Seminar Algorithms for Big Data

Fast Random Integer Generation in an Interval

Based on a paper of the same title by Daniel Lemire

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29th February 2024 · Algorithm Engineering (Prof. Dr. Ulrich Meyer)

Motivation

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TBD TBD TBD

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- Set $n = b - a$ and draw a uniform random integer $x \in [0, n)$
- Return $x + a$

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Definition (Power Remainder)

For $W, n \in \mathbb{N}$, we write $\mathcal{R}_n^W$ for $2^W \bmod n$.

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Is the generated number uniform in $[0, n)$?

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Idea: Use rejection sampling to achieve uniformity!

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Unbiased Algorithms

The OpenBSD Algorithm

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Can we do better?

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- Happens with probability $\frac{2^W - \mathcal{R}_n^W}{2^W} > \frac{1}{2}$

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- Number of integer divisions operations equal to number of rounds
- Return a number in round if $x < 2^W - \mathcal{R}_n^W$
- Happens with probability $\frac{2^W - \mathcal{R}_n^W}{2^W} > \frac{1}{2}$
- Expected number of integer division operations is $\frac{2^W}{2^W - \mathcal{R}_n^W} < 2$

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$$n \xrightarrow{\text{binary}} \underbrace{\overbrace{0}^{2^{W-1}},\ldots,0,}_{\text{only 0's}} \overbrace{1}^{2^{\lfloor \log_2 n \rfloor}}, \underbrace{0/1,\ldots,\overbrace{0/1}^{2^1},\overbrace{0/1}^{2^0}}_{\text{series of 0's and 1's}}$$

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- Every number $x \le n$ only needs the last $\lfloor \log_2 n \rfloor + 1$ bits

The Bitmask Algorithm

- Consider the binary representation of n:

$$n \xrightarrow{\text{binary}} \underbrace{\overbrace{0}^{2^{W-1}},\ldots,0}_{\text{only 0's}}, \overbrace{1}^{2^{\lfloor \log_2 n \rfloor}}, \underbrace{0/1,\ldots,\overbrace{0/1}^{2^1},\overbrace{0/1}^{2^0}}_{\text{series of 0's and 1's}}$$

- Every number $x \leq n$ only needs the last $\lfloor \log_2 n \rfloor + 1$ bits
- Get these bits with a bitwise-AND with

$$2^{\lfloor \log_2 n \rfloor + 1} - 1 \xrightarrow{\text{binary}} \underbrace{\overbrace{0}^{2^{W-1}},\ldots,0}_{\text{only 0's}}, \underbrace{\overbrace{1}^{2^{\lfloor \log_2 n \rfloor}},1,\ldots,\overbrace{1}^{2^1},\overbrace{1}^{2^0}}_{\text{only 1's}}$$

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- At most 2 rounds in expectation
- No integer division at all
- Computation of leading 0's needs `clz` instruction
- Roughly as expensive as a `div` instruction

Lemire's Algorithm

Multiply-And-Shift

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$$(\texttt{rand()} \cdot n) \gg W$$

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$$(\texttt{rand()} \cdot n) \gg W = (\texttt{rand()} \cdot n) \div 2^W$$

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4 Conclusion

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Bitmask	0	0	✓
Lemire	$\frac{n}{2^W}$	1	✓

End of Talk