QuaRot Extended

Outlier-Free 4-Bit Inference in Rotated LLMs

Machine Learning in Practice
Professor Gary Kazantsev
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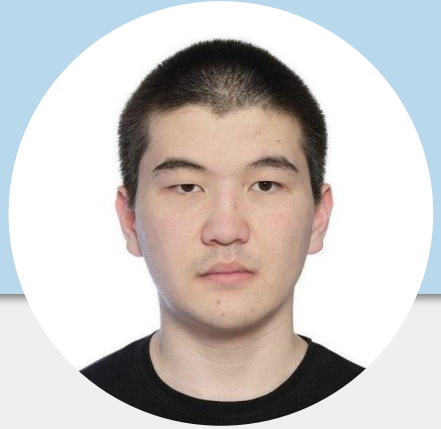


Ali Bauyrzhan

Daisy John

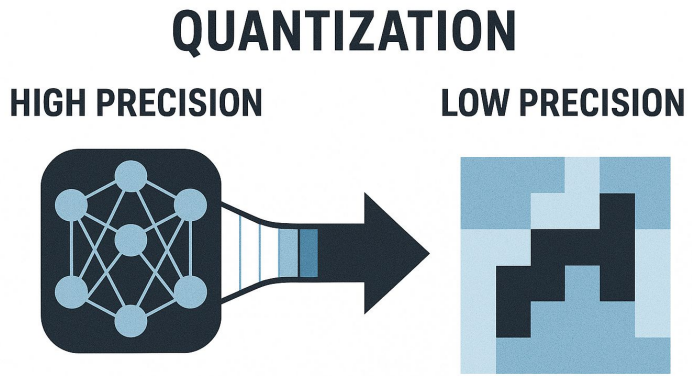
Topics

- Background
- QuaRot Paper's Purpose
- QuaRot's Contribution
- Challenges
- Three Main Extensions
- Matrix Optimization
- Dataset Integration
- Skew based quantization mode
- Challenges
- Future Work
- Conclusion
- References

Introduction and Background

Why did we choose this paper?

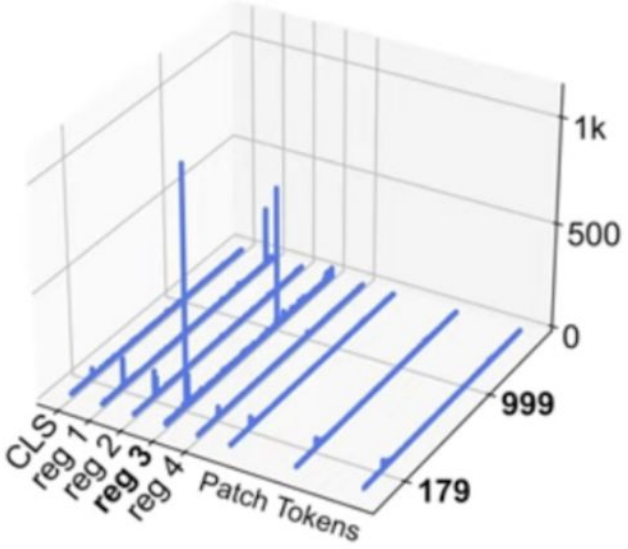
- LLMs are widely used, but hard to deploy privately due to high GPU/memory needs.
- Quantization is crucial for efficient, private LLM deployment.
- This 2024 paper proposes an innovative method (QuaRot) using rotations for 4-bit quantization.
- Curious how authors addressed all major quantization challenges using rotational methods.
- Achieved only 0.47 perplexity loss and retained 99% accuracy on LLAMA2-70B.

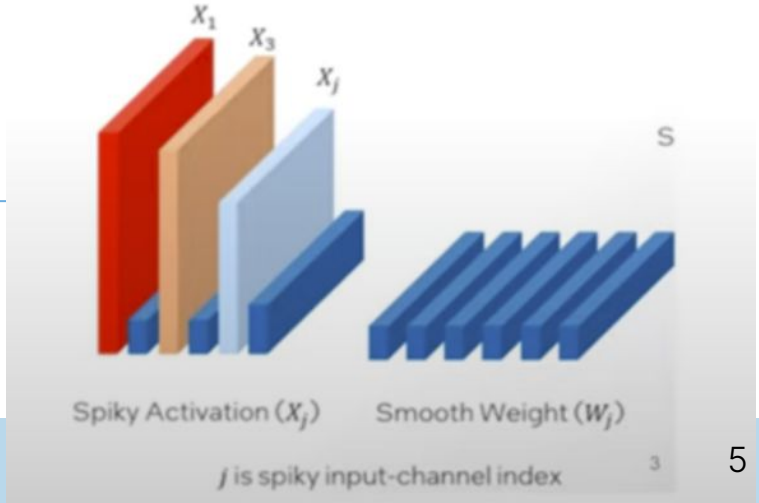


Purpose of QuaRot

What were the tasks?

- Quantize all parts of LLMs (weights, activations, and KV cache) to 4 bits for efficient inference and reduced memory usage.
- Remove outlier features in activations and cached values, which make low-bit quantization difficult.
- Apply a unified approach (randomized Hadamard rotations) to enable end-to-end quantization without significant accuracy loss.





Purpose of QuaRot

What were the paper's contributions?

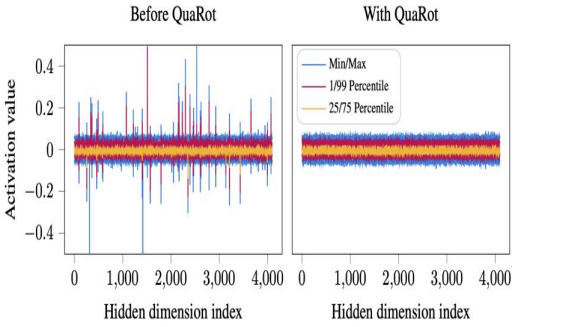


Figure 1: The distributions of activations at the input to the FFN block in LLAMA2-7B model, in the tenth layer. Left: using the default configuration as downloaded from Hugging Face. Right: after processing using QuaRot. The processed distribution has no outliers, leading to superior quantization.

- Rotates weights and activations with randomized Hadamard matrices, spreading outliers and making quantization easier.
- Fuses rotations into model weights using computational invariance, so model outputs remain unchanged.
- Applies online Hadamard transforms to the attention KV cache, enabling 4-bit quantization of all model parts.
- All quantization and modifications are done in preprocessing, so inference is fast and requires no extra computation.

Paper Extensions

We extended the results from the paper in the following ways:

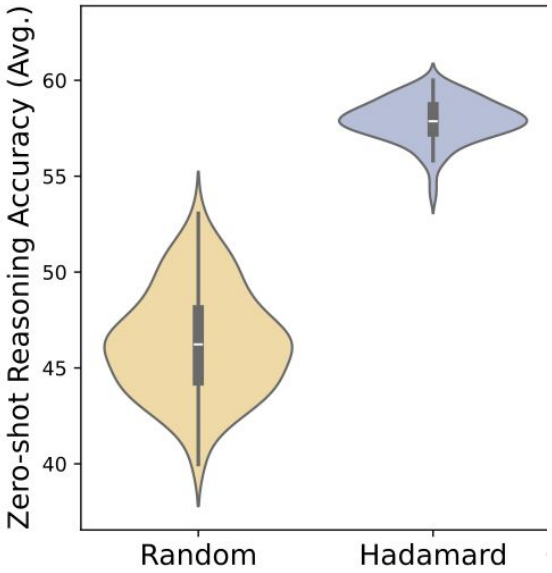
Alternative Rotation Matrix Optimization

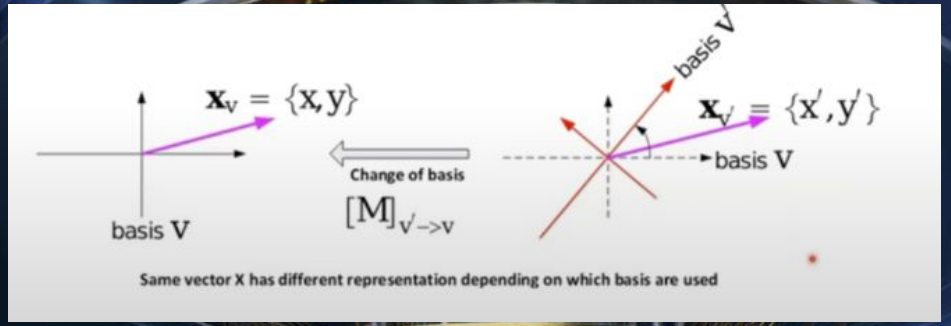
Skew Based Quantization mode selection

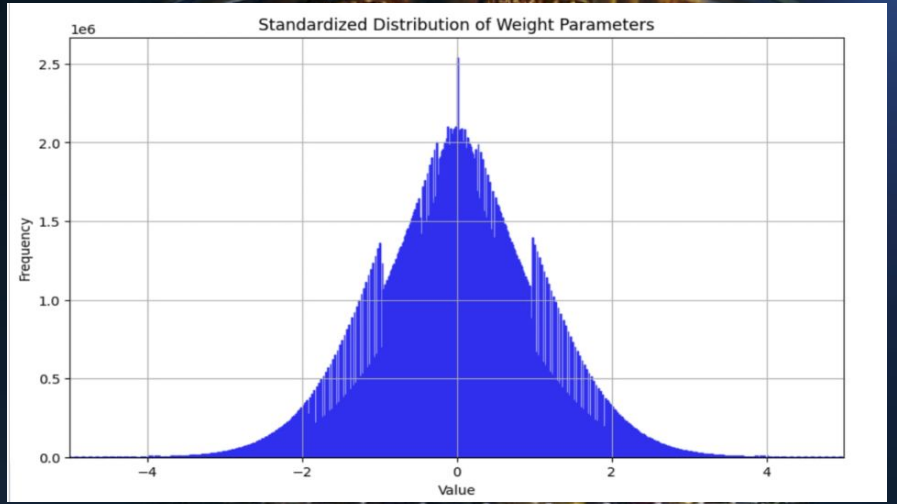
Integrated datasets

Paper Extensions

Extensions 1
Matrix Optimization







Extensions 2 : Integrated Datasets

WIKITEXT2

collection of over 100 million tokens extracted from verified articles on Wikipedia

C4

C4 is a colossal, cleaned version of Common Crawl's web crawl corpus.

PTB

Diagnostic ECG Database obtained using non-commercial, PTB - prototype recorder

WIKITEXT103

collection of over 100 million tokens extracted from verified articles on Wikipedia

PILE

consists of 22 smaller, high-quality datasets combined together

Paper Extensions

Extensions 3 : Skew Based Quantization mode selection

How can we **decrease performance loss**?

Symmetric Quantization:

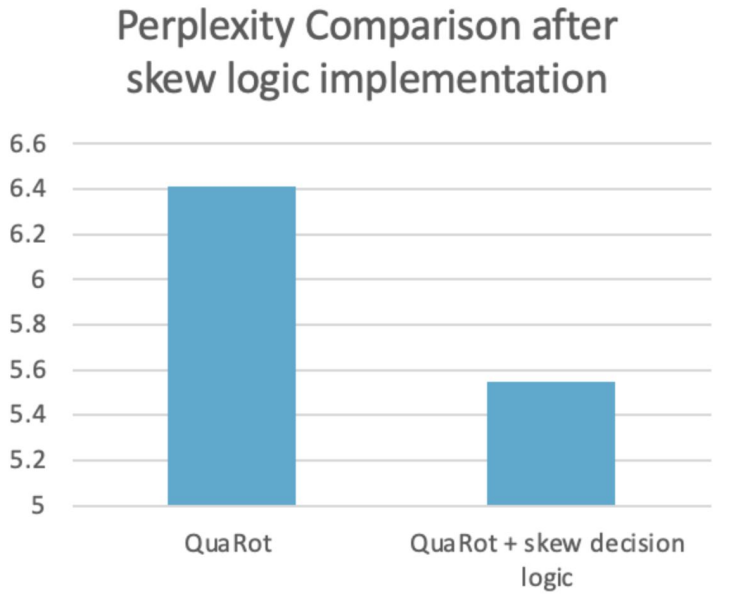
If distribution skewed, this will waste range reserving space

Better when mean centered around 0

Asymmetric Quantization:

Shift range to match actual data

Thresholds: skewness, value of the mean

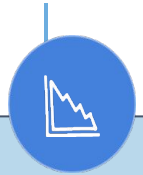


Challenges

Challenges in reproducing the results

System and environment requirements were not up to date

Hardware limitations



No documentation and limited comments

Hugging Face access (takes a while)

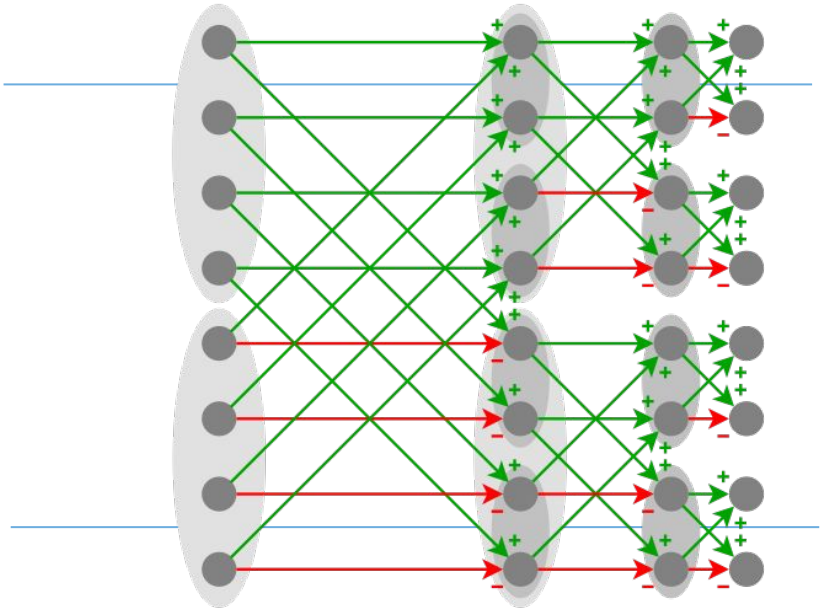
Unable to reproduce the results for large models

Conclusion

Future developments:

Combine with spinquant

Further testing in different resources



References

Research Paper Chosen

- QuaRot: Outlier-Free 4-Bit Inference in Rotated LLMs (https://arxiv.org/pdf/2404.00456)

Research Paper code link

- https://github.com/spcl/QuaRot

Other Sources

- https://arxiv.org/abs/2405.16406
- https://huggingface.co/meta-llama/Llama-2-7b
- Wikitext2, C4, PTB, Wikitext103 and Pile datasets
- Chat GPT used in debugging

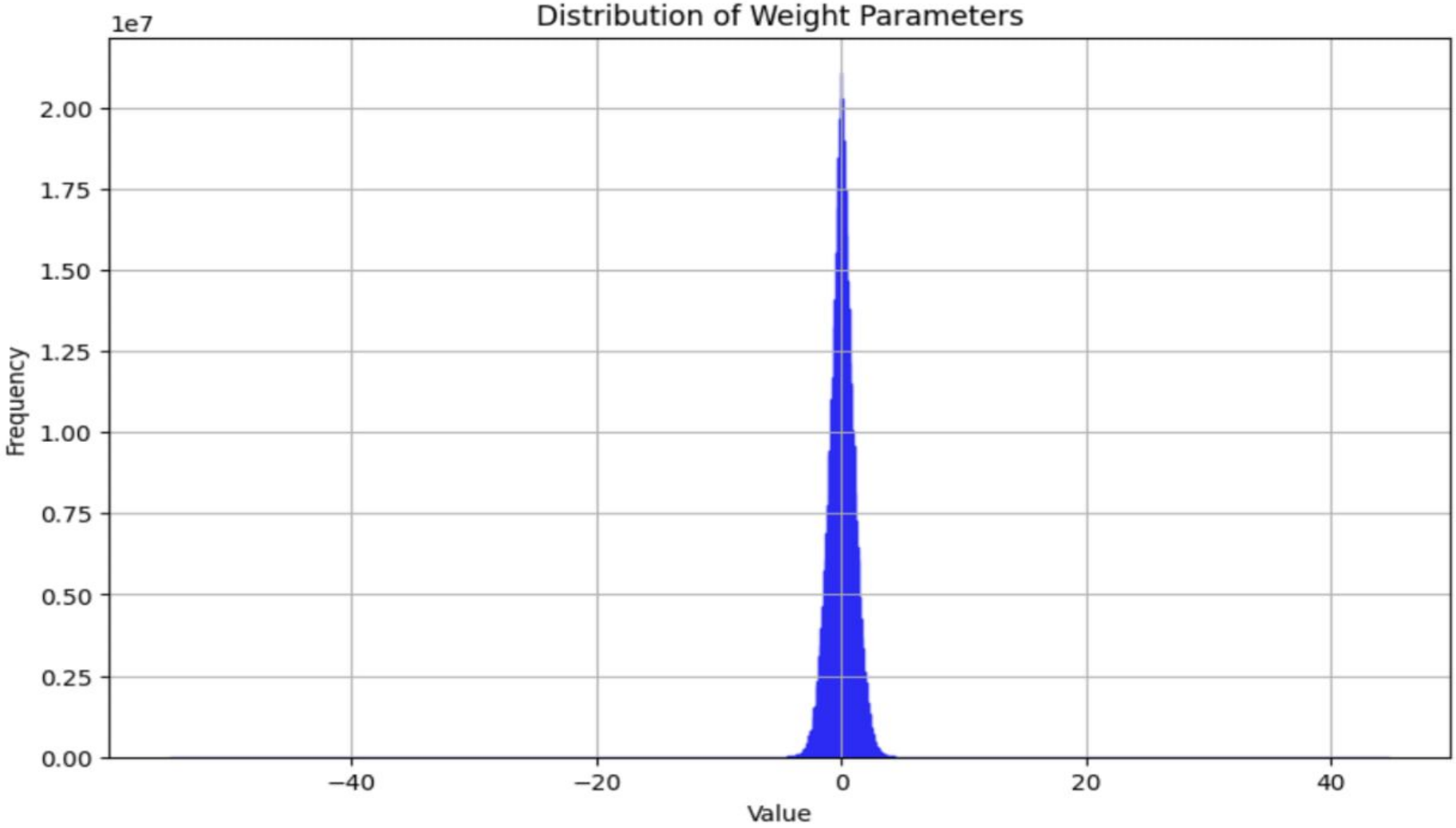
Background- QuaRot

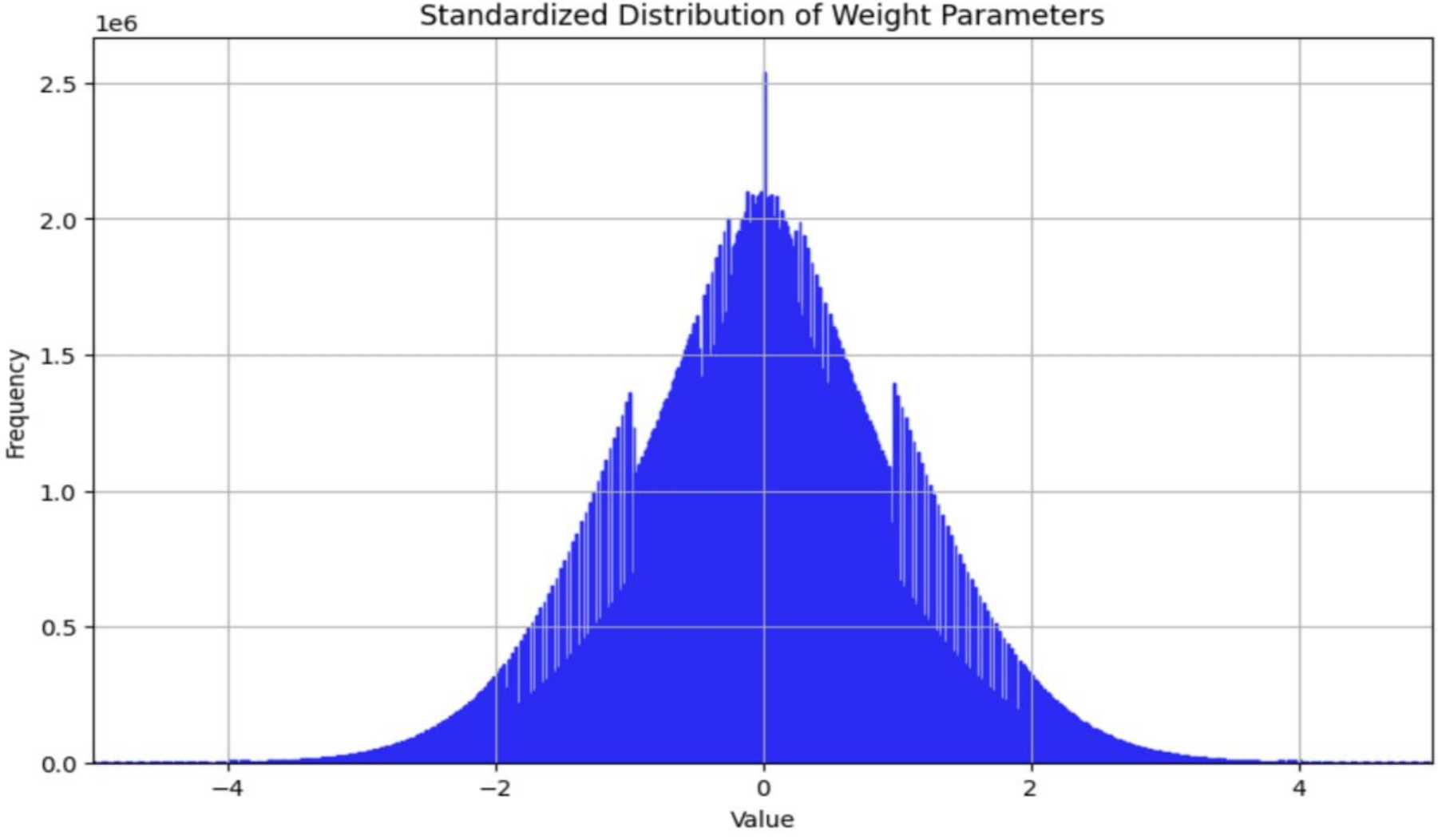
What Is the Hadamard Transform?

- The Hadamard transform is an orthogonal operation that rotates data into a new basis using only reflections and rotations.
- Unlike the Fourier transform, which uses sine waves and complex numbers, Hadamard uses simple square wave basis functions consisting of only +1 and -1.
- It is extremely efficient: requiring only additions and subtractions, with no complex math when working with real inputs.
- This makes it ideal for fast, hardware-friendly transformations in quantization workflows.

Fast Walsh–Hadamard transform

The fast Walsh–Hadamard transform applied to a vector of length 8


Distribution of Weight Parameters
1e7
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
Frequency
−40
−20
0
20
40
Value


Standardized Distribution of Weight Parameters
1e6
2.5
2.0
1.5
1.0
0.5
0.0
Frequency
−4
−2
0
2
4
Value