Random Number Generation

CMSC 426 - Computer Security

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Outline

- Properties of PRNGs
- LCGs
- NIST SP 800-90A
- Blum, Blum, Shub

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Random Number Uses

- Generation of symmetric keys
- Generation of primes (p and q) for RSA
- Generation of secret keys for Diffie-Hellman
- Nonces for cryptographic protocols

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The "P" in "PRNG"

- Don't typically have access to a true random number generator (RNG).
- RNGs require some source of random noise, i.e. special hardware.
- Instead, use an algorithm that produces numbers that appear random - a **Pseudo-Random Number Generator** or **PRNG**.
- NIST documents also refer to a PRNG as a Deterministic Random Bit Generator (DRBG).

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PRNG Requirements

- **Statistical Properties.** What does it mean to "appear random?"
    - Output of the PRNG should be *uniformly distributed*.
    - Outputs should appear *independent*. Can not infer a value from a previous or future value.
- **Unpredictability**. For cryptography, the statistics don't matter so much as that the values be unpredictable.

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A simple PRNG

- The **Linear Congruential Generator** (LCG) is perhaps the most commonly used PRNG.
- Given constants a, c, and m and an initial seed X_0, generate numbers according to the formula

$$X_{n+1} = (a\,X_n + c) \bmod m$$

- The selection of the constants is important.

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LCG Examples

- Example: $a = c = 1$.
- Example: $a = 7$, $c = 0$, $m = 32$, $X_0 = 1$.
- Example: $a = 5$, $c = 0$, $m = 32$, $X_0 = 1$.

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Good LCGs?

- What would make an LCG good?
    1. Full-period generating — generates all values $0 < X < m$.
    2. Should appear random as determined by a battery of statistical tests.
    3. Efficient on current architectures (64 bit).

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LCG Parameters

- If n is a power of two, choose a, c such that
  1. c is relatively prime to n (so c is odd).
  2. a - 1 is divisible by 4.

  Hull & Dobell, *Random Number Generators*, SIAM Review, Vol. 4, No. 3 (July 1962), pp. 230 - 254.

- Some examples from Wikipedia:

	n	a	c
glibc	2^{31}	1103515245	12345
MS Quick C	2^{32}	214013	2531011

LCGs are Weak

- Unfortunately, LCGs are not appropriate for cryptography.
- **Example:** n = 256, a = 3, c = 7. We can recover the values n, a, and c just by observing X_i.
- Python uses a PRNG called a *Mersenne Twister*, which is better than an LCG, but still not good enough for cryptography.

NIST SP 800-90A

- PRNG based on AES in CTR mode which *is* suitable for cryptographic applications.
- Note: NIST uses the term *Deterministic Random Bit Generator* (DRBG) rather than PRNG.
- The algorithm consists of separate *Initialization* and *Generation* phases.
- We'll see a simplified version of the standard using AES-128…

Initialization

- The following steps initialize the PRNG:
  1. Obtain 256 bits of random "seed" data; the first 128 bits will be denoted (K_0), and the remaining 128 bits will be denoted (V_0).
  2. Initialize V and K to zero.
  3. Update $V \leftarrow V + 1 \bmod 2^{128}$.
  4. Encrypt V with key K; save the output K'.
  5. Update $V \leftarrow V + 1 \bmod 2^{128}$.
  6. Encrypt V with key K; save the output V'.
  7. Set $K = K_0 \oplus K'$ and $V = V_0 \oplus V'$.

Generation

- Generation of *n* blocks of pseudo-random data:
  1. Update $V \leftarrow V + 1 \bmod 2^{128}$.
     Encrypt *V* with key *K*; save output as *X*.
  2. Update *Output* ← *Concatenate(Output, X)*.
  3. Repeat steps 1 - 3 a total of *n* times.
  4. Return *Output*.
- After generation, *V* and *K* are updated using steps 3 - 7 of the Initialization.
- A counter tracks the total number of pseudo-random bits produced; after some threshold, the PRNG must be re-initialized.

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Testing

- SP 800-90A states that *known answer testing* “shall” be performed for various sub-functions in implementations of the PRNG.
- *Known answer testing* is just running the algorithm with inputs and outputs specified in the standard.
- Implementation requires patience, attention to detail, and extensive testing — it is preferable to use an existing, validated implementation than to write your own.

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Blum, Blum, Shub

- We’ve seen a simple PRNG that isn’t suitable for cryptography (LCG) and a complicated generator that is (SP 800-90A).
- The Blum, Blum, Shub (BBS) generator is simple and secure — but has its own limitations.
- BBS is provably secure if used correctly; its security is based on the difficulty of factoring.

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BBS Parameters

- Construct a composite modulus $M = p \cdot q$ with the following properties:
  - *p* and *q* are primes of “cryptographic size” (at least 512 bits each)
  - *p* and *q* are both congruent to 3 mod 4.
- Generate a *seed* x_0, a random positive integer less than *M* and relatively prime to *M*.

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BBS Generation

- The state of the generator is updated according to the rule:

$$x_{i+1} = x_i^2 \bmod M.$$

- From each x_i, extract the low-order bit. That is, the pseudo-random sequence is:

$$b_i = x_i \bmod 2,\ i = 1, 2, 3, \ldots$$

- **Example:** $p = 7$, $q = 11$, $x_0 = 17$.

Security and Efficiency

- Given a sequence of b_i values, it is "difficult" to recover a state x_j (future or past).
- The difficulty is proven to be equivalent to a hard mathematical problem, which is in turn is believed to be equivalent to factoring M.
- **So what is the downside?** Efficiency. We are computing one modular exponentiation for *each bit* of pseudo-random output.

Which PRNG to use?

- For *non-cryptographic* applications, such as simulations, an LCG is usually sufficient.
- For *large volumes of pseudo-random bits*, a PRNG from SP 800-90A will be secure and efficient.
- For *small volumes of critical pseudo-random bits*, BBS would be a reasonable choice.

There are many other PRNGS: this is just a sample!

Next time: Cryptography Lab