeding is critical, and <u>must</u> be done (do <u>not</u> use it before!)
  → After seeding, /dev/urandom should be used in all cases
  Speed should be > 200MB/s on a desktop CPU (Linux kernel 5.x or later)

Seeding (from Debian /etc/init.d/urandom):

```
cat "seedfile" > /dev/urandom
```

Recommendation: Seed at the very least with 256 bits of entropy

Note: There are quite a few myths around about /dev/(u)random
Most are wrong, some are dangerous
Unfortunately, that even includes "man random(4)" !
→ If in doubt, ask an expert!

Bad Seeding Examples

- Seeding /dev/urandom from /dev/random
  → That does not work, as both are interfaces to the <u>same</u> generator!
- Seeding with the system time (may/will be predictable!)
- Seeding with a single entropy source (depends)
- Just waiting a few seconds after boot and hoping for the best
- Seeding with a copied seed file (VM or system image clone)
- Java SecureRandom() with a broken implementation (Android...)

  → Security depends on (obscure) details. This is <u>bad</u> design!

Using cryptography with bad keys from badly seeded CPRNGs is <u>worse</u> than not using cryptography, as it gives a false sense of security!

This violates the "Principle of least surprise"

Storing Cryptographic Keys Securely

This is difficult!

Due to time restrictions not treated here.

→ If in doubt, ask an expert

Some Comments on Passwords

There are a lot of myths around...

- Myth: Longer is better!
  Reality: Around 8...12 characters security stops improving. It may get worse with longer ones though.
- Myth: You need as pecial symbol in it!
  Reality: This adds very little security but does frequently cause problems.
- Myth: You need to change passwords every 1...3 months!
  Reality: People use worse passwords or re-use passwords if they need to change them regularly. This does <u>decrease</u> security. For example, NIST and the BSI have stopped requiring time-based password changes completely.
- Myth: You can reliably assess password quality on input.
  Reality: You cannot. You can enforce some length. You should compare to known bad passwords.
  Hashed list example: https://haveibeenpwned.com/Passwords
  Plain text list example:
  https://gitlab.com/kalilinux/packages/seclists/-/tree/kali/master/Passwords/Common-Credentials

Storing Passwords

Problem: User-supplied passwords need to be stored for verification

- Solution 1: Store in plain in a database
  → If hacked, attacker has all passwords!
  → Even worse, many users use the same passwords in multiple places!
- Solution 2: Use a single crypto-hash h and store h(pwd)
  - Verification: Compare h(pwd) and h(user_supplied_pwd)
  - Attacker gets only h(pwd)

How much effort is reversing h(pwd)?

Example: A modern PC does about 5M SHA1 hashes per second per CPU

Passwords: letters + digits + 10 special symbols → 6.2 bit entropy/char

Breaking effort (1 CPU): 4 chars → 6 sec, 6 char → 9h, 8 char → 5.4 years

But: 1. Rainbow-tables → Compute once, break many passwords fast

2. Graphics cards → may be > 1000x as fast (5.4 years → 2 days)

Rainbow Table

A table that on lookup of h(pwd) delivers pwd
→ Break a larger set of password-hashes (think the 500M from Yahoo)

Note: Base form, optimizations to save space are possible

Creation for a given set of passwords {pwd}:

1) For all elements p of {pwd}: calculate h(p)
2) Create a hash-table: h(p) → p
   Traditionally: Sort {h(p)}, and do binary search.
   But: sorting O(n log n), bin-search O(log n), while hashing O(n)/O(1) (usually)

Effort (single hash, random 6.2bit/char entropy passwords, estimates):

- 6 char pwd: CPU: a few days, space: ~ 2TB
- 8 char pwd: Graphics card: a few days, space: ~10EB (~1000 disks)
- 10 char pwd: May be infeasible today

Storing Passwords

- Refinement: Salted hashing to make Rainbow-Tables unusable:

  Store salt, h(pwd+salt). Salt: Random, non-secret, 64bit or more
  → One Rainbow table per salt value needed
  → Storage space for Rainbow table becomes prohibitive

- Refinement: Iterated hashing, to slow-down brute-force reversal:

  Instead of h(pwd), store h(…(h(pwd)...)), for, say, 1 sec of hashing time
  → Attacker gets massively slowed down
  → Around 1M iterations for 1 sec on modern CPUs

Combination of both is the old (!) state-of the art

- PBKDF2() implements this with some refinements
  Reference: RFC 2898
  DK = PBKDF2(hash, password, salt, iteration_count, result_bits)

So What is Wrong with PBKDF2?

It does not need much memory to compute it!

- Graphics cards (~64kB RAM per core for example) still work well
- ASICs and FPGAs work well

Needed is hashing + iteration + "large memory property"

- Older partial and <u>obsolete</u> solutions: bcrypt(), scrypt()

Current state-of-the-art: Argon2:

- Use this whenever possible
- Time and memory parameter
  => Parameters tunable to target situation
- Computing with less memory makes things massively slower
- Recommendations: CPU: ~ 1 sec, RAM: 100M or more if possible

Hardware RNGs

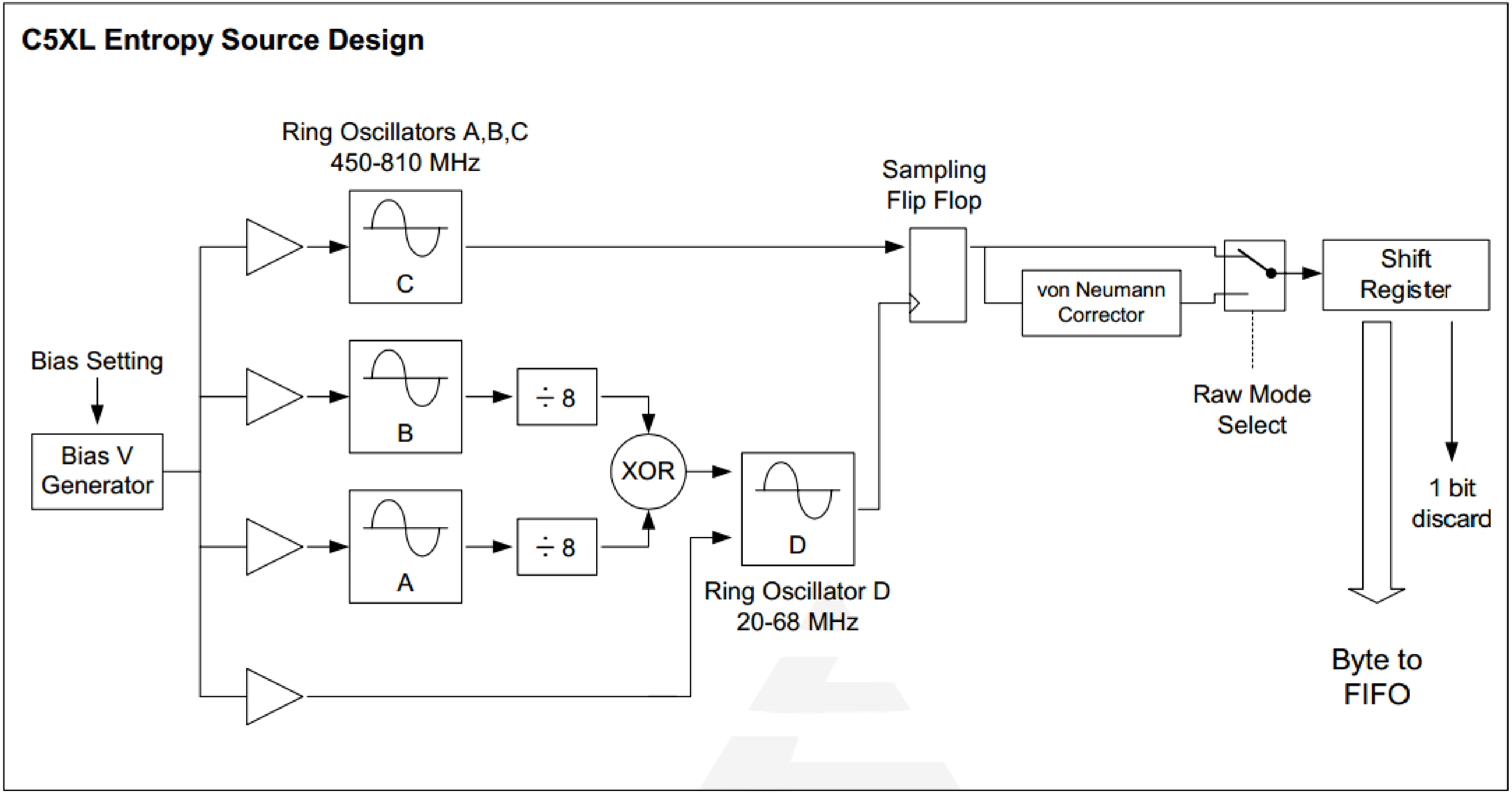
True random number generators found (for example) in some CPUs

- Produces "true" randomness (usually thermal noise and/or quantum effects)
  Note: Quantum effects often called "true random", but reality is we simply do not know how they work...
- Usually have high bandwidth (for example > 1MB/s random data)
- Not dependent on any external interactions or software (main advantage)
- Usually easy to use on assembler-level

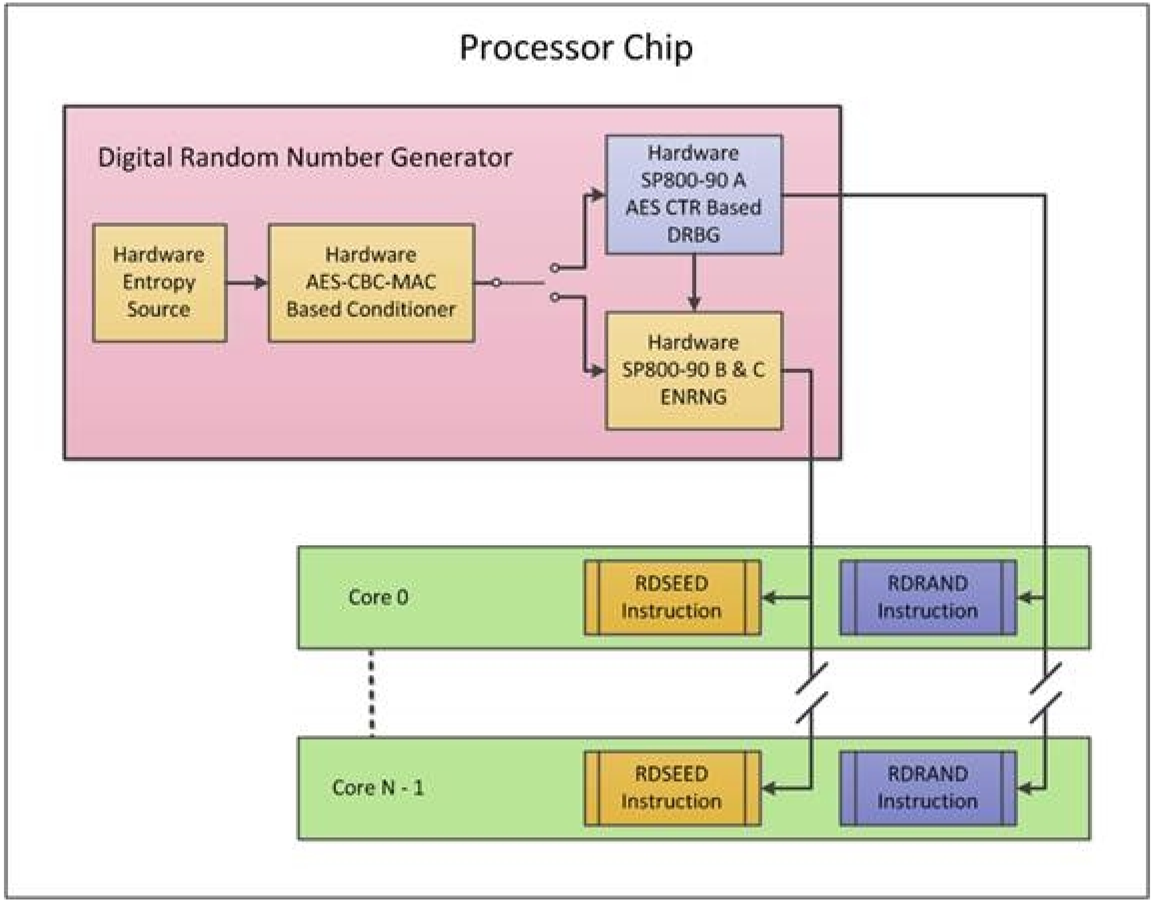
But:

- Implementation is more or less "trusted"
  Note: "trusted" = "can break your security" = "you have to trust it..."
- Problematic implementations exist and are widespread

Example 1: Via C3 Hardware CPRNG Schematic



Example 2: Intel RDRAND Schematic



The Conditioner is a problem….

Compromise on Design-Level

The C3 CPRNG is a non-compromised design:

- Raw signal can be verified
- May still be implemented in a compromised fashion!
- May still be implemented as something different!
- Note: Delivers around 0.75 bit/bit in entropy

Intel RDRAND is a compromised design:

- Impossible to read and verify raw randomness
- Impossible to distinguish compromised implementation from good one

→ Do not depend on this alone!
→ Linux kernel does not trust it and only uses it as additional conditioner, not as Entropy-source (update: Kernel may now be set to trust it)

Reference (archived copy): https://archive.fo/Md6TM

Storing Private Data (as a Service Provider)

Aim: Preserve privacy

How to do that?

- Encrypt everything!
  But: Data needs to be used at some time and then it needs to be decrypted
  Made worse by desires of marketing…
- Do <u>not</u> store private data in the first place!
  What you do not have cannot be stolen or misused…
- Abstract or anonymize private data
  → May be enough for the intended use (and for marketing)
  Warning: This is really difficult to get right!

Disk/Storage Encryption

Refers to encryption done by the OS (or storage device)

Example full-disk encryption (FDE):

- LUKS (Linux)

Example File-level disk encryption:

- EncFS (Linux)

Note: File-level encryption is less secure, but more flexible

- Leaks file-names, time-stamps, length, etc.
- May allow overwrite-attacks

Disk Encryption Protects Against What?

Basically only:

- Your disks being stolen
- Your non-running (!) computer being stolen
  => That does not sound so great for a server or laptop…

It does not help for:

- Being hacked while the disk is decrypted (mapped)
- The running machine with decrypted (mapped) disks is stolen

Privacy benefits are limited!

One important case though: Disks/tapes/etc. being decommissioned insecurely

Encryption in the Cloud

Usually, this means disk encryption

Protects:

- A non-running VM disk image (if done right)

Problems:

- Same problems as disk encryption
- No protection against the cloud provider
- Keys may leak to other VMs on the same hardware (numerous problems)
- Marketing, the copyright industry and the "Four Horsemen of the Infocalypse" will ensure your data does get scanned, analyzed, aggregated, etc.

→ Encryption in the cloud is basically marketing. Assume data in the cloud is only secure if it never reaches the cloud non-encrypted.

JavaScript Client-Side Encryption in Web-Apps

"JavaScript Crypto" (basically applies to all browser-executed code)

- Widely used to achieve compatibility, but pretty bad security level

Common problems:

- Browser may be arbitrarily old and/or insecure
- You <u>must</u> trust the browser (it can always attack you successfully)
- How do you deliver the code securely? If you can, you may not need it...
- The code is <u>not</u> under user-control, so hacking the server hacks it as well
- …

Reference:
https://web.archive.org/web/20110925120934/http://www.matasano.com/articles/javascript-cryptography/

→ Do not rely on it. (Note: Some people strongly disagree)

- Will "WebCrypto" fix this? I do not think so: https://tonyarcieri.com/whats-wrong-with-webcrypto

→ This may still need a long time to become secure, if it ever does...