# Quantum Random Number Generator for One Time Password Generation

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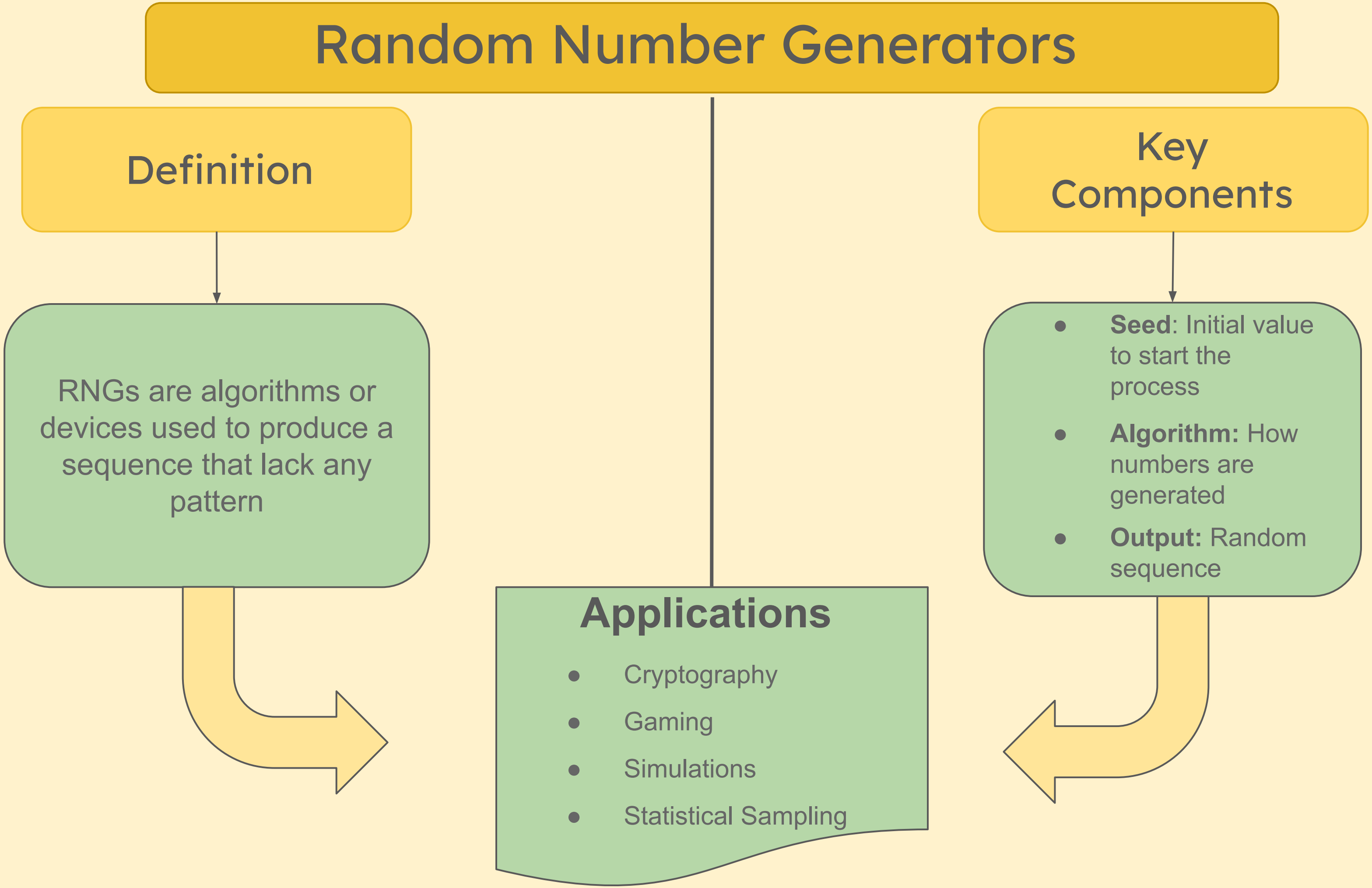
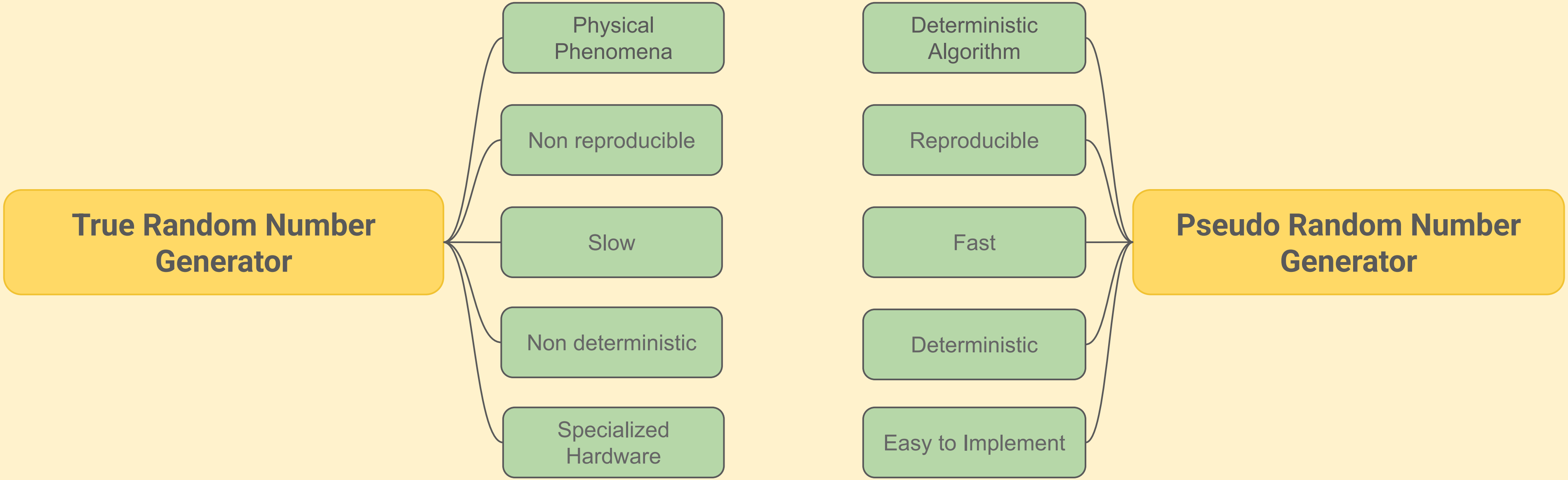

Random Number Generators
Definition
RNGs are algorithms or devices used to produce a sequence that lack any pattern
Key Components
Seed: Initial value to start the process
Algorithm: How numbers are generated
Output: Random sequence
Applications
Cryptography
Gaming
Simulations
Statistical Sampling

# TRNG vs PRNG


True Random Number Generator
Physical Phenomena
Non reproducible
Slow
Non deterministic
Specialized Hardware
Pseudo Random Number Generator
Deterministic Algorithm
Reproducible
Fast
Deterministic
Easy to Implement

# Quantum Random Number Generator

Quantum Mechanics

↓

Superposition

↓

$$|\psi\rangle = \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle$$

↓

$|0\rangle \xleftarrow{50\%}$ Measurement $\xrightarrow{50\%} |1\rangle$

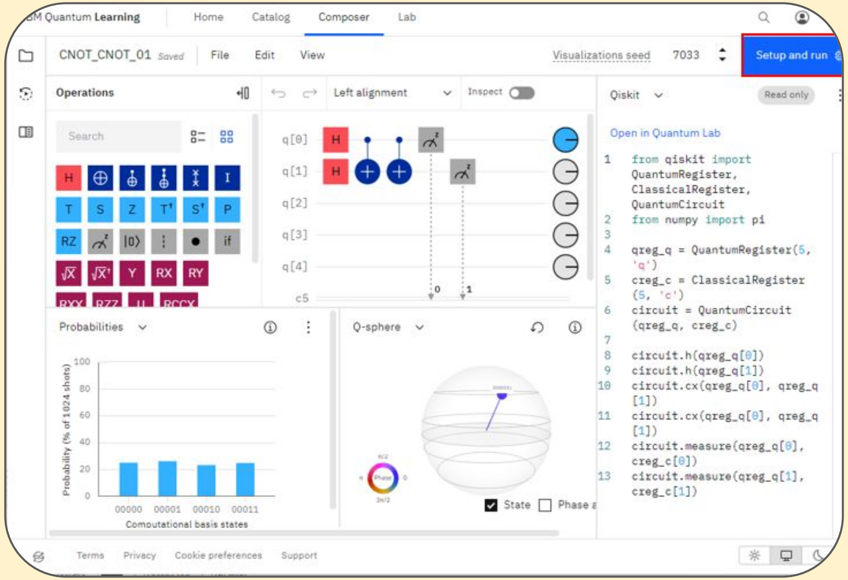
True Random Number Generator!

# Fundamental Tools for Quantum

IBM Quantum Platform → Access to a real Quantum computer

IBM Quantum Platform → Circuit simulation

Qiskit → Python framework for quantum computing simulation

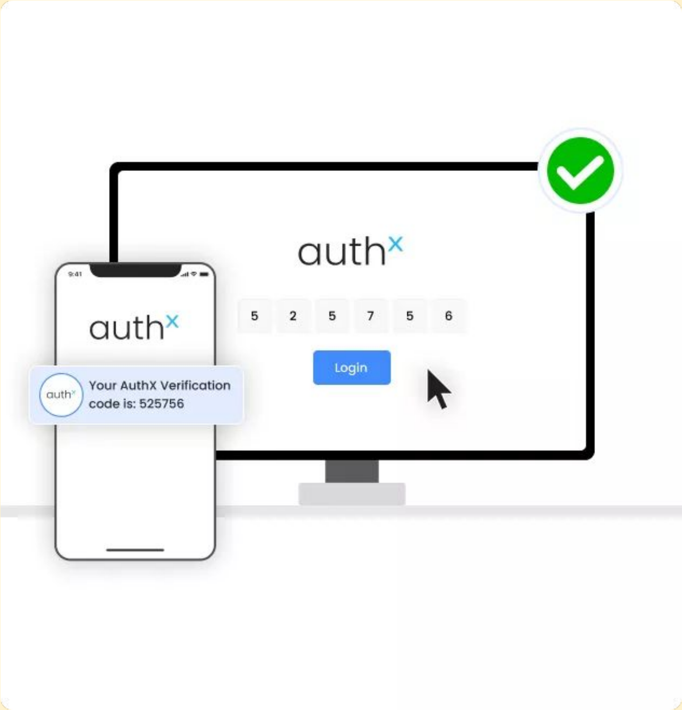


# One-time Passwords

A **One-Time Password (OTP)** is a code valid for only one login session or transaction. Unlike static passwords, OTPs are dynamic and expire after use or after a short time period.

- Single Use
- Time/event based
- Flexibility in delivery methods,using a different channel

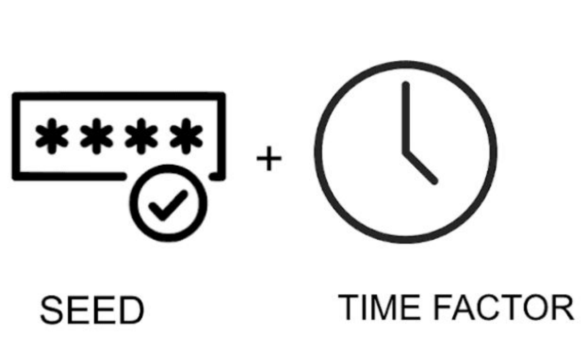
The main purpose of OTP is strengthen authentication by adding a unique, temporary code that can only be used once



# Types of OTP

Event-based OTP (HOTP) generates a new code each time a specific action or event occurs, such as a button press or login attempt.

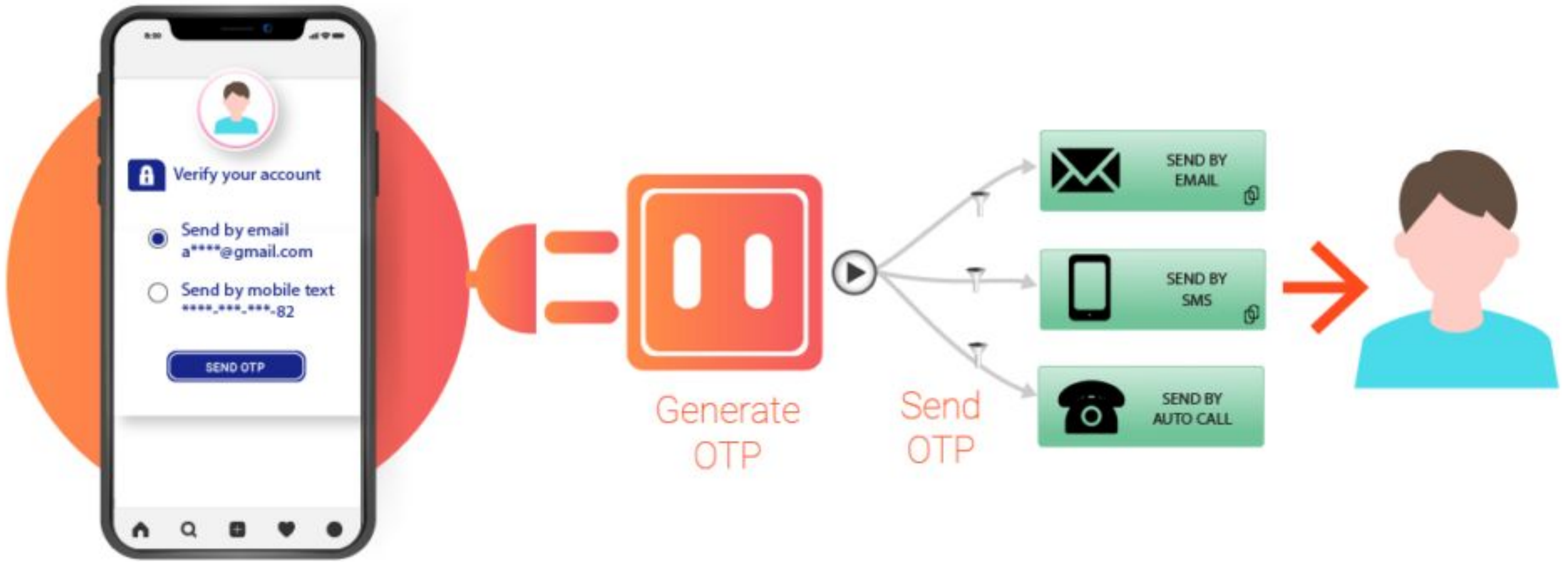
1. **Hardware token devices** used in corporate environments for secure login.
2. **Banking systems** requiring OTP generation for each transaction or login.
3. **Smart card authentication** where codes are generated on demand.


Time-based OTP generates new codes valid for a fixed time interval depending on the application

1. **Two-Factor Authentication (2FA)** apps like Google Authenticator or Authy.
2. **Cloud services login**, e.g., Gmail, AWS, or GitHub with time-sensitive codes.
3. **Mobile banking apps**

# Out of band



Verify your account
Send by email
a****@gmail.com
Send by mobile text
****-***-***-82
SEND OTP
Generate OTP
Send OTP
SEND BY EMAIL
SEND BY SMS
SEND BY AUTO CALL

# Seed

OTP verification & drift detection

656843

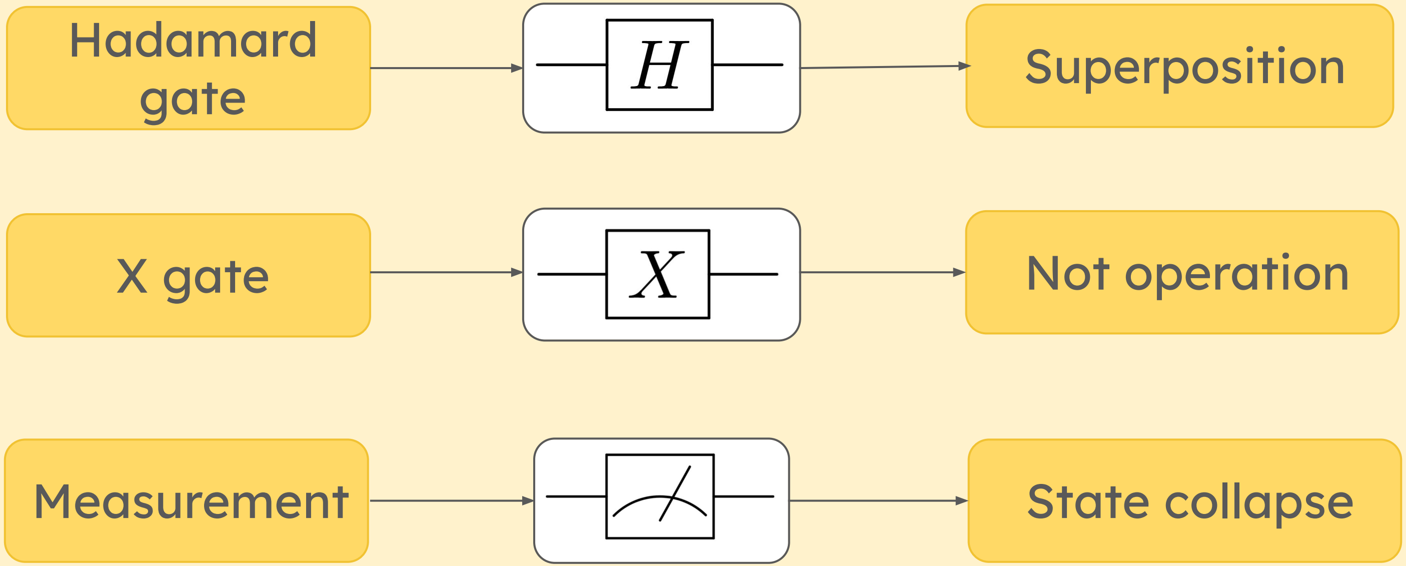
06

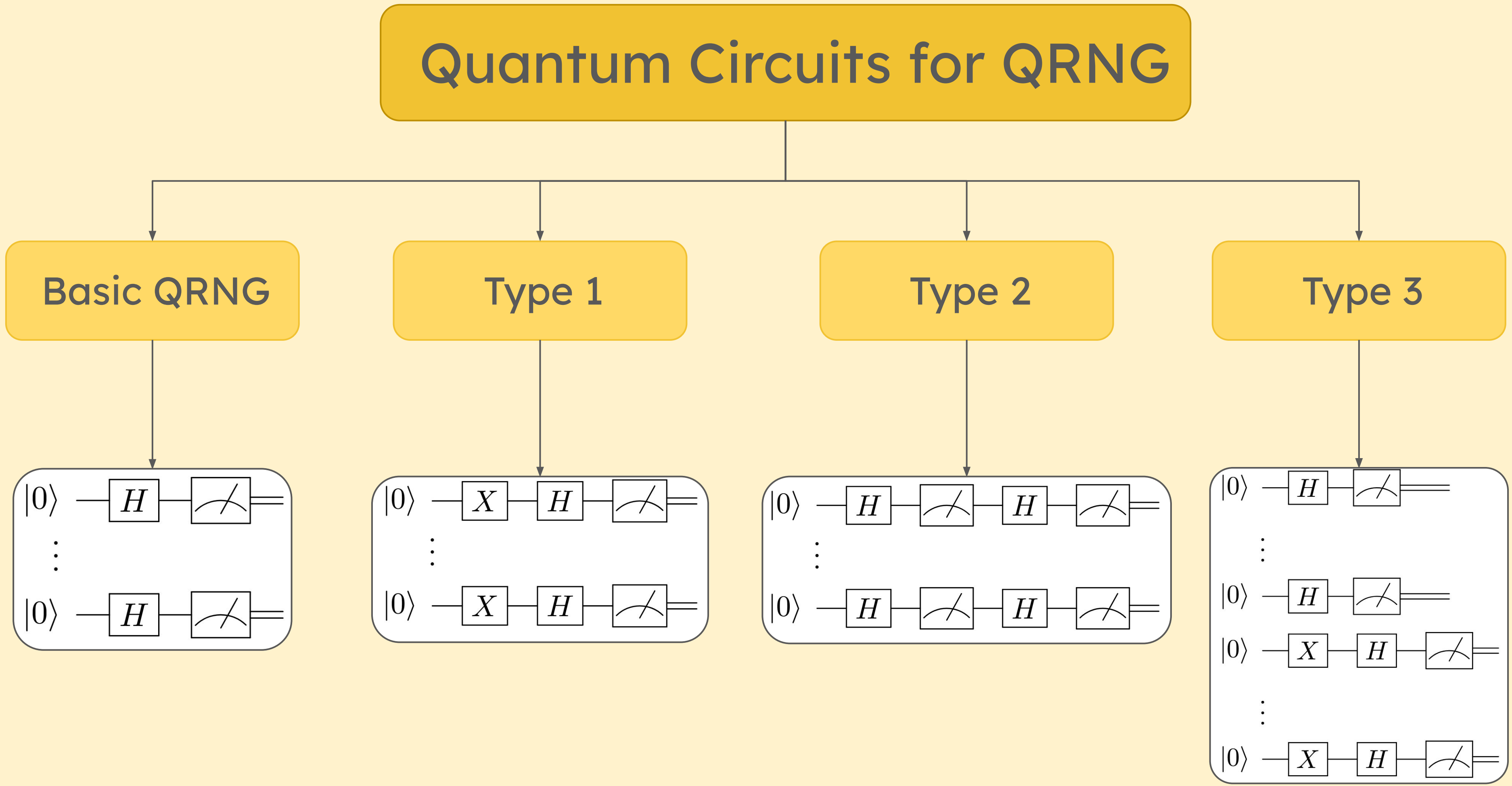
*skew ±*

4

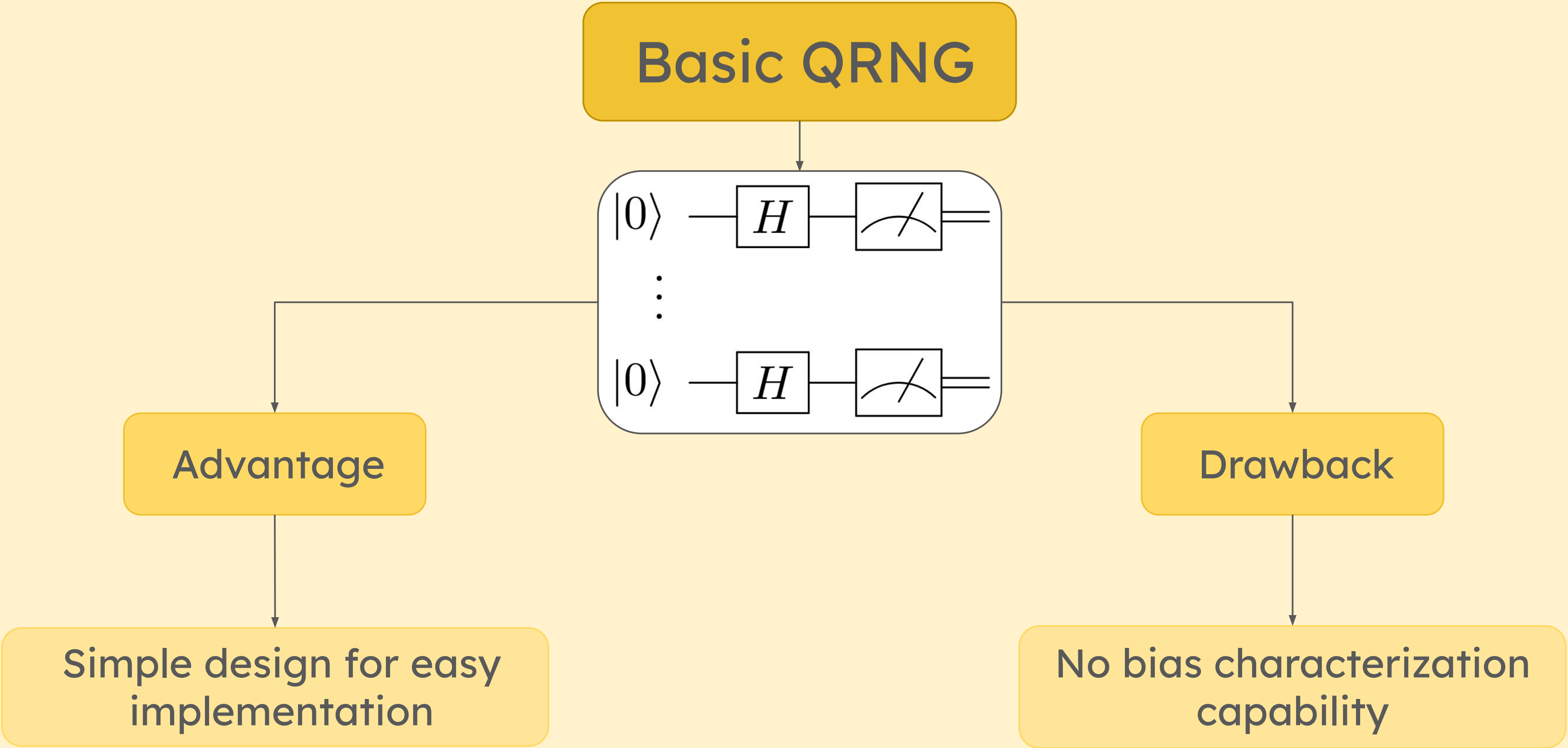
| Skew | OTP |
|---|---|
| -120 sec. | 110094 |
| -90 sec. | 045519 |
| -60 sec. | 244073 |
| -30 sec. | 346095 |
| **0 sec.** | **▸ 656843 ◂** |
| 30 sec. | 183023 |
| 60 sec. | 370820 |
| 90 sec. | 647587 |
| 120 sec. | 683708 |

# Quantum Gates

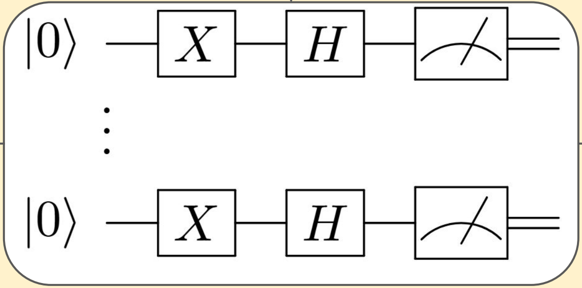




Quantum Circuits for QRNG
Basic QRNG
Type 1
Type 2
Type 3
|0⟩ H
|0⟩ X H


Basic QRNG
|0⟩
H
|0⟩
H
Advantage
Simple design for easy implementation
Drawback
No bias characterization capability

# Type 1 QRNG



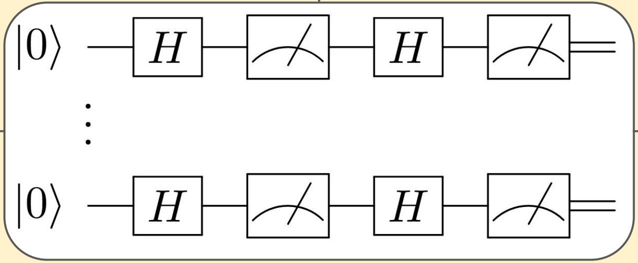

## Advantage

It explores how bit-flip symmetry affects the output distribution

## Drawback

Additional gate introduces further potential sources of error

# Type 2 QRNG




**Advantage**

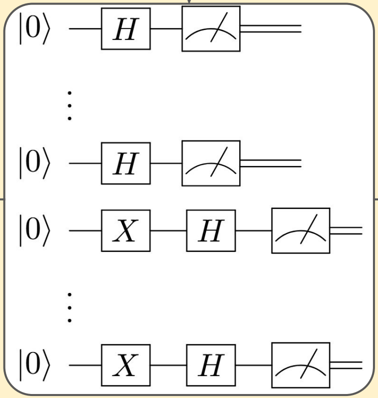
Evaluates gate-measurement correlation

**Drawback**

Extremely sensitive to decoherence and measurement-induced errors

CHOSEN FOR THE EXPERIMENT!

# Type 3 QRNG

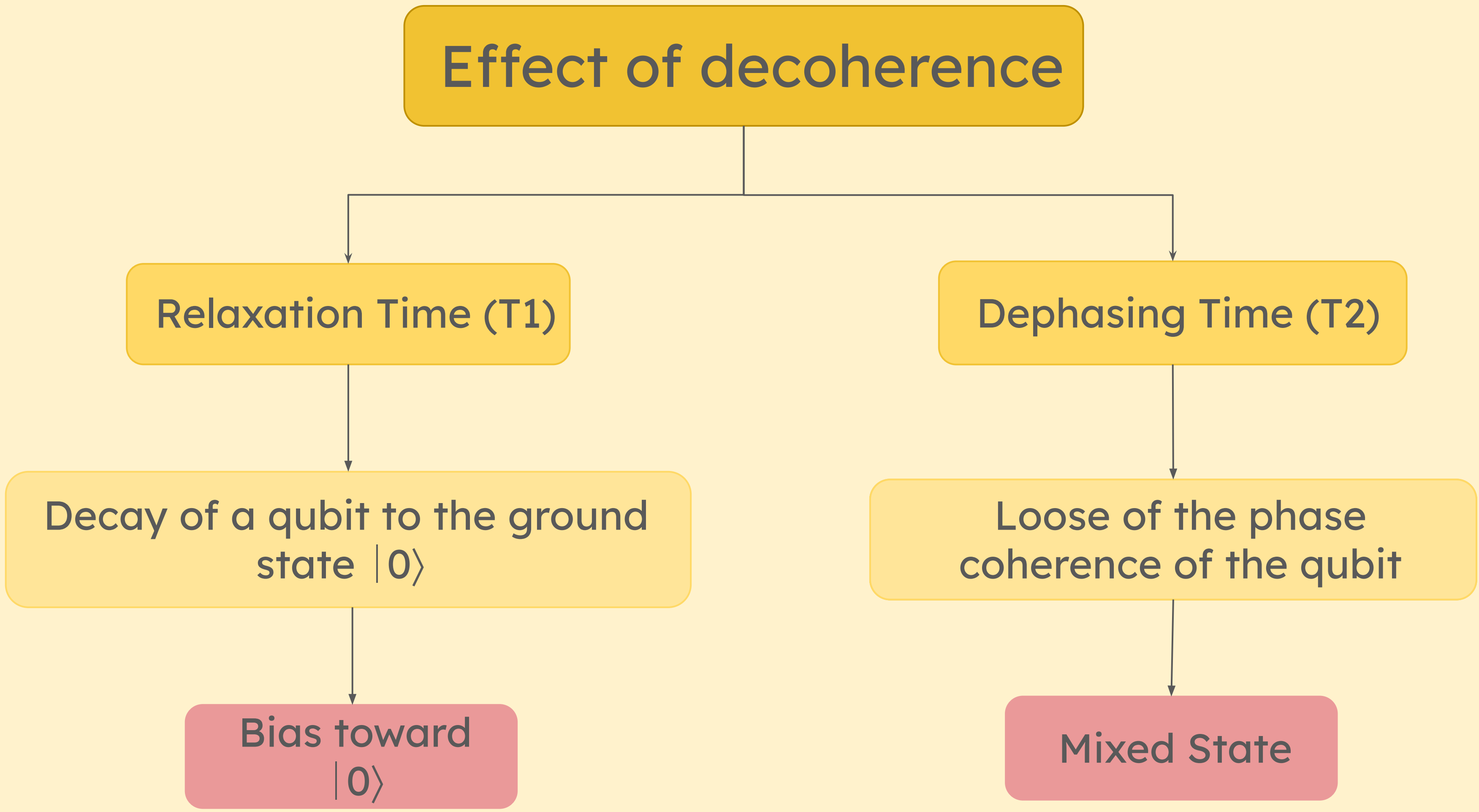


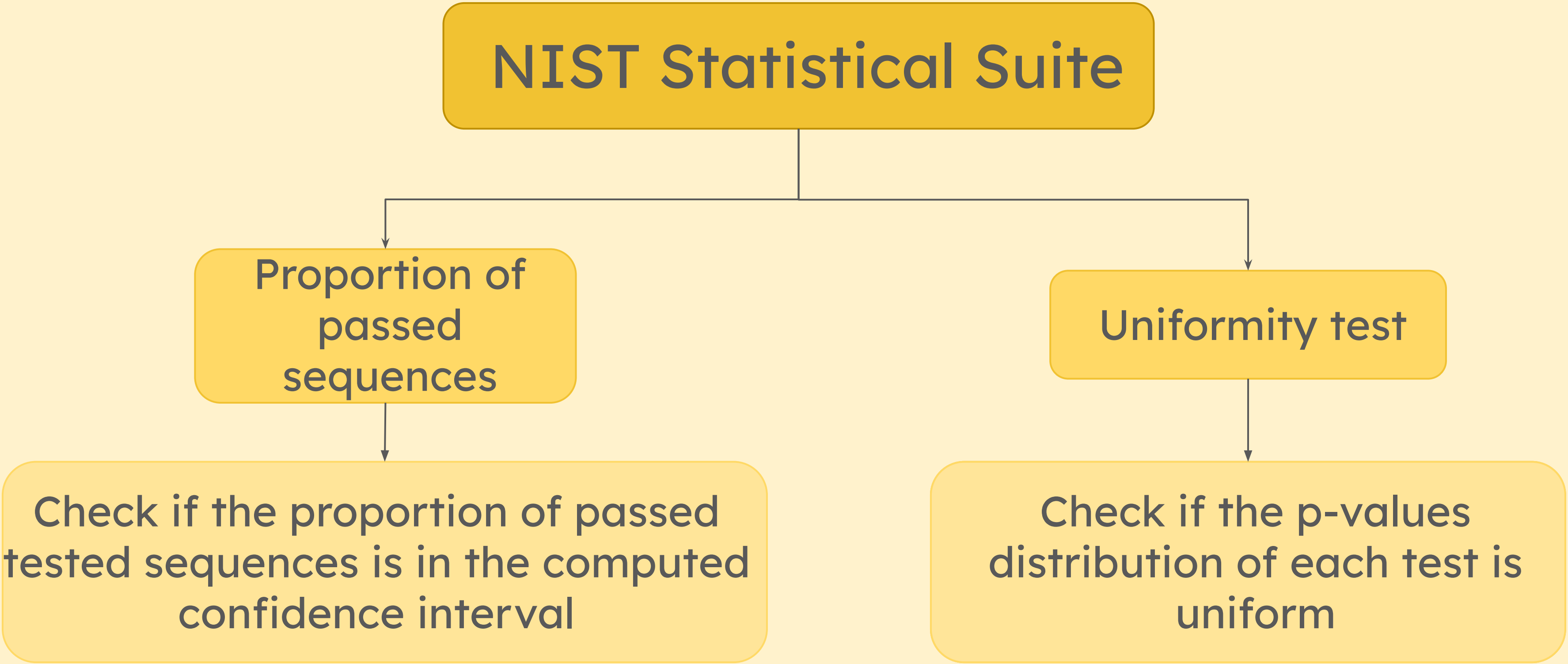

## Advantage

Mitigates initialization biases through complementary setups

## Drawback

Increased complexity


Effect of decoherence
Relaxation Time (T1)
Dephasing Time (T2)
Decay of a qubit to the ground state $|0\rangle$
Loose of the phase coherence of the qubit
Bias toward $|0\rangle$
Mixed State


NIST Statistical Suite
Proportion of passed sequences
Check if the proportion of passed tested sequences is in the computed confidence interval
Uniformity test
Check if the p-values distribution of each test is uniform

# Experiment

Length = 1,040 million
Block size = 19
Sample size = 139
Quantum computer =
ibm_sheerbroke

- As input a sequence of binary digits

In this code snippet we create the quantum random number directly from an account, specifying the token

```
# 65 mila shots to have a 1 milion bit number
# "447ab388994f0e83d45c52c41eb003beb31c6932a2e941e60b3b3a708a0995449d76517def2e1d141287186156dbfb2bef29095442da9d1e62ed9e329ff843e3"
g = QRNG()
g.chooseCircuit(QRNG_type=3, qubits_number=16)
M_number = g.generate_Numbers(num_qrn = 50, token ="" ,quantum_computer = "ibm_sheerbroke", num_shots = 65000, verbose = False, simulation = False)
```

+ Code + Text

In this code snippet, we use the function retrieve_from_IBM to retrieve the jobs from the different account(since we have only 10 minutes available for each one) and the function will collapse the results in only one output. The txt file should formatted to have the token in the first row and in the following all the job_ids

```
lista_job = [
     "job_alex_1.txt",
     "job_mirko_2cav.txt",
     "job_alex_2.txt",
     "job_mirko_3hotmail.txt",
     "job_alex_3.txt",
     "job_vito1_pallavolo.txt",
     "job_gianlu1.txt",
     "job_vito2_s333996.txt",
     "job_gianlu2gianluca.schiano@yahoo.txt",
     "job_vito_3vitocucinelli05.txt",
     "job_gianlu3schianog399.txt",
     "job_vito_4vitov2.txt",
      "job_mirko_1.txt"

]
qrns_from_IBM = g.retrieve_from_IBM(files = lista_job)
```

# Experiment

- Apply a series of different statistical tests (currently 15 main tests in SP 800-22 Rev 1a, some with sub-tests). For each test applied to a sequence, the suite calculates a p-value.
- A significance level denoted by α is chosen ($\alpha = 0.01$).
  - If the calculated p-value $\geq \alpha$, the sequence is considered to have passed that specific test,
  - If the calculated p-value $< \alpha$, the sequence is considered to have failed that test.

We choose the parameter alpha to use to run statistical test. The parameter indicates the number of numbers that will fail the test(in this case only 1% of the sample size)

```
g.statistical_test(alpha = 0.01,list_qrns=M_numbers)
```

```
def statistical_test(self, alpha,list_qrns = None):
  self.NIST_tests(verbose=True,list_qrns=list_qrns)
  self.proportion_passed_sequences_test(alpha = alpha)
  self.uniformity_test(alpha = alpha)
```

# Proportion of passed sequences

- Frequency (Monobit) test, Cusum test and Runs test are the 3 most important tests and fails
- Frequency within Block test, derives from Frequency test
- All these test fails, but Frequency within Block test has an higher p-value than Frequency Test

Systematic Bias

Table 1: Proportion of passed sequences

| Test Name | Pass Rate | Verdict |
|---|---|---|
| Frequency (Monobit) | 0.292 857 | FAIL |
| Frequency within Block | 0.592 857 | FAIL |
| Runs | 0.278 571 | FAIL |
| Longest Runs in Block | 0.728 571 | FAIL |
| Matrix Rank | 0.992 857 | PASS |
| Discrete Fourier Transform | 0.971 429 | PASS |
| Overlapping Template Matching | 0.964 286 | FAIL |
| Maurer's Universal | 1.000 000 | PASS |
| Linear Complexity | 0.978 571 | PASS |
| Serial | 0.996 429 | PASS |
| Approximate Entropy | 1.000 000 | PASS |
| Cumulative Sums (Cusum) | 0.257 143 | FAIL |
| Random Excursions | 0.894 643 | FAIL |
| Random Excursions Variant | 0.963 492 | FAIL |

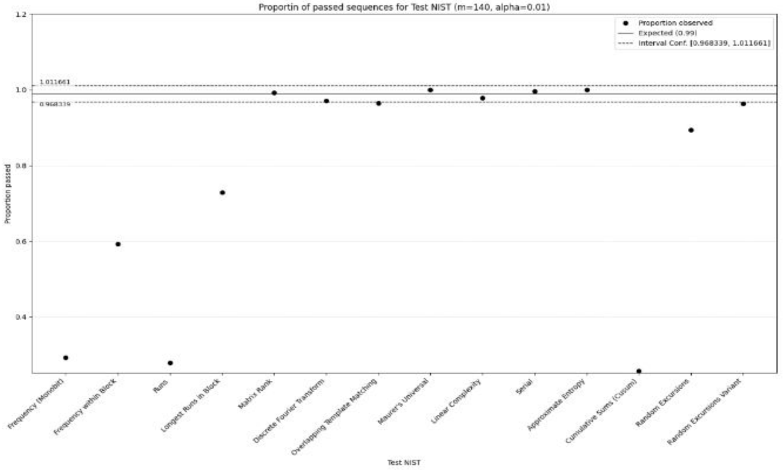
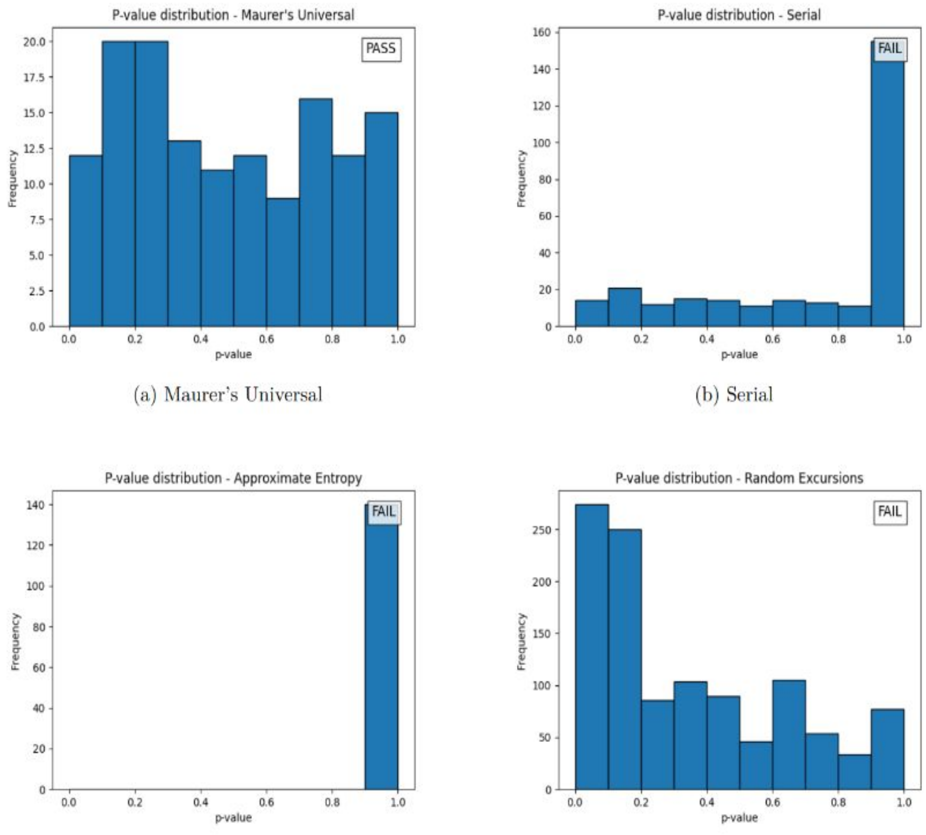



Figure 2: Proportion of passed sequences

# Uniformity Test

- Serial and Approximate entropy test pass the first test, but the frequency of p-value is not uniformly distributed.
- For Serial and Approximate entropy(and not only) the uniformity test is failed
- If the random number generator is good, should produce numbers that have uniformly distributed p-values

Systematic Bias




(a) Maurer's Universal (b) Serial

(c) Approximate Entropy (d) Random Excursions