The automated testing of randomness with multiple statistical batteries

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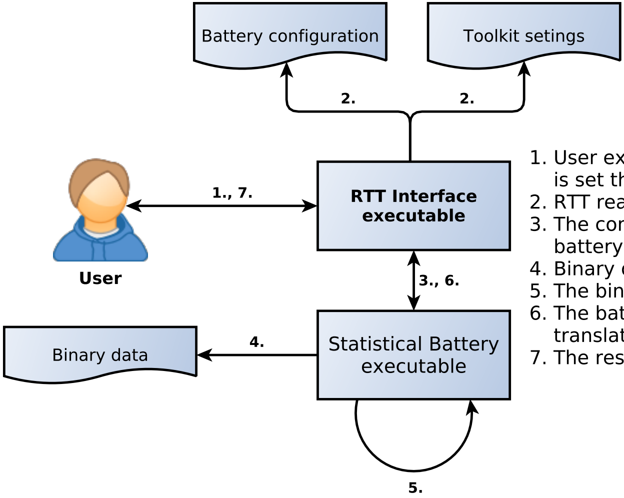
Thesis structure

- Creation of a unified interface supporting multiple statistical batteries.
    - NIST Statistical Testing Suite
    - Dieharder
    - TestU01
- Conducting the baseline (control) experiment to create a reference point for the further experiments.
- Evaluating randomness of outputs of well-known cryptographic primitives.
- Analysing validity of the Dieharder battery results.

Randomness Testing Toolkit – overview

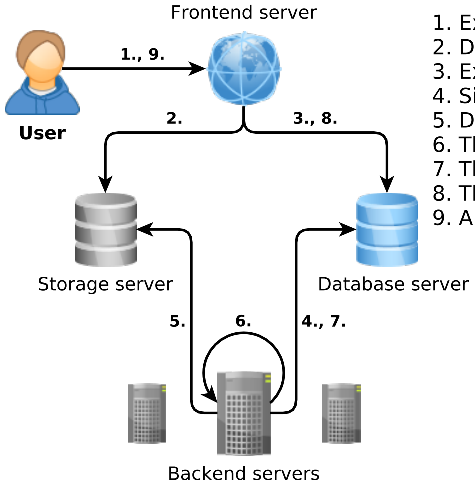
- Design and implementation of a tool for consistent randomness evaluation.
- Intended to be used by users without prior knowledge about statistical testing as well as by researchers in CRoCS.
- The developed tool (RTT) acts as an interface between the user and the statistical batteries – common format of the battery settings and results.
- The toolkit supports multiple statistical batteries – NIST STS, Dieharder, and TestU01; it is possible to add more batteries over time.
- Both standalone program and online service were developed.

Randomness Testing Toolkit – local interface



1. User executes the binary, basic configuration is set through command-line arguments.
2. RTT reads advanced settings in common format
3. The common settings are translated into battery-specific settings.
4. Binary data is read from file supplied to battery.
5. The binary stream is analysed.
6. The battery-specific results are gathered and translated into unified format by RTT.
7. The results are stored for user to inspect.

Randomness Testing Toolkit – web service



1. Experiment and data are submitted.
2. Data is uploaded.
3. Experiment and related jobs are created.
4. Single pending job is selected.
5. Data is downloaded.
6. The data is analyzed.
7. The results of the analysis are stored.
8. The results in the database are presented.
9. Analysis of the data is inspected.

Statistical testing of randomness – 1/2

Testing hypothesis – H_0
During the experiments, we evaluated the hypothesis that the analysed data were produced by a truly random generator. We denote the hypothesis as H_0 (null hypothesis).

Statistical battery
Software with the purpose of detecting biases in data stream; collection of statistical tests.

Statistical test
A single unit in a statistical battery checking some property of the data (e.g. count of ones). Output of a test is the probability that the analysed data were produced by TRNG. Each test in a given battery will either fail (H_0 rejection) or pass (H_0 retainment).

Statistical testing of randomness – 2/2

Significance level – α

The significance level is set prior to the experiments (usually 0.001) and based on it, the null hypothesis is rejected or retained.

False positive (Type I error)

The false positive result is observed when H_0 holds true, but it is rejected – stream produced by TRNG is evaluated as non-random. The probability of Type I error is α.

False negative (Type II error)

The false negative result is observed when H_0 is false, but it is not rejected – stream generated by biased generator is evaluated as random.

Establishing baseline results

- The result of a battery is obtained from the proportion of the failed tests in the battery (e.g. we consider the data biased if more than 2 out of 15 tests fail). However, even data generated by a perfect TRNG may fail some tests (false positives).
- To identify the maximum count of failed tests (assuming that the H_0 holds) we processed 8 TB of data generated by a quantum random generator (control experiment). Further experiments were interpreted based on these results.
- To make the result interpretation more straightforward, results of certain tests were grouped together. As a consequence, the counts of failed tests are closer to expected (theoretical) numbers and therefore more easy to evaluate.

Analysis of well-known algoritms – 1/2

Goal: Evaluate randomness of the outputs of round-reduced cryptographic primitives and observe their security margins.

- We analysed 15 algorithms in multiple configurations. In total, more than 80 data streams were processed. The algorithms were chosen based on their popularity (AES, DES, RC4, ...) or their success in crypto competitions eSTREAM and SHA3 (Rabbit, Keccak, Grøstl, ...).
- The interpretation of the results was based on the baseline obtained in the previous experiment.
- The results were compared to another randomness analysis approach developed in CRoCS (EACirc).

Analysis of well-known algoritms – 2/2

Experiment results

- **Comparison to EACirc:** The batteries supported by RTT perform as equally well or better than EACirc. This can be caused by many reasons, namely by data consumption (EACirc requires a lesser amount of data) or internal data representation.
- **Security margins:** Majority of the analysed algorithms had the security margins higher than 80%. Even with a considerable increase in the performance of the statistical tools, the biases in full versions of the algorithms would go undetected.
- **Biased outputs of full algorithms:** Statistical bias was detected in the outputs of the ciphers RC4 and Rabbit (winner of the eSTREAM competition). Compared to already published distinguishers our approach is easy and automated, but we assume zero IV and structured input data.

Analysis of the results of Dieharder battery – 1/2

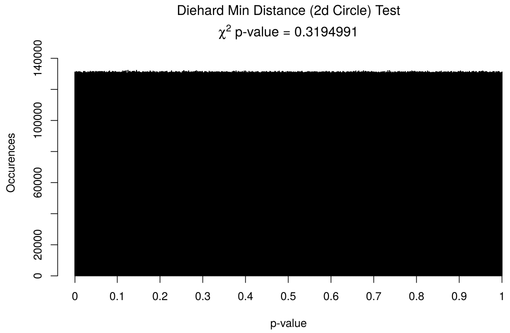
Goal: Verifying uniformity of partial results of Dieharder battery.

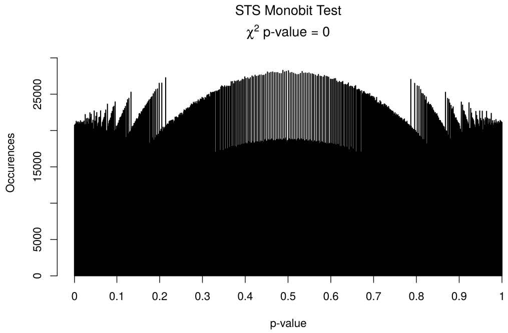
- Partial results of the battery are expected to be uniformly distributed on the interval $(0, 1]$ during random data analysis; the assumption of uniformity is used to further process the battery results.
- To verify this hypothesis, 8 TB of random data were processed by each test (110 tests in total). More than a billion of partial results was extracted and analysed.

Experiment results

- Out of 110 partial result sets, we found that 39 sets were not uniformly distributed.
- The broken assumption can cause wrong result interpretation.
- Further implications of the non-uniformity are a part of ongoing research.

Analysis of the results of Dieharder battery – 2/2

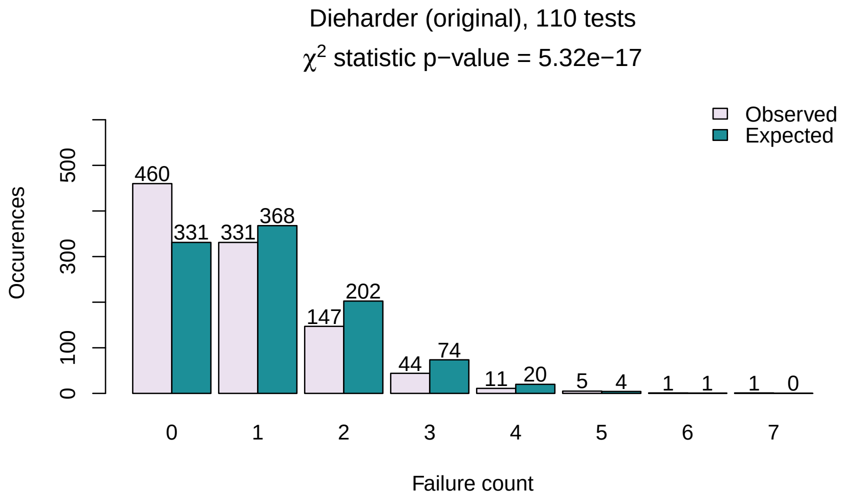




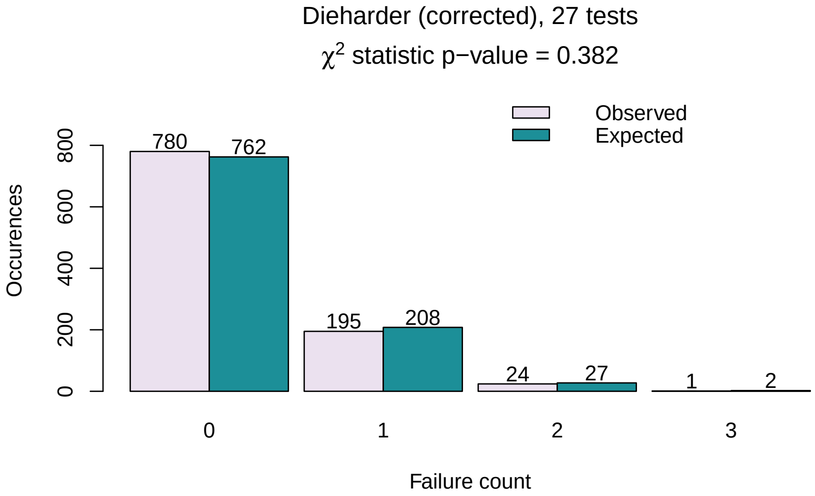
References

- **Randomness Testing Toolkit**
  https://github.com/crocs-muni/randomness-testing-toolkit
- **EACirc**
  https://github.com/crocs-muni/eacirc
- **NIST Statistical testing suite**
  http://csrc.nist.gov/groups/ST/toolkit/rng/documentation_software.html
- **Dieharder**
  http://www.phy.duke.edu/~rgb/General/dieharder.php
- **TestU01**
  http://simul.iro.umontreal.ca/testu01/tu01.html

Baseline experiment – uncorrected results



Baseline experiment – corrected results



Baseline experiment – reference failure counts

	Closeness to expected results		
Battery name	Uncorrected	Uncorrected	**Allowed failures**
Dieharder	$5.32 \cdot 10^{-17}$	0.38	$3/27$
NIST STS	$2.17 \cdot 10^{-2}$	$4.44 \cdot 10^{-7}$	$2/15$
TU01 Small Crush	0.71	0.95	$2/10$
TU01 Crush	$3.36 \cdot 10^{-11}$	$3.31 \cdot 10^{-3}$	$3/32$
TU01 Rabbit	$2.02 \cdot 10^{-5}$	$1.45 \cdot 10^{-23}$	$2/16$
TU01 Alphabit	$2.14 \cdot 10^{-8}$	$2.8 \cdot 10^{-7}$	$1/4$
TU01 Block Alphabit	$1.87 \cdot 10^{-68}$	$5.15 \cdot 10^{-47}$	$1/4$

Analysis of well-known algorithms – results

	Top biased round			
Algorithm	RTT	EACirc	**Total rounds**	**Security margin**
AES	3	3	10	7 rounds (70%)
BLAKE	1	1	16	15 rounds (94%)
Grain	6	2	13	7 rounds (54%)
Grøstl	2	2	14	12 rounds (86%)
JH	6	6	42	36 rounds (86%)
Keccak	3	2	24	21 rounds (88%)
MD6	10	8	104	94 rounds (90%)
Rabbit	4	0	4	0 rounds (0%)
RC4	–	–	–	0 rounds (0%)
Salsa20	2	2	20	18 rounds (90%)
Single DES	5	4	16	11 rounds (69%)
Skein	4	3	72	68 rounds (94%)
SOSEMANUK	4	4	25	21 rounds (84%)
TEA	5	4	32	27 rounds (84%)
Triple DES	3	2	16	13 rounds (81%)