

# fn sample\_bernoulli\_exp1

Michael Shoemate

March 14, 2025

This proof resides in “**contrib**” because it has not completed the vetting process.

Proves soundness of `fn sample_bernoulli_exp1` in `mod.rs` at commit `0be3ab3e6` (outdated<sup>1</sup>).  
`fn sample_bernoulli_exp1` returns a sample from the  $Bernoulli(\exp(-x))$  distribution for some rational argument in  $[0, 1]$ . This proof is an adaptation of subsection 5.1 of [CKS20].

## Vetting History

- Pull Request #519

## 1 Hoare Triple

### Preconditions

- `x` is of type `Rational` and  $x \in [0, 1]$
- `SampleBernoulli` is implemented for `Rational` probabilities

### Pseudocode

```
1 def sample_bernoulli_exp1(x) -> bool:
2     k = 1
3     while True:
4         if sample_bernoulli_rational(x / k, false): #
5             k += 1
6         else:
7             return is_odd(k) #
```

### Postcondition

For any setting of the input parameter `x` such that the given preconditions hold, `sample_bernoulli_exp1` either returns `Err(e)` due to a lack of system entropy, or `Ok(out)`, where `out` is distributed as  $Bernoulli(\exp(-x))$ .

## 2 Proof

Assume the preconditions are met.

**Lemma 2.1.** `sample_bernoulli_exp1` only returns `Err(e)` when there is a lack of system entropy.

<sup>1</sup>See new changes with `git diff 0be3ab3e6..1677dcd rust/src/traits/samplers/cks20/mod.rs`

*Proof.* In all usages of `SampleBernoulli`, the argument passed satisfies its definition preconditions, by the preconditions on `x` and function logic. Thus, by its definition, `sample_bernoulli_rational` only returns an error when there is a lack of system entropy. The only source of errors in `sample_bernoulli_exp1` is from the invocation of `sample_bernoulli_rational`. Therefore `sample_bernoulli_exp1` only returns `Err(e)` when there is a lack of system entropy.  $\square$

**Lemma 2.2.** Let  $k^*$  denote the final value of `k` on line 7. Then  $P[K^* > n] = \frac{x^n}{n!}$  for any integer  $n > 0$  [CKS20].

*Proof.* For  $i \geq 0$ , let  $a_i$  denote the  $i^{th}$  outcome of `sample_bernoulli_rational` on line 4. By the definition of `sample_bernoulli_rational`, under the established conditions and preconditions, each  $A_i$  is distributed as  $Bernoulli(x/i)$ .

$$\begin{aligned}
P[K^* > n] &= P[A_1 = A_2 = \dots = A_n = \top] && \text{since } K^* > n, \forall i \leq n, a_i = \top \\
&= \prod_{k=1}^n P[A_k = \top] && \text{all } A_i \text{ are independent} \\
&= \prod_{k=1}^n \frac{x}{k} && \text{since } A_k \sim Bernoulli(x/k) \\
&= \frac{x^n}{n!}
\end{aligned}$$

$\square$

**Lemma 2.3.**  $is\_odd(K^*) \sim Bernoulli(\exp(-x))$  [CKS20].

*Proof.*

$$\begin{aligned}
P[K^* \text{ odd}] &= \sum_{k=0}^{\infty} P[K^* = 2k + 1] \\
&= \sum_{k=0}^{\infty} (P[K^* > 2k] - P[K^* > 2k + 1]) \\
&= \sum_{k=0}^{\infty} \left( \frac{x^{2k}}{(2k)!} - \frac{x^{2k+1}}{(2k+1)!} \right) && \text{by 2.2} \\
&= \exp(-x)
\end{aligned}$$

Since `k` is distributed according to  $K^*$ , then `out` is distributed as  $Bernoulli(\exp(-x))$ .  $\square$

*Proof.* 1 holds by 2.1 and 2.3.  $\square$

## References

[CKS20] Clément L. Canonne, Gautam Kamath, and Thomas Steinke. The discrete gaussian for differential privacy. *CoRR*, abs/2004.00010, 2020.