Value at Risk and Expected Shortfall

MIT Quantum Hackathon
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Suppose we hold a 60/40 U.S. stock/bond portfolio...

...how far might we **reasonably deviate from our expected return** over the next month?

...what's the likelihood we'll experience an **extreme loss** over the next month?

To answer these questions, we start by measuring the portfolio's volatility.

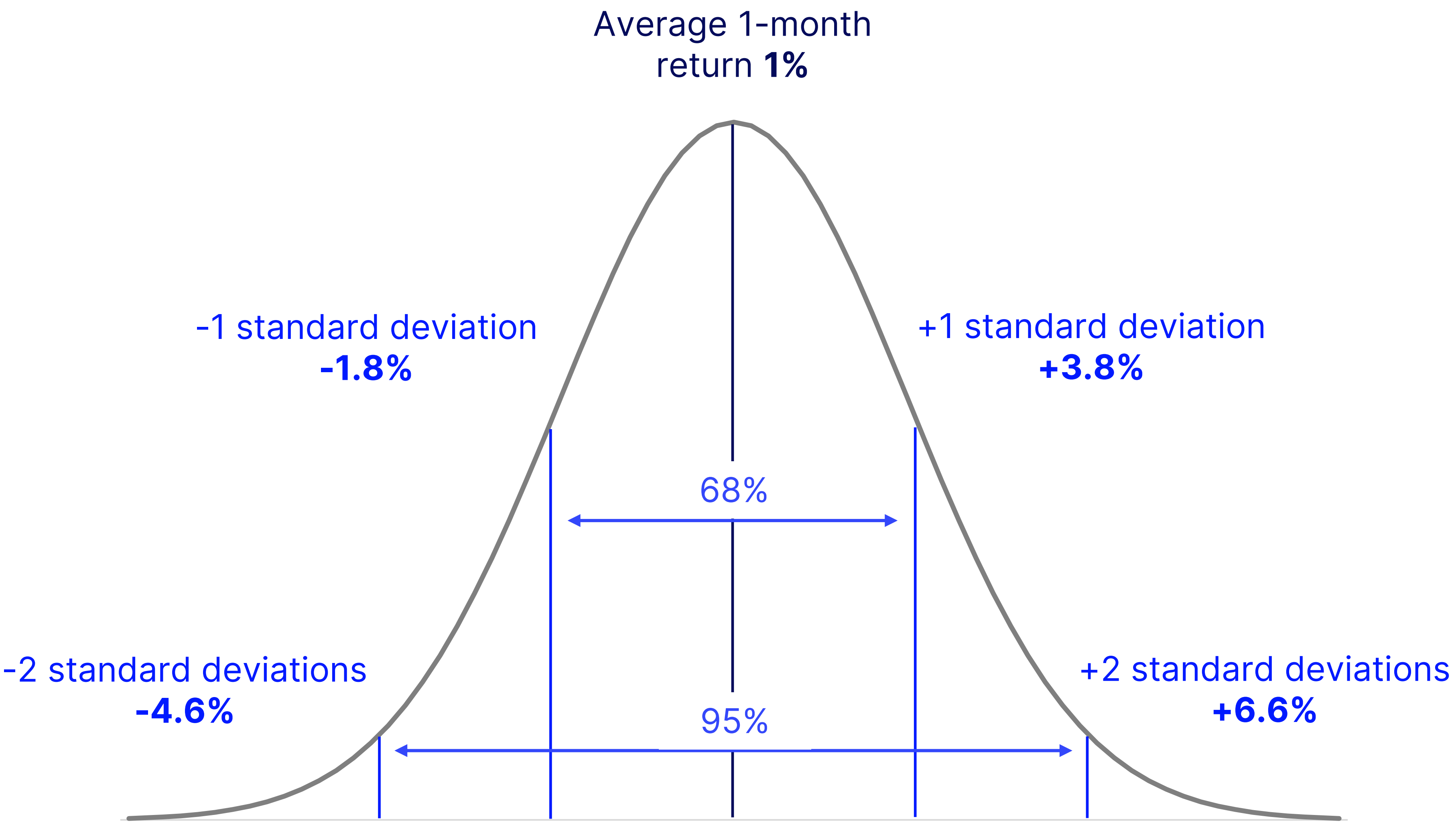
Measuring volatility: Standard deviation

	60/40 Portfolio
1/31/1975	9.0%
2/28/1975	4.1%
3/31/1975	1.7%
4/30/1975	2.3%
5/30/1975	4.2%
6/30/1975	3.3%
⋮	⋮
7/31/2023	2.1%
8/31/2023	-1.4%
9/29/2023	-3.8%
10/31/2023	-2.1%
11/30/2023	7.0%
12/29/2023	4.5%

Standard deviation of the portfolio's monthly returns:

$$\sigma_m = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2} = \mathbf{2.8\%}$$

Normal distribution



Measuring exposure to loss: Value-at-Risk (theoretical)

With 95% confidence, what's the worst expected loss at the end of next month?

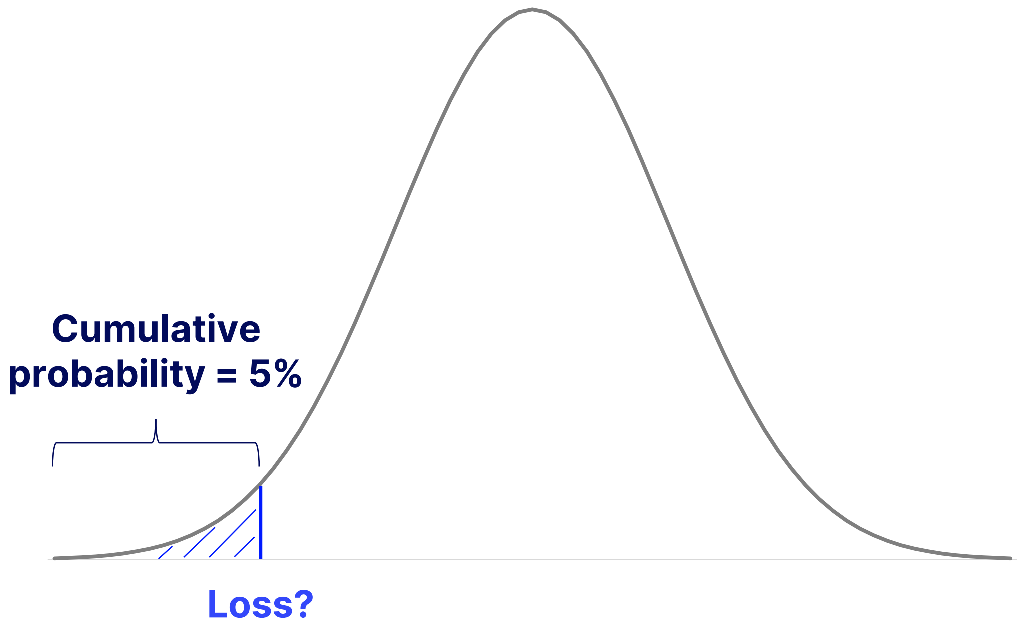
1) Use the inverse of the cumulative normal distribution function to determine the standardized loss (z-score) corresponding to the 5% left-tail of the distribution.

Z-score threshold = -1.64

2) Convert to non-standardized loss threshold:

$$Loss = \bar{x} + z\sigma$$

Value-at-Risk = -3.6%



Measuring exposure to loss: Value-at-Risk (simulation)

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Assume those are random numbers drawn from a defined distribution. The **5th** percentile value is the 5% VaR.

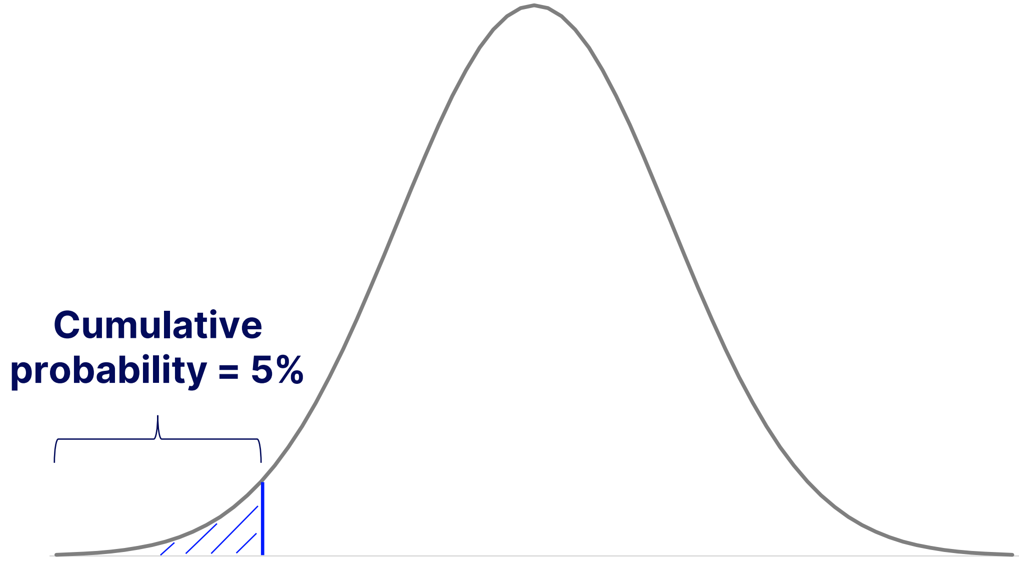
How does the empirical value converge to the theoretical value as we increase the number of samples?

Expected Shortfall

What's the average expected loss in the worst-case scenarios (exceeds the VaR level)?

- **Theoretical**
- **Empirical (simulation)**

How does the empirical value converge to the theoretical value as we increase the number of samples?



$$\mathrm{ES}_\alpha = \mathbb{E}[X \mid X \leq \mathrm{VaR}_\alpha]$$

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