ΤΜΗΜΑ ΠΛΗΡΟΦΟΡΙΚΗΣ

Secure Pseudo Random Generators

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Introduction

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Random numbers or symbols

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Work and ***time*** consuming

True vs pseudo-random numbers

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True random number generator

Measures some physical phenomenon that is expected to be random and then compensates for possible biases in the measurement process.

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- radioactive decay (ex. https://www.fourmilab.ch/hotbits/)

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Example:

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$X_4 = (2 \cdot 4 + 3) \mod 5 \Rightarrow X_4 = 11 \mod 5 = 1$

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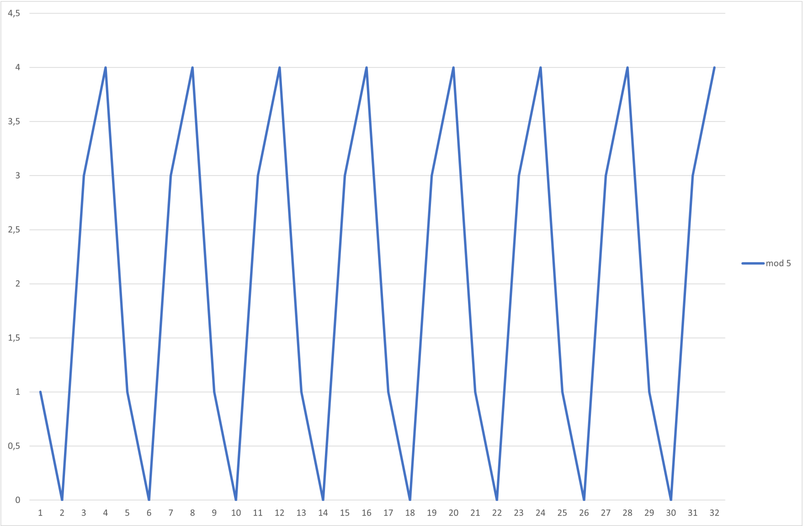
$X_4 = (2 \cdot 4 + 3) \mod 5 \Rightarrow X_4 = 11 \mod 5 = 1 \equiv X_0$

Linear Congruential Generator - LCG - Graph



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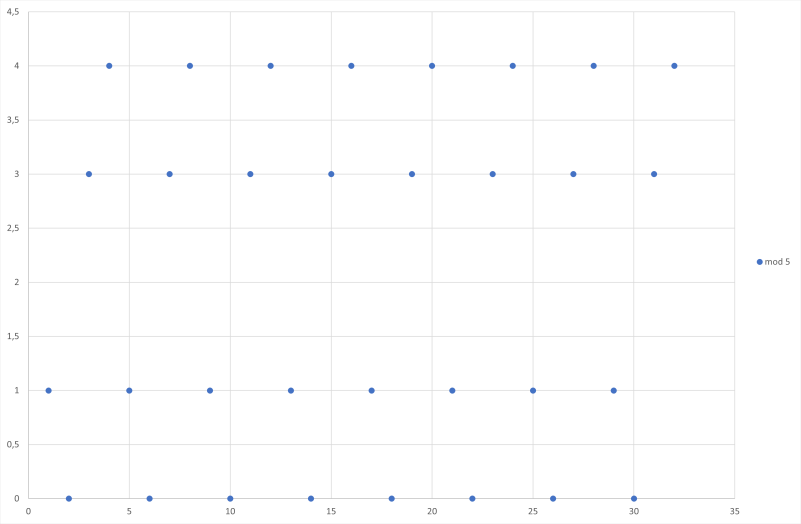

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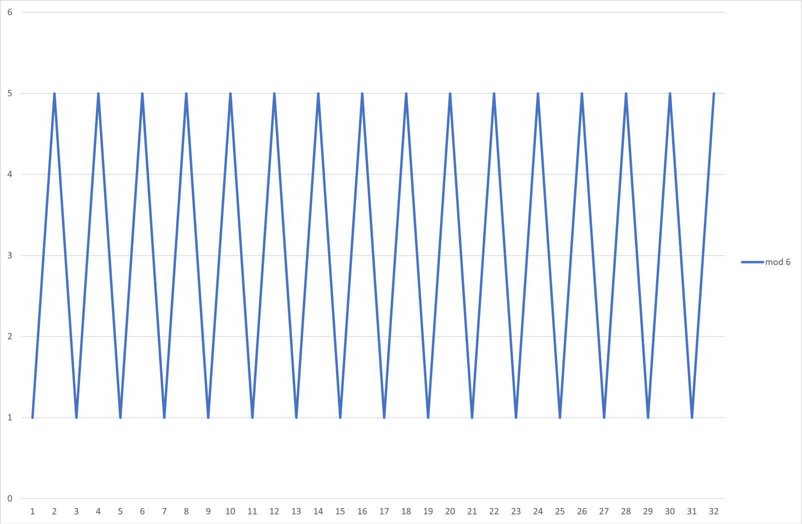

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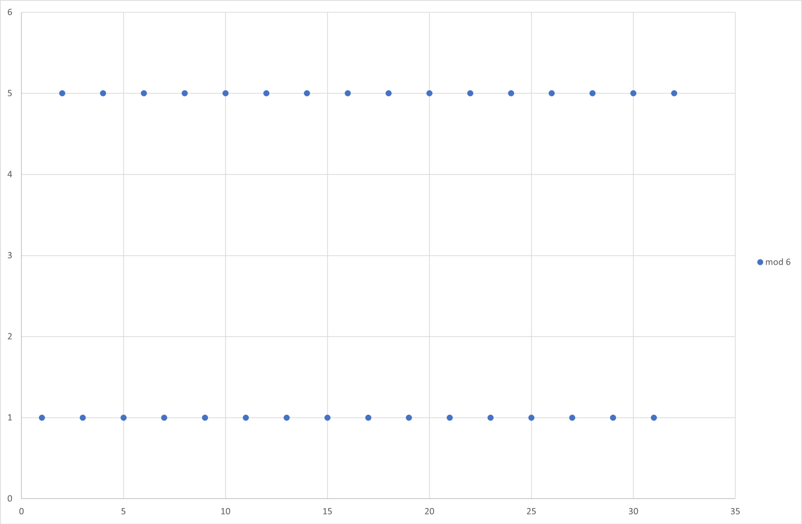

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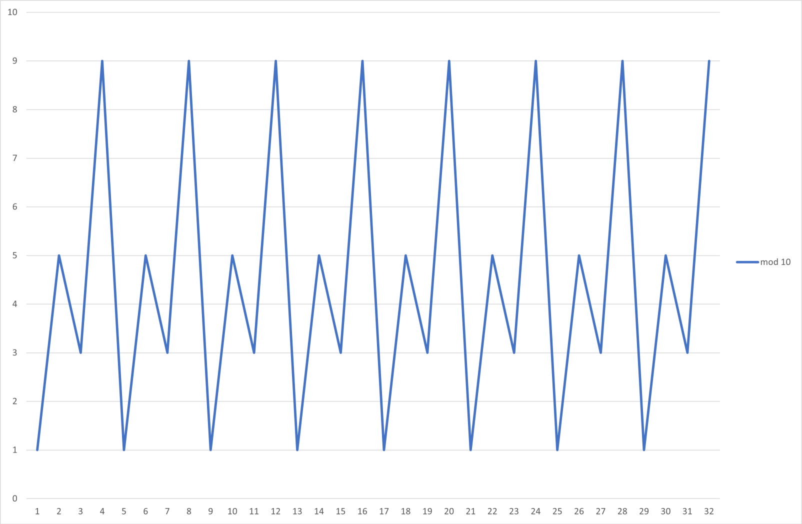

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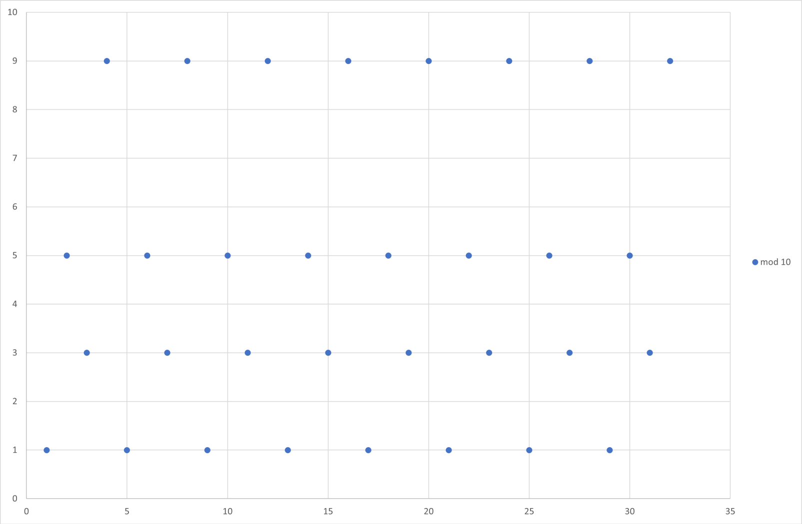

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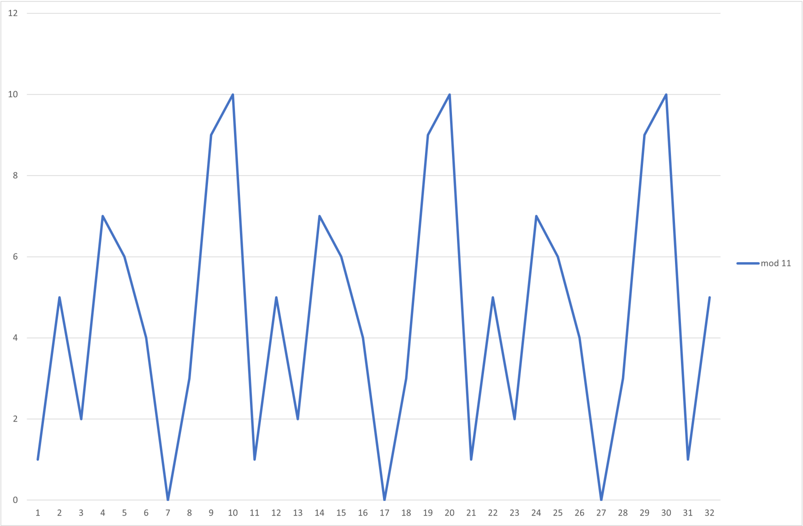

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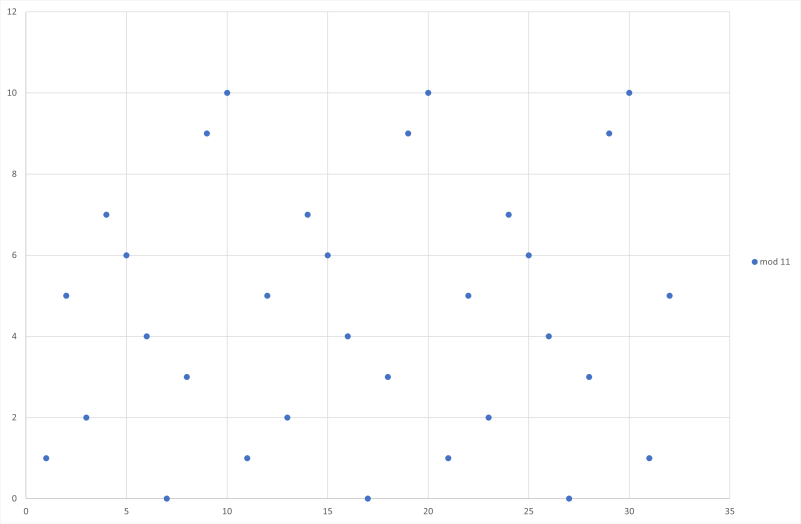

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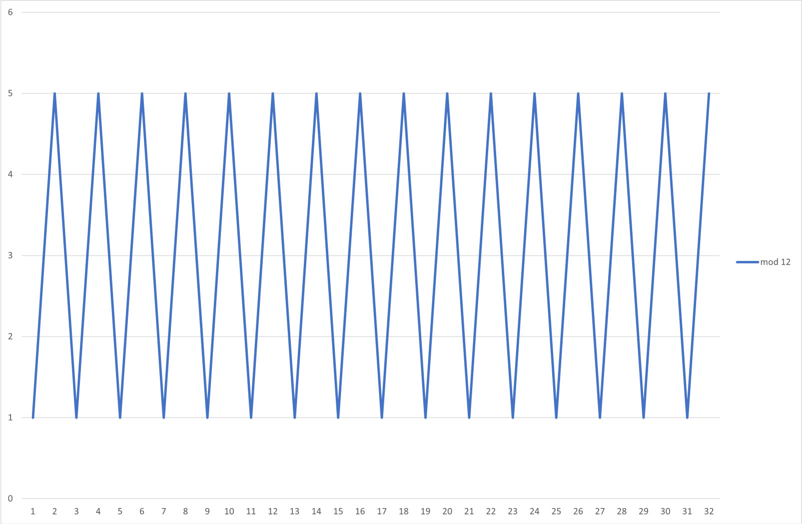

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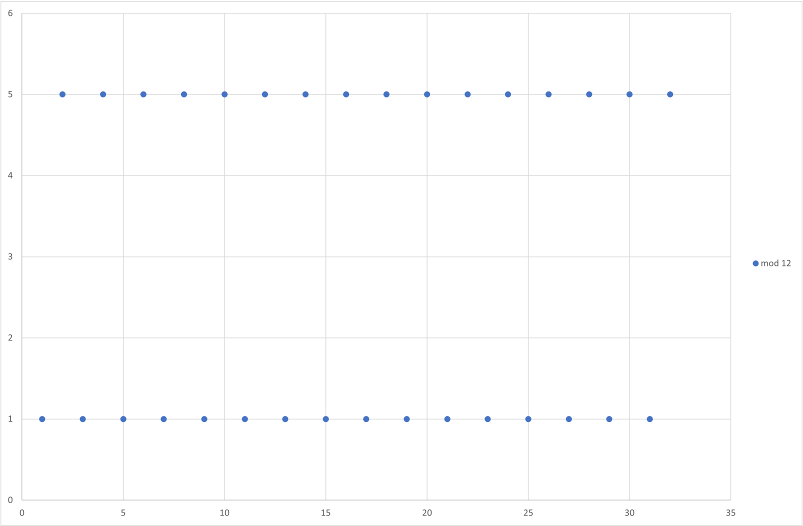

Linear Congruential Generator - LCG - Table

Source	modulus *m*	multiplier *a*	increment *c*	output bits of seed in *rand()* or *Random(L)*
ZX81	$2^{16} + 1$	75	74	
Numerical Recipes from the "quick and dirty generators" list, Chapter 7.1, Eq. 7.1.6 parameters from Knuth and H. W. Lewis	2^{32}	1664525	1013904223	
Borland C/C++	2^{32}	22695477	1	bits 30..16 in *rand()*, 30..0 in *lrand()*
glibc (used by GCC)[17]	2^{31}	1103515245	12345	bits 30..0
ANSI C: Watcom, Digital Mars, CodeWarrior, IBM VisualAge C/C++[18] C90, C99, C11: Suggestion in the ISO/IEC 9899,[19] C17	2^{31}	1103515245	12345	bits 30..16
Borland Delphi, Virtual Pascal	2^{32}	134775813	1	bits 63..32 of *(seed × L)*
Turbo Pascal	2^{32}	134775813 (8088405_{16})	1	
Microsoft Visual/Quick C/C++	2^{32}	214013 ($343FD_{16}$)	2531011 ($269EC3_{16}$)	bits 30..16
Microsoft Visual Basic (6 and earlier)[20]	2^{24}	1140671485 ($43FD43FD_{16}$)	12820163 ($C39EC3_{16}$)	
RtlUniform from Native API[21]	$2^{31} - 1$	2147483629 ($7FFFFFED_{16}$)	2147483587 ($7FFFFFC3_{16}$)	
Apple CarbonLib, C++11's `minstd_rand0`,[22] MATLAB's v4 legacy generator mcg16807[23]	$2^{31} - 1$	16807	0	see MINSTD
C++11's `minstd_rand`[22]	$2^{31} - 1$	48271	0	see MINSTD
MMIX by Donald Knuth	2^{64}	6364136223846793005	1442695040888963407	
Newlib	2^{64}	6364136223846793005	1	bits 62..32 (46..32 for 16-bit int)
Musl	2^{64}	6364136223846793005	1	bits 63..33
VMS's **MTH$RANDOM**,[24] old versions of glibc	2^{32}	69069 ($10DCD_{16}$)	1	

Figure: Parameters of LCGs in common use. Source: Wikipedia

Linear Congruential Generator - LCG - Graph

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$X_0 = 1, a = 16807, c = 0, m = 2^{31} - 1$

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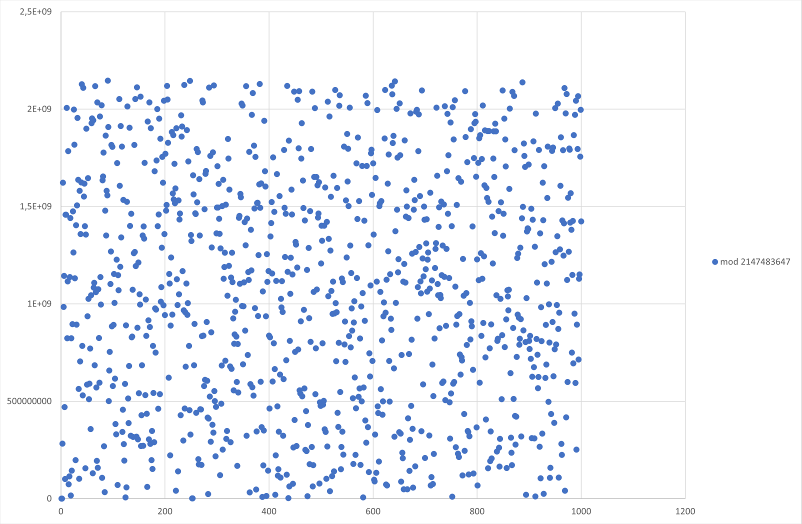

Secure Pseudo Random Number Generator

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- Satisfy the next-bit test

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- Withstand state compromise extension attacks

Secure Pseudo Random Number Generator

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Satisfy the next-bit test

That is, given the first k bits of a random sequence, there is no polynomial-time algorithm that can predict the $(k+1)th$ bit with probability of success non-negligibly better than 50%.

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Satisfy the next-bit test

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Withstand state compromise extension attacks

In the event that part or all of its state has been revealed (or guessed correctly), it should be impossible to reconstruct the stream of random numbers prior to the revelation. Additionally, if there is an entropy input while running, it should be infeasible to use knowledge of the input's state to predict future conditions of the CSPRNG state.

Differences

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- PRNG is only required to pass certain statistical test

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- PRNG is only required to pass certain statistical test
- CSPRNG must pass all statistical tests that are restricted to polynomial time in the size of the seed

Designs

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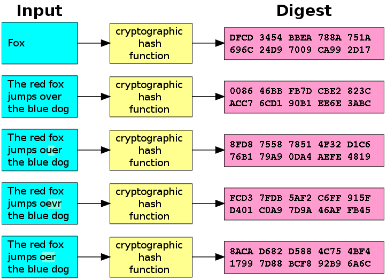

Figure: Hash encryption. Source: Wikipedia

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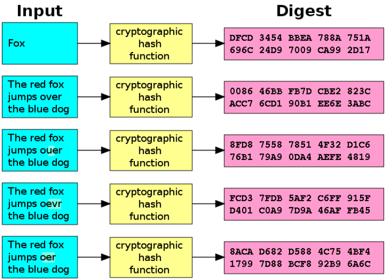

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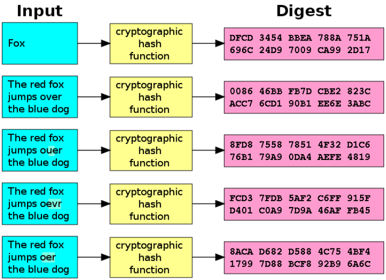

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- those based upon mathematical problems thought to be hard
- special-purpose designs

Standards

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- FIPS $186-4$

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- NIST SP $800 - 90A$

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- NIST SP $800-90A$
    - $Hash\_DRBG$

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- NIST SP $800-90A$
  - *Hash_DRBG*
  - *HMAC_DRBG*

Standards

- FIPS $186 - 4$
- NIST SP $800 - 90A$
  - *Hash_DRBG*
  - *HMAC_DRBG*
  - *CTR_DRBG*

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    - $Hash\_DRBG$
    - $HMAC\_DRBG$
    - CTR_DRBG
    - $Dual\_EC\_DRBG$

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- NIST SP $800-90A$ Rev.1

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- NIST SP $800-90A$ Rev.1
- ANSI $X9.17-1985$ Appendix C

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- NIST SP $800-90A$ Rev.1
- ANSI $X9.17-1985$ Appendix C
- ANSI $X9.31-1998$ Appendix A.2.4

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  - $Hash\_DRBG$
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- NIST SP $800 - 90A$ Rev.1
- ANSI $X9.17 - 1985$ Appendix C
- ANSI $X9.31 - 1998$ Appendix A.2.4
- ANSI $X9.62 - 1998$ Annex A.4, obsoleted by ANSI $X9.62 - 2005$, Annex D ($HMAC\_DRBG$)

Cryptographic PRNGs

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Some classes of CSPRNGs include

- stream ciphers

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- stream ciphers
- block ciphers running in counter or output feedback mode

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- special designs based on mathematical hardness

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Entropy collection

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Entropy collection

- keyboard clicks

Cryptographic PRNGs

Some classes of CSPRNGs include

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- block ciphers running in counter or output feedback mode
- combination PRNGs
- special designs based on mathematical hardness

Entropy collection

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- etc

Secure Random Generators (CSPRNG)

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Typically modern OS CSPRNG APIs combine the constantly collected entropy from the environment with the internal state of their built-in pseudo-random algorithm with continuous reseeding to guarantee maximal unpredictability of the generated randomness with high speed and non-blocking behavior in the same time.

Veracrypt encryption program

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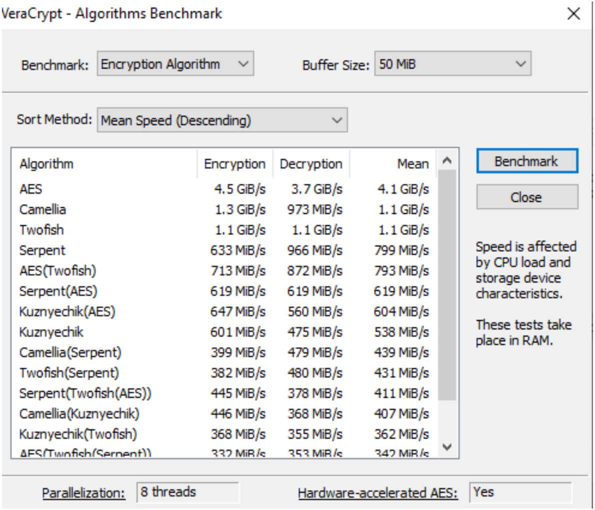
- Parallelization and pipelining allow data to be read and written as fast as if the drive was not encrypted.
- Encryption can be hardware-accelerated on modern processors.
- Provides plausible deniability, in case an adversary forces you to reveal the password: Hidden volume (steganography) and hidden operating system.

Veracrypt encryption random number generation



Algorithm	Encryption	Decryption	Mean
AES	4.5 GiB/s	3.7 GiB/s	4.1 GiB/s
Camellia	1.3 GiB/s	973 MiB/s	1.1 GiB/s
Twofish	1.1 GiB/s	1.1 GiB/s	1.1 GiB/s
Serpent	633 MiB/s	966 MiB/s	799 MiB/s
AES(Twofish)	713 MiB/s	872 MiB/s	793 MiB/s
Serpent(AES)	619 MiB/s	619 MiB/s	619 MiB/s
Kuznyechik(AES)	647 MiB/s	560 MiB/s	604 MiB/s
Kuznyechik	601 MiB/s	475 MiB/s	538 MiB/s
Camellia(Serpent)	399 MiB/s	479 MiB/s	439 MiB/s
Twofish(Serpent)	382 MiB/s	480 MiB/s	431 MiB/s
Serpent(Twofish(AES))	445 MiB/s	378 MiB/s	411 MiB/s
Camellia(Kuznyechik)	446 MiB/s	368 MiB/s	407 MiB/s
Kuznyechik(Twofish)	368 MiB/s	355 MiB/s	362 MiB/s
AES(Twofish(Serpent))	332 MiB/s	353 MiB/s	342 MiB/s

Figure: Benchmark algorithms

Veracrypt encryption random number generation

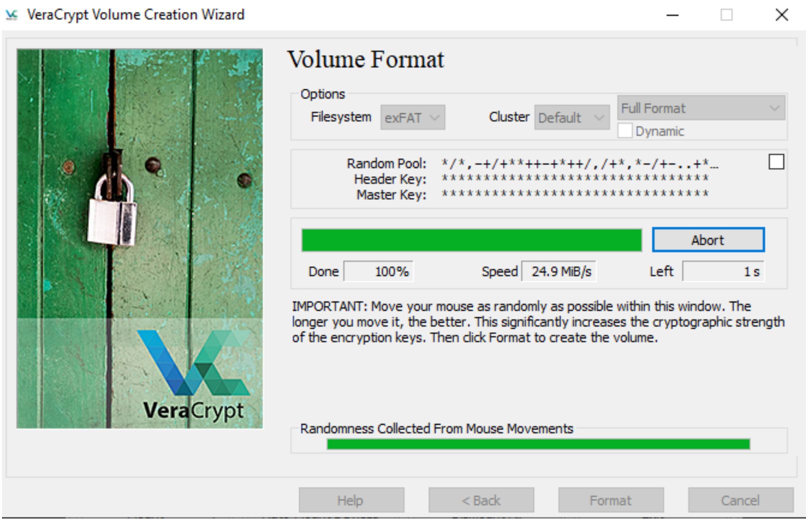


Figure: Random pool

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- Wikipedia
  - Cryptographically secure pseudorandom number generator
  - Pseudorandom number generator
  - Linear congruential generator

Thank you - QA

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