

Perceptual Convolution

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About Me

- Age 29
- Wrote first C++ program at the age of 8 (with help from my dad)
- Freelance Developer
- Based in Berlin, Germany

Motivation

- Why do we care about Convolution?
 - It's used everywhere
 - It's very compute heavy
 - Realtime constraints
 - Audio Effects
 - Gaming
 - VR

State of the art convolution

- Frequency domain multiplication
- Partitioned algorithms
 - Frank Wefers: Partitioned convolution algorithms for real-time auralization

Exact/Dense Convolution

- Dense Matrix
- Performance Tuning
 - SIMD
 - Sample types: `float16` vs. `float32` vs. `float64`
 - Memory layout: Interleaved vs split-complex

Sparse Convolution

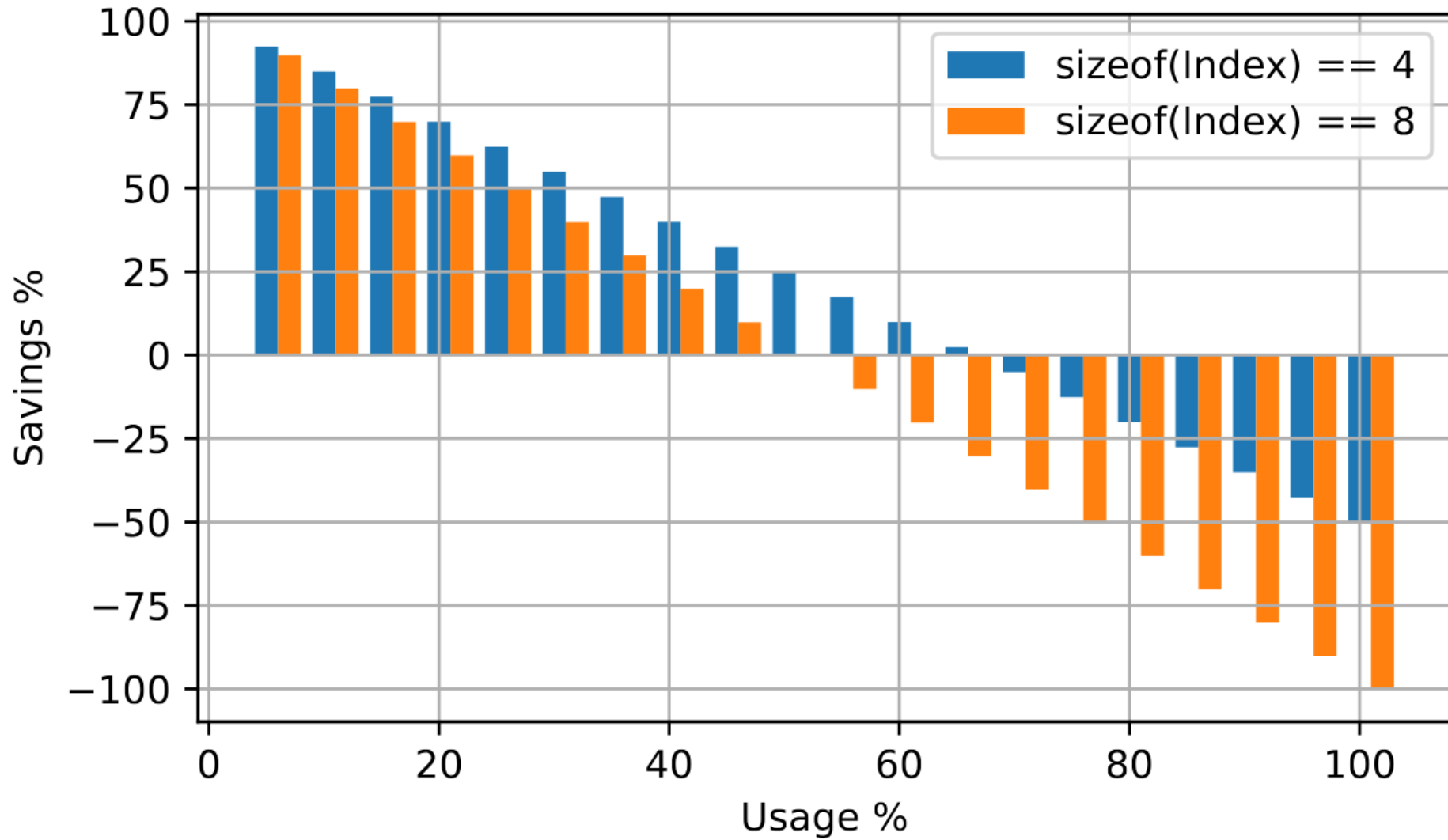
- Sparse Matrix
- Memory Savings
- Performance Tuning
 - SIMD not as easy to apply
 - Same with Split-complex

Sparse Matrix

- Compressed Sparse Row/Column (CSR/CSC)

```
1 struct CSRMatrix
2 {
3     std::vector<std::complex<float>> values;
4     std::vector<size_t> colum_indices;
5     std::vector<size_t> row_indices;
6 };
```

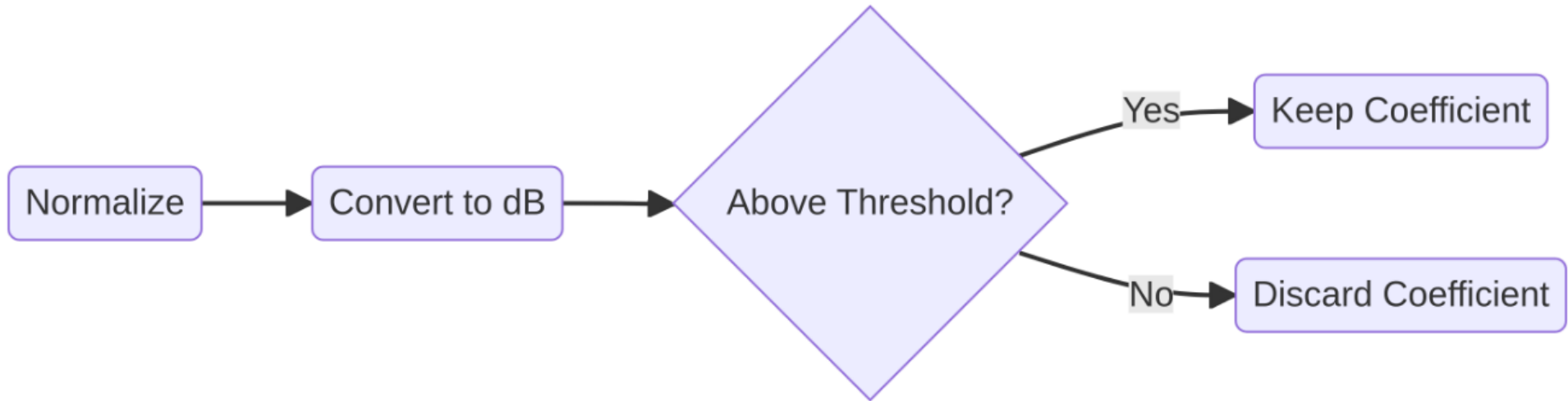
Memory Savings



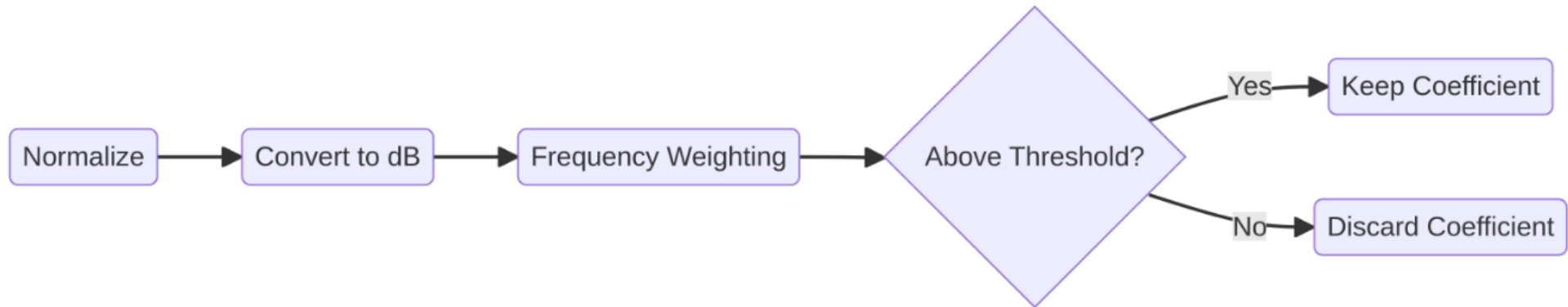
Perceptual Convolution

- Filter Selection
 - Energy distribution over frequency
 - Lower frequencies are more important / carry more energy
 - Simple Threshold
 - Weighted Threshold
 - Dense/Sparse Hybrid

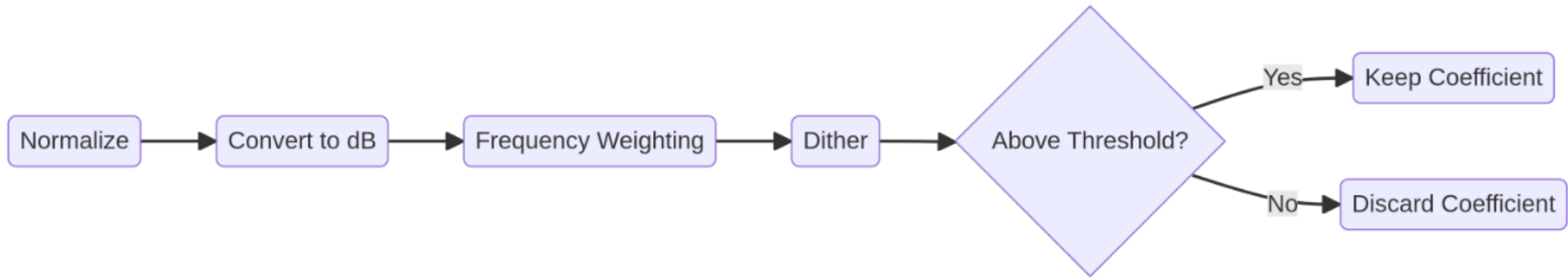
Naive Coefficient Selection



Weighted Coefficient Selection



Dithered Coefficient Selection



Implementation

- C++ lacks abstractions for sparse vector/matrix types
 - C++23 has `std::mdspan`
 - C++26 has `std::linalg`
- Many changes to a regular dense convolution engine
 - Would need to fork/modify the `juce::Convolution` engine
- github.com/neo-sonar/neo
 - dsp/fft/convolution library
 - standard abstractions

Demo

- Demo plugin
- Simple CLI application

In the Future

- Automated sparsification
 - Wavelet transform to analyse the IR

Definitions

- **Dense:** Multiplication of signal and filter in the frequency domain using *dense* data structures
- **Sparse:** Multiplication of signal and filter in the frequency domain using *sparse* data structures
 - **Perceptual:** Metrics of human sound perception are used in the sparsification process

Thank you

- Questions?