PV181 Laboratory of security and applied cryptography

Random values and Random Number Generators

Marek Sýs
sysox@mail.muni.cz, A405

CRoCS
Centre for Research on Cryptography and Security

You will learn

- What types of RNG you can find in libraries.
- What is entropy and why it is important.
- What RNGs are (in)apropriate for crypto.
- How to generate secure random values:
  - in *python, C*
- Why standard **rand()** and others (e.g. Mersenne Twister) are insecure.

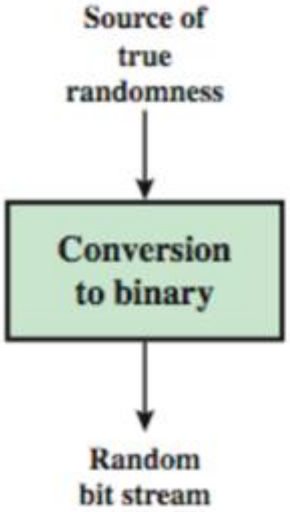
RNG types

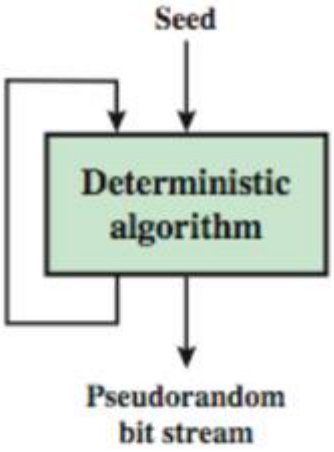
True random (TRNG)

- Source: physical device (noise) radio decay, thermal noise, …
- non-deterministic, aperiodic, **slow**

Pseudo random (PRNG)

- Source: software function
- **deterministic**, periodic, very fast





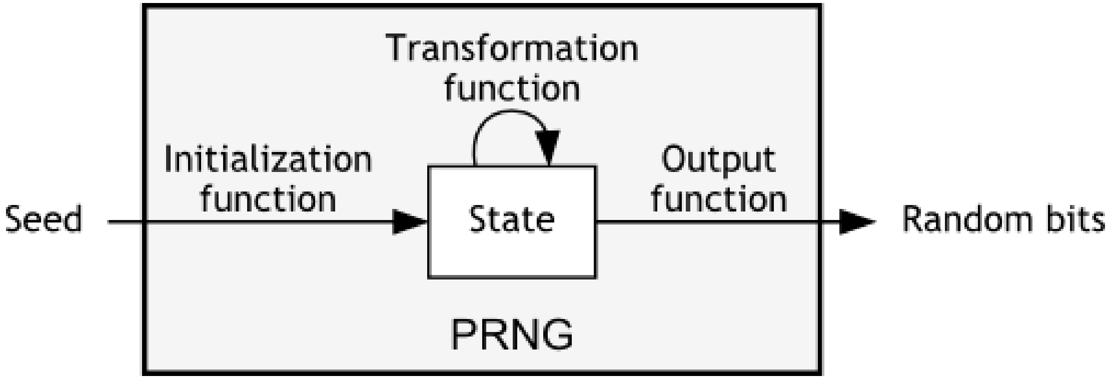
PRNG

defined by 3 functions: Init, Transform, Output

State = Init(Seed)

State = Trans(State)

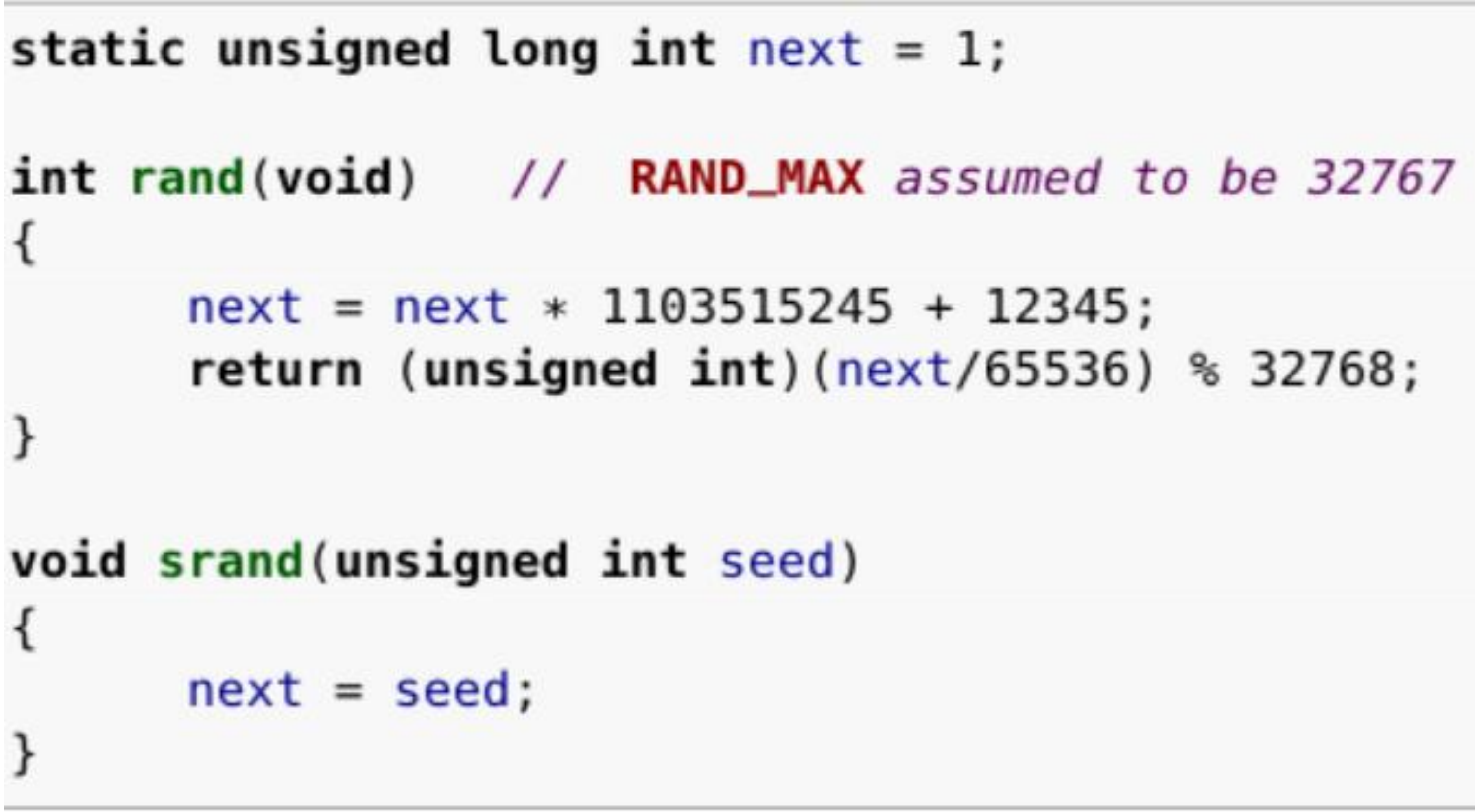
rnd = Out(State)



Cryptographically secure PRNG (CSPRNG)

- **generated data** leaks no information about **next** or **previous** values ⇒ no info about Seed, State

Example
ANSI C portable functions



```c
static unsigned long int next = 1;

int rand(void)   //  RAND_MAX assumed to be 32767
{
      next = next * 1103515245 + 12345;
      return (unsigned int)(next/65536) % 32768;
}

void srand(unsigned int seed)
{
      next = seed;
}
```

Standard library functions

ANSI C(rand), Java(java.util.random),...

- very fast but **very insecure** LCG generator

Linear Congruential Generator(LCG)

- $s_{n+1}=a*s_n+b$ mod m (fixed constants a,b,c)

rnd value = *State*

⇒ next rnd values easily computed

Trans is linear: *f(x) = ax+b mod m*

⇒ previous states (hence rnd values) computed

Weak generators

Python random() - Mersenne Twister

- seed can be reconstructed from generated values
  - see tool for gclib, mt, java, etc.

C rand(): LCG generators (+ some tweaks)

- glibc (used by GCC) rand() - LCG and “linear additive feedback” (r[i] = r[i-31] + r[i-3])

C++: LCG or MT or Lagged fibonacci

- minstd_rand(0 or 1), mt19937(_64)

Entropy

- measure of uncertainty
  - related to probability, attack complexity, unpredictability
- Examples:
  - 2 random bytes A,B
    - 16 bits of entropy = 2^16 possibilities for A,B
  - 2 random bytes A, B with additional information A XOR B = 0 (gained 8 bits of e.)
    - system A,B has 8 bits of e. = 2^8 possibilities
  - with additional information A > 128 (gained 1 bit)
    - system has only 7 bits of e = 2^7

Practice

CSPRNG:

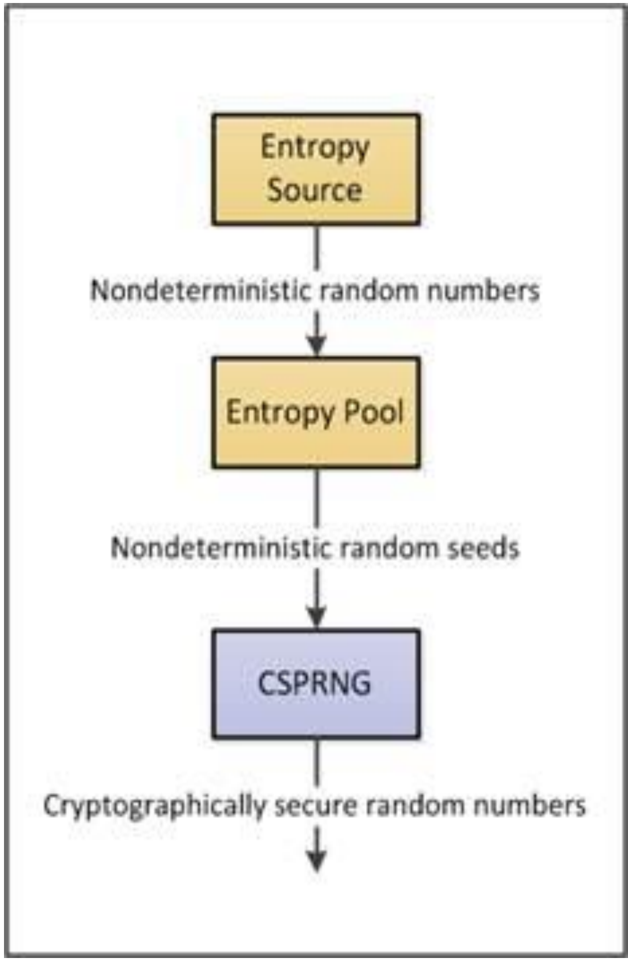
- seeded from entropy pool

Entropy pool:

- stores entropy
- usage decreases entropy in pool

TRNG (entropy source):

- repeatedly adds entropy to pool


Entropy Source
Nondeterministic random numbers
Entropy Pool
Nondeterministic random seeds
CSPRNG
Cryptographically secure random numbers

TRNG and pools

Linux: two entropy pools (files) *dev/(u)random*

- keyboard timings, mouse movements, IDE timings

Windows: similar to Linux

- binary register *HKEY_LOCAL_MACHINE\SYSTEM\RNG\Seed*

Additional entropy sources (if available):

- TPM, RNRAND instruction, hardware system clock (RTC), Interrupt timings, havege daemon, jitter RNG

Unix infrastructure

- pool of entropy - 2 files connected with the pool
  - pool saved at shut down!

- /dev/random
  - always produces some entropy but,
  - blocking - can block the caller until entropy available (entropy estimation)
- /dev/urandom
  - amount of entropy not guaranteed
  - always returns quickly (non blocking)

Operations

- open and read from the file to get entropy
  - use read(2) but always check if returned value == requested number of bytes (reading can be interrupted!!!)
- It is also possible to write to **/dev/random**
  - privileged (harmless) user can mix random data into the pool - entropy is increased (but not entropy counter)
- information about the pool in files
  - see content of proc/sys/kernel/random/*

Facts and recommendations

- Not all info on internet are true/reflects reality!
  - It is not necessary that dev/random blocks.
  - dev/random is more secure than dev/urandom (see Myths about dev/urandom)
- dev/(u)random accessing same pool
  - when pool initialized (entropy collected in the past) files provide same quality => use /dev/urandom
- things are dynamically changing – "All of these functions provide the **same bytes**. No difference in behavior *after initialization*." (Inside the kernel Linux, 13.09.22 ☺)

Unix: methods and quality

Good sources(C):

- **initialized** random/urandom
- getrandom() + flags:
  - source: random or urandom
  - blocking or non-blocking (also blocks until initialized)
- get_random_bytes() - kernel space
- similar in Python: os.urandom(), os.getrandom(), secrets.token_bytes()

Weak sources:

- rand, time(rdtsc instruction, clock func,...), uninitialized urandom

How to generate key

Good sources of entropy:

- initialized dev/urandom,
- CSPRNG seeded by dev/urandom,
- stream cipher with key generated by dev/urandom,

Implementation matters!

- seed should be protected (e.g. erased after usage)
- dev/urandom could be interrupted – always check number of obtained bytes
- use library functions to generate key – do not implement mechanism – many checks needed

Practice (python)

Working online:

1. Go to https://mybinder.org
2. Copy link https://github.com/sysox/PV181_RNG/ to Github field, press launch
3. Use PV181_RNG_python.ipynb with tasks
   - look into PV181_RNG_python_solution if necessary

Working locally:

- Copy code from cells of PV181_RNG_python.ipynb to your IDE

Practice C

Use Jupyter noteboos is just description of tasks – not as executable notebook you used in python!

Use **putty** and go to **aisa.fi.muni.cz**:

- xlogin + secondary password

For uploading files to aisa use **winscp** or **wget**

Linux RNG design

- 3 entropy pools (store random data)
  - can be viewed as PRNG - “Init” func **mixes** (using ChaCha20) input rnd data to the state ⇒ state depends input data and **all** previous states!!
- input_pool (state of 4096 bits)
  - accumulate (collects, compress) the entropy from hardware events to the state
  - feeds exclusively (no access to this pool)
    - – blocking_pool (state of 1024 bytes)
    - – non-blocking_pool (ChaCha20 stream cipher)
      - only key (256) is fed by true rnd values
    - – state (“seed” for other pools) is saved at shutdown

See Gauvrit’s blog with nice scheme