

# Comparing Quantization Across Hardware

Benchmarking LLM Inference on Edge Devices

Mike Doan · Jenny Dinh

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# Introduction & Background

## The Rise of Local LLM Deployment

- Growing interest in running LLMs **locally** rather than via cloud APIs
- Target environments:
  - **Edge devices**: smartphones, embedded systems
  - **Consumer hardware**: laptops, gaming PCs
  - **Enterprise GPUs**: data center deployments

## The Memory Challenge

- LLMs contain **massive weights** requiring significant memory

- Activations during inference are also substantial
- Example: Llama-3.1-8B requires 16GB in FP16

# Background: What is Quantization?

**Quantization** reduces the precision of model weights and activations to decrease memory footprint and improve inference speed.

Precision	Bits per Weight	Memory (8B model)
FP16 / BF16	16 bits	16 GB
INT8 (W8A8)	8 bits	8 GB
INT4 (W4A8)	4 bits	4 GB
NF4	4 bits	4 GB

**Trade-off:** Lower precision → smaller memory, faster inference, but potential accuracy loss

# Background: Quantization Strategies

## Weight-Only Quantization

- **INT8**: 8-bit integer weights
- **INT4**: 4-bit integer weights
- **NF4**: 4-bit NormalFloat (QLoRA)

## KV-Cache Quantization

- Reduces memory for long contexts
- INT8 or INT4 KV cache

## Activation Quantization

- **W8A8**: Both weights and activations in INT8
- **W4A4**: Aggressive 4-bit for both

## Group-wise Quantization

- GPTQ: Post-training quantization
- AWQ: Activation-aware weights

# Purpose & Motivation

## Research Questions

1. How do different **quantization strategies** impact inference performance across hardware?
2. What are the **accuracy-efficiency trade-offs** for edge deployment?
3. Can we create a **reproducible benchmarking framework** for the community?



## Gap in Existing Work

- Few plug-and-play toolkits for **cross-platform quantization sweeps**
- Limited public data on **edge device performance**
- Need for standardized comparison methodology

# Target Hardware & Scope

## Edge Devices

- **Google Pixel 7/8** (Android)
  - ARM CPU + Adreno GPU
  - OpenCL backend

## Consumer Hardware

- **MacBook** (Apple Silicon)
  - Metal backend
  - Unified memory

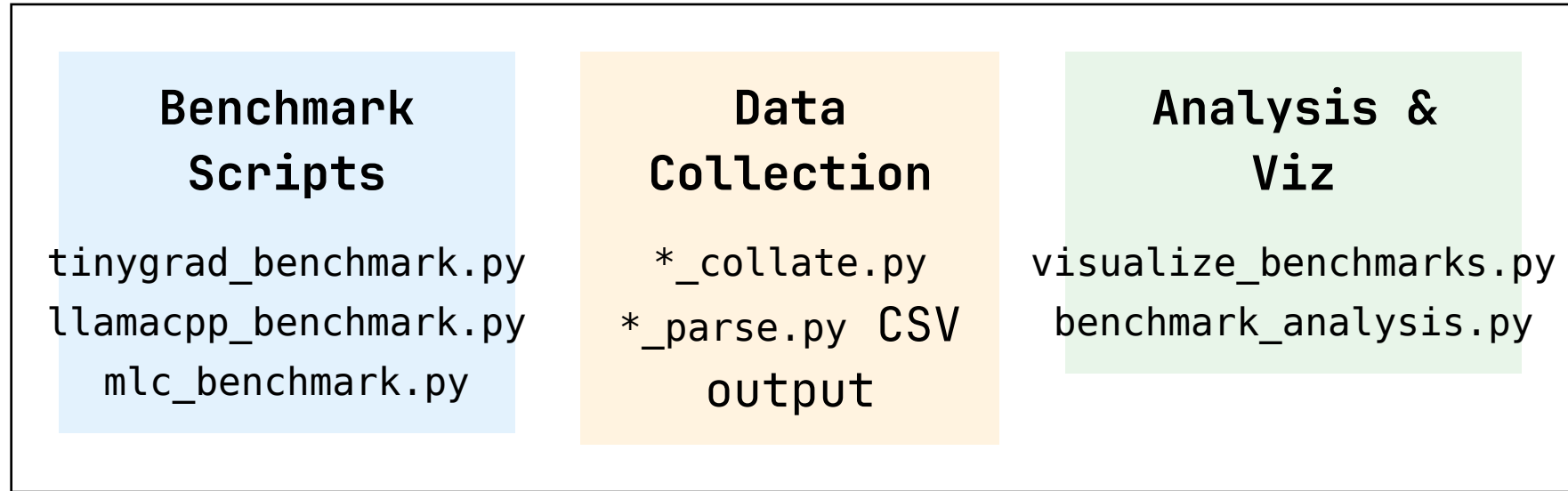
## Runtimes Evaluated

- **llama.cpp** (GGUF format)
- **tinygrad** (Metal/OpenCL)
- **MLC-LLM** (TVM-based)

## Models

- Llama-3.2-1B-Instruct
- Qwen2.5-1.5B
- (Extensible to larger models)

# System Architecture



## Key Design Principles

- **Reproducibility:** Seeded runs, UUID tracking
- **Extensibility:** Easy to add new backends/devices

- **Standardized schema:** Consistent CSV format across all backends

# Benchmark Workflow

## 0. Pixel Setup

Termux + SSH + OpenCL

croc, cmake, clang

## → 1. Model Prep

Download models

Quantize (GGUF/HF)

## → 2. Run Benchmarks

Execute on devices

Output: .txt logs

## 5. Presentation

Embed plots

typst compile



## 4. Visualize

Generate plots

.png files



## 3. Collate

Parse logs

Structured CSV

Flow: Pixel setup → Model prep → Benchmarks → Collation → Visualization → Presentation



# Data Schema

Each benchmark run captures:

BenchmarkRow:

step: int	# Token generation step
enqueue_latency_ms: float	# Time to enqueue
total_latency_ms: float	# Total time
tokens_per_sec: float	# Throughput
memory_throughput_gb_s: float	
param_throughput_gb_s: float	
platform: str	# Darwin, Linux, Android
device: str	# Metal, OpenCL, CUDA
hostname: str	# Machine identifier
size: str	# Model size (1B, 3B, 8B)
quantize: str	# nf4, int8, float16, default
seed: int	# For reproducibility
uuid: str	# Unique run identifier

# Implementation: Tinygrad Backend

- Pure Python ML framework with Metal/OpenCL support
- Server mode for OpenAI-compatible API

```
# Start inference server
```

```
PYTHONPATH=./deps/tinygrad/ python tinygrad_benchmark.py \  
    --port 7776 --size 1B
```

## Quantization Support

- default: No quantization
- nf4: 4-bit NormalFloat
- int8: 8-bit integer
- float16: Half precision

# Implementation: llama.cpp Backend

- C/C++ implementation with GGUF model format
- Highly optimized for CPU and GPU inference

# Run benchmark

```
python llamacpp_benchmark.py
```

# Collate results

```
python llamacpp_collate.py
```

## Key Features

- Native quantization support in model files
- Metal backend for Apple Silicon
- OpenCL for Android devices

# Implementation: Pixel Device Setup

## Bootstrap (Termux)

```
# Install from F-Droid
pkg update && pkg upgrade
pkg install python git openssh
pkg install cmake clang ninja
pkg install golang

# Install uv & croc
curl -LsSf astral.sh/uv/install.sh | sh
go install github.com/schollz/croc/v10@latest
```

## SSH Access (Tailscale)

```
# On Pixel
sshd
passwd
id # Get username (u0_a190)

# From host
ssh u0_a190@<tailscale-ip> -p 8022
```

## OpenCL GPU Setup

```
# Install OpenCL for Adreno GPU
pkg install openccl-headers openccl-vendor-driver

# Set environment
export LD_LIBRARY_PATH=/system/vendor/lib64:
$LD_LIBRARY_PATH
export GPU=1
export OPENCL=1
```

## Build & Transfer

```
# Build llama.cpp with OpenCL
cmake .. -DGGML_OPENCL=ON
cmake --build . -j$(nproc)

# Transfer models with croc
croc send model.gguf
```

Full setup guide: docs/WORKFLOW.md & setup/PIXEL-SSH.md

# LLM Evaluation: Verifiers Framework

Beyond raw throughput, we measure downstream task accuracy:

## Setup

```
# Start model server
python tinygrad_benchmark.py \
    --port 7776 --size 1B

# OpenAI proxy (streaming)
python openai_proxy.py \
    --backend-port 7776 \
    --proxy-port 7777
```

## Run Evaluation

```
# GSM8K math benchmark
OPENAI_API_KEY=dummy \
uv run vf-eval gsm8k \
    -m local \
    -b http://localhost:7777/v1 \
    -n 20 -r 1 -t 512
```

Available benchmarks: gsm8k, math, gpqa, simpleqa, wordle

# Metrics Collected

## Performance Metrics

### Latency

- Time to first token (TTFT)
- Per-token generation time

### Throughput

- Tokens per second (tok/s)
- Memory bandwidth (GB/s)

## Resource Metrics

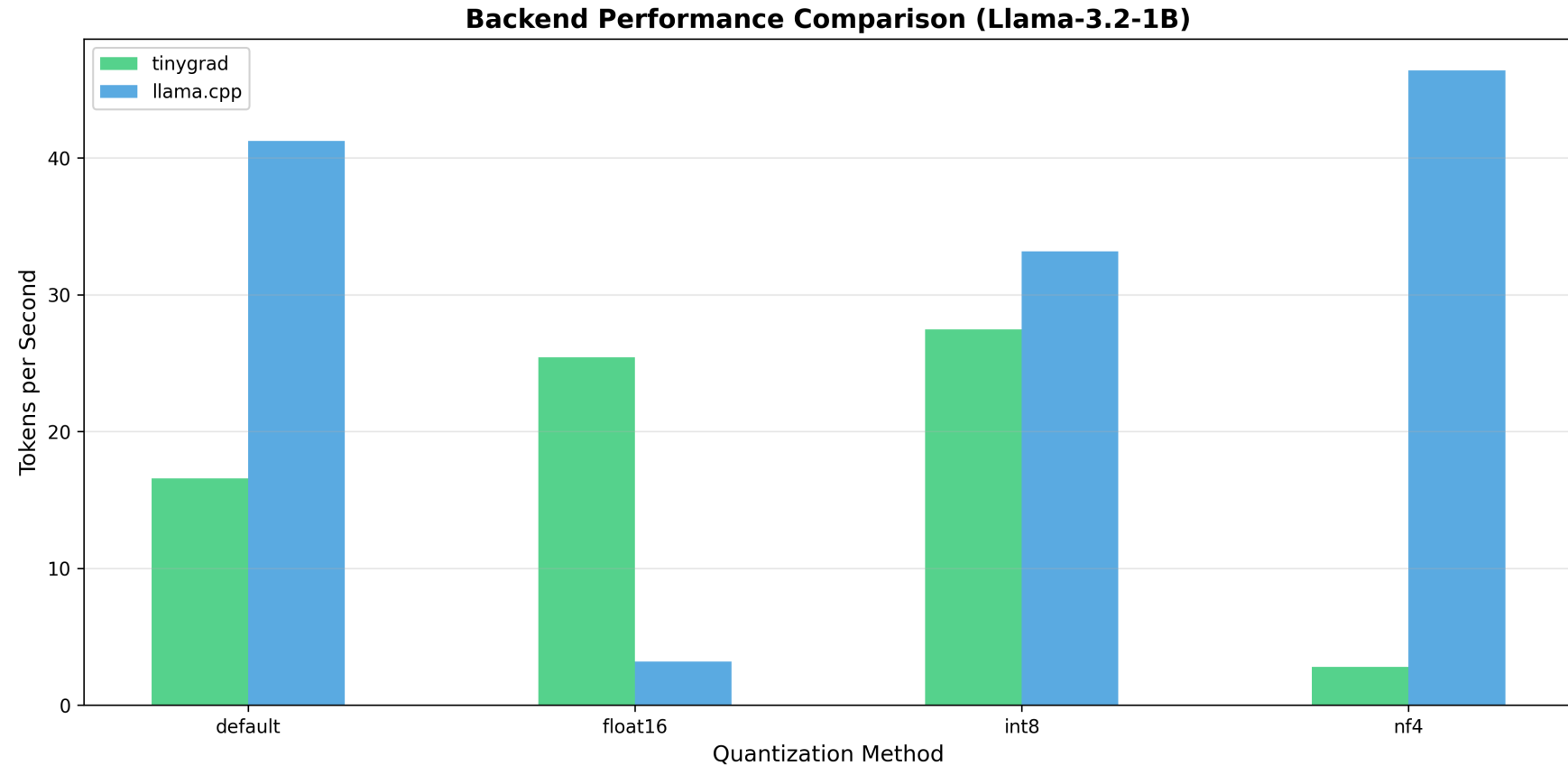
### Memory

- Model load size (MB)
- Peak utilization

### Accuracy

- Downstream benchmark scores
- (GSM8K, MATH, etc.)

# Results: Throughput Comparison

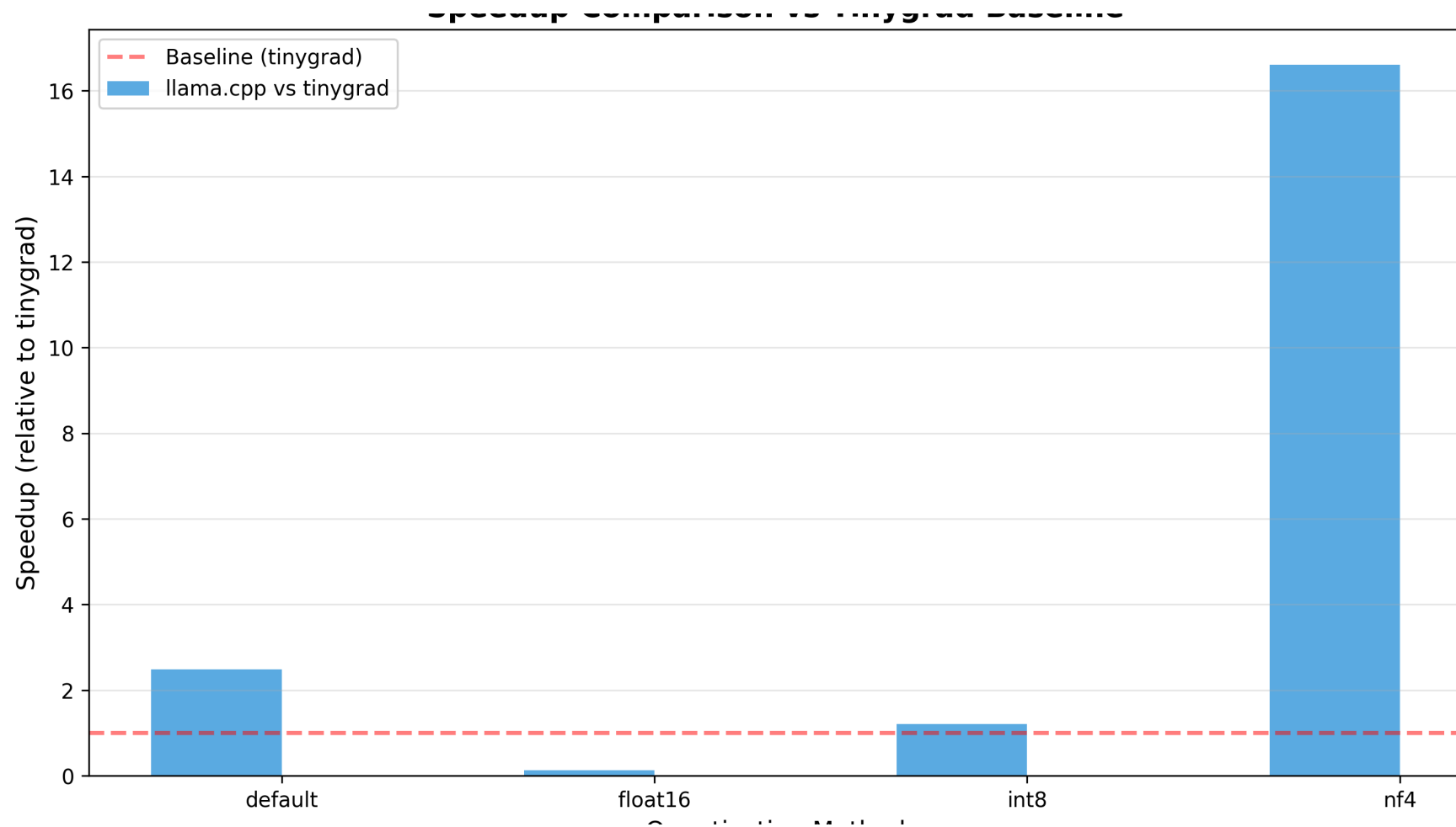




## Key findings:

- llama.cpp excels with NF4 (46.4 tok/s) and default (41.3 tok/s)
- tinygrad performs best with INT8 (27.5 tok/s) and float16 (25.4 tok/s)
- Performance varies significantly by quantization method

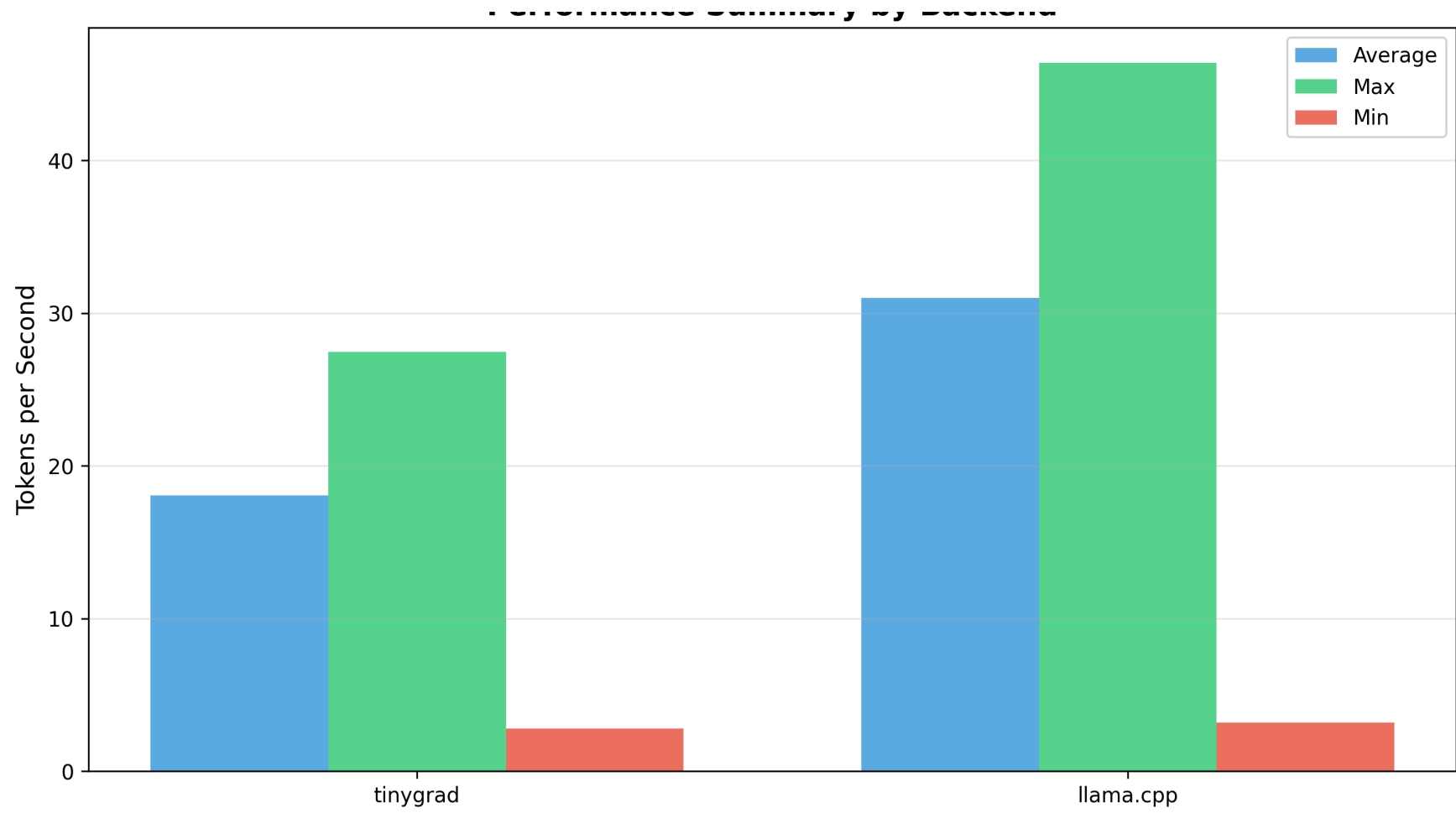
# Results: Speedup Analysis



## Observations:

- llama.cpp shows 16.6x speedup over tinygrad for NF4
- tinygrad leads by 8.0x for float16 workloads
- INT8 and default show modest llama.cpp advantage (1.2-2.5x)

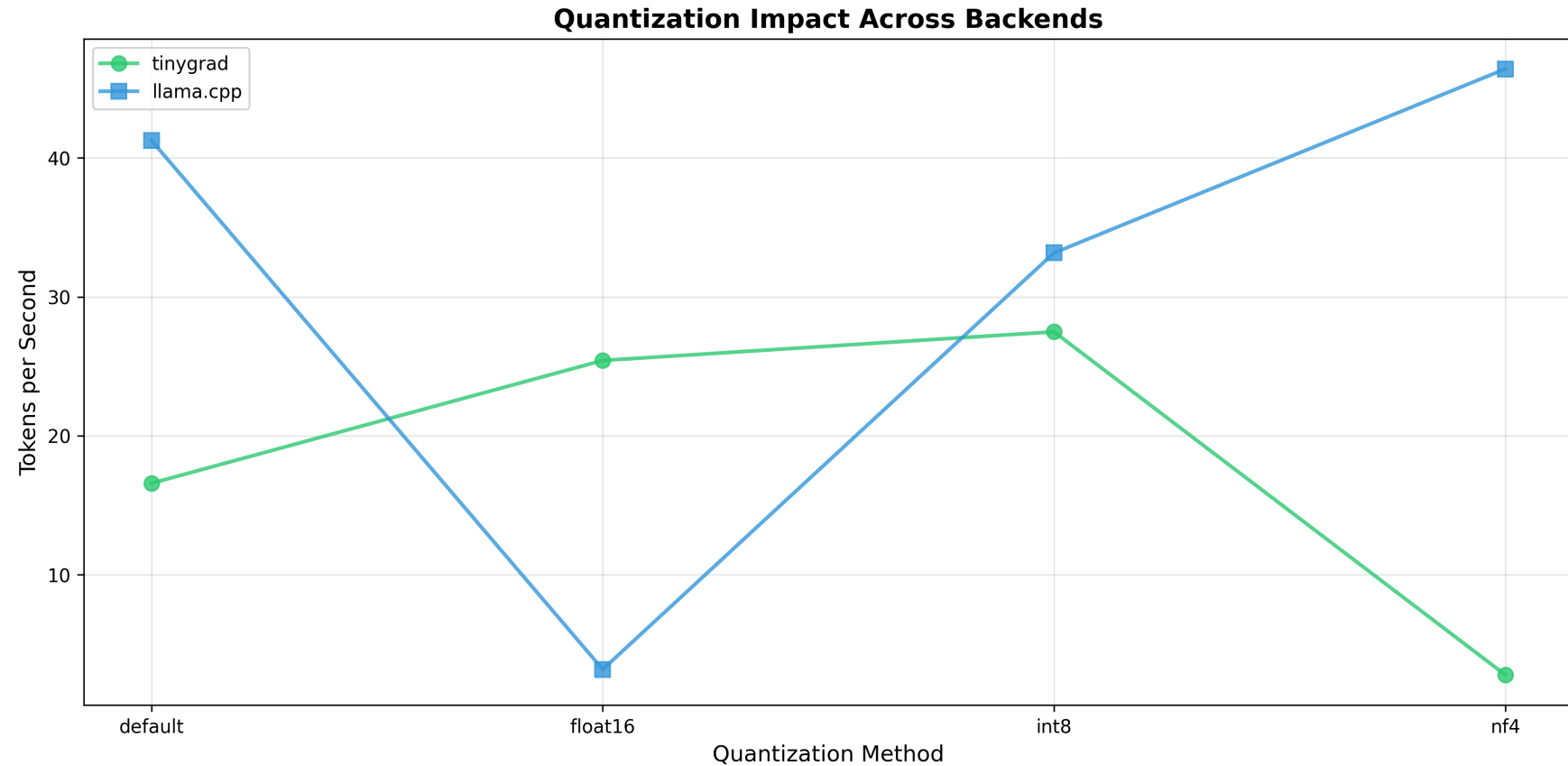
# Results: Performance Summary



## Backend comparison:

- llama.cpp: Average 31.0 tok/s, peak 46.4 tok/s (NF4)
- tinygrad: Average 18.1 tok/s, peak 27.5 tok/s (INT8)
- Overall llama.cpp shows 1.7x better average performance

# Results: Quantization Impact

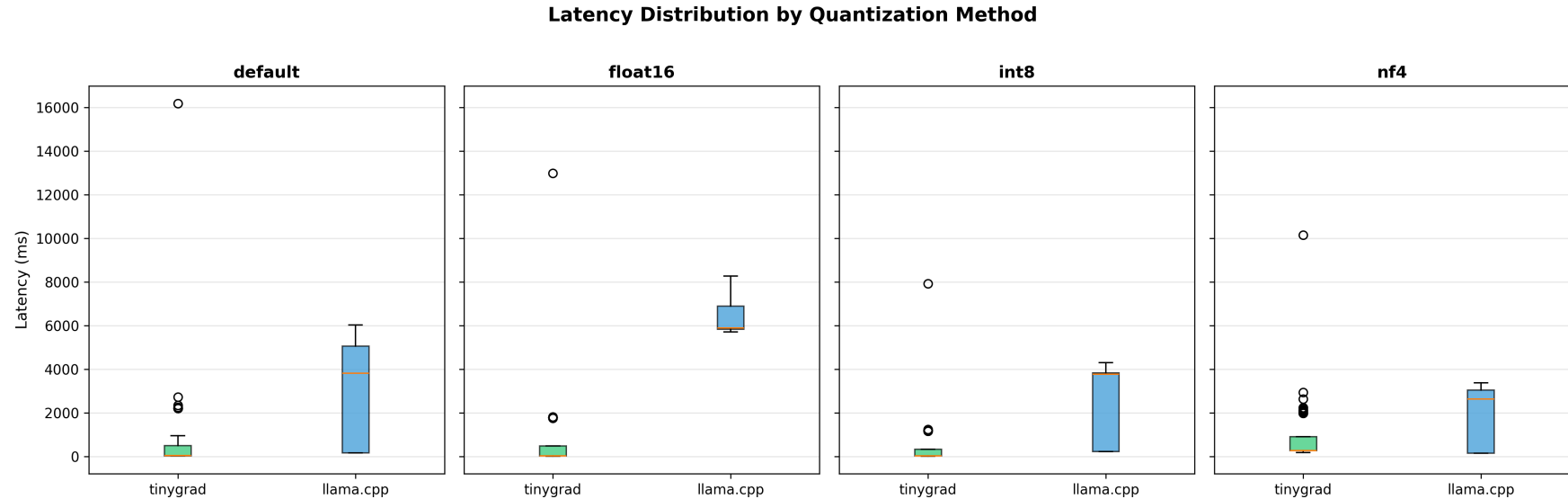




## Trends:

- Different backends favor different quantization strategies
- llama.cpp benefits most from aggressive quantization (NF4)
- tinygrad shows more consistent performance across methods

# Results: Latency Analysis

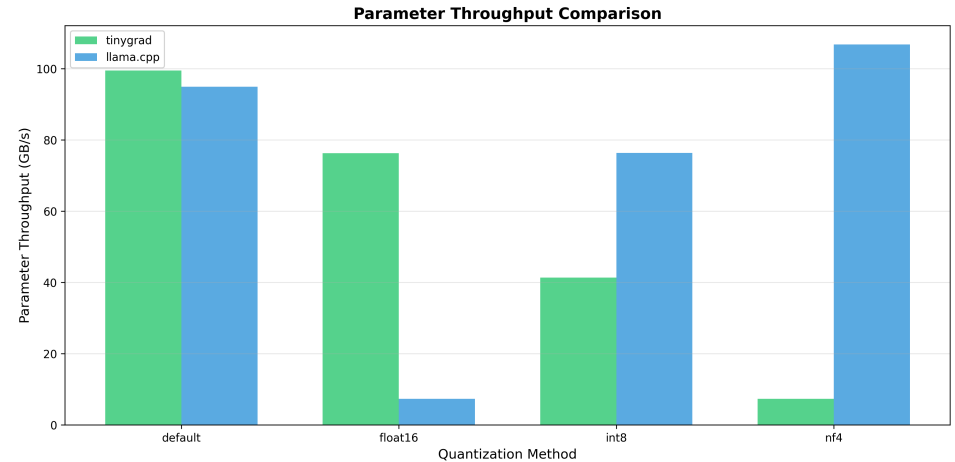
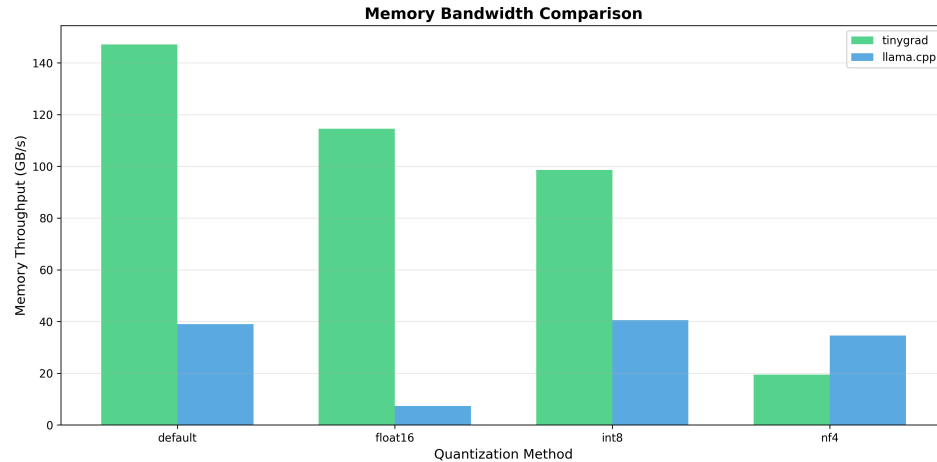


## Latency variance:

- Box plots show distribution of per-token generation time
- llama.cpp shows lower variance for NF4 and default

- `tinygrad` has more consistent latency across quantizations

# Results: Memory & Parameter Throughput

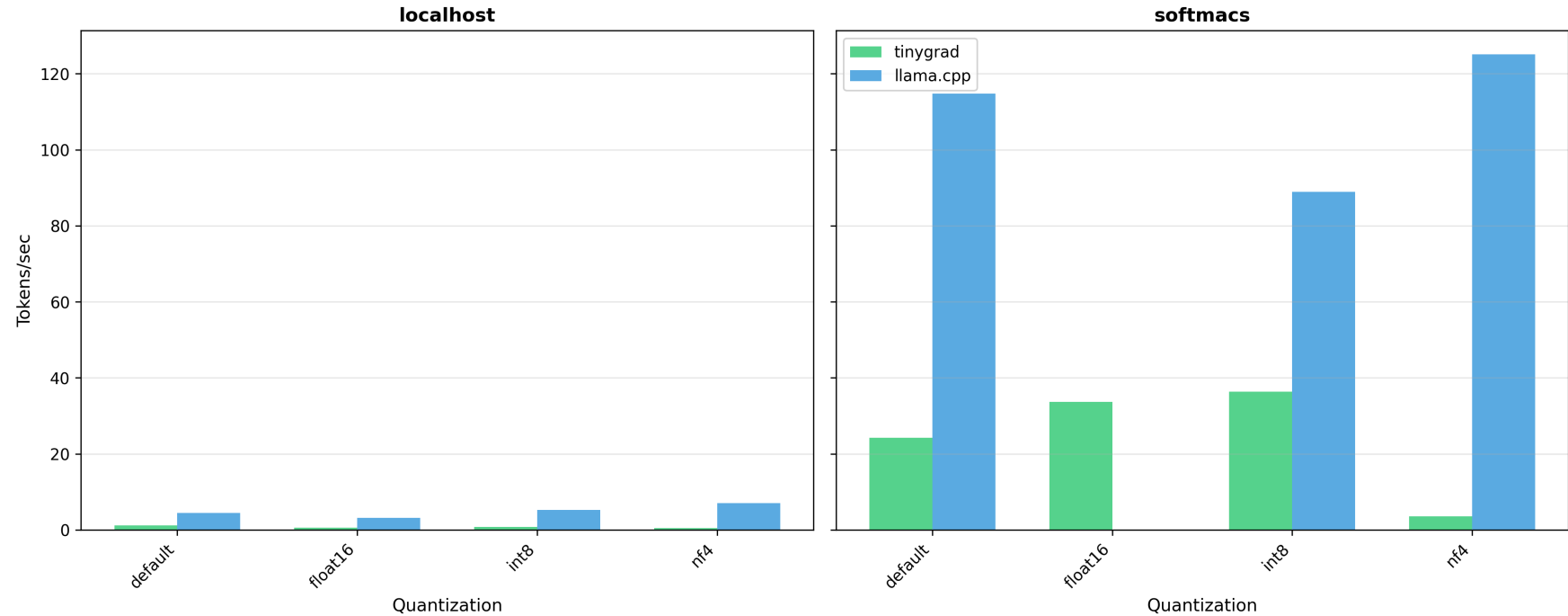


## Observations:

- Memory bandwidth closely correlates with tokens/sec
- Parameter throughput shows compute efficiency per quantization

# Results: Multi-Device Comparison

Performance Comparison Across Devices



## **Cross-device insights:**

- MacBook (softmacs) shows stronger performance overall
- Android device (localhost) exhibits different characteristics
- Backend choice impacts relative performance across hardware

# Results: Performance Summary Table

Backend	Default	FP16	INT8	NF4
llama.cpp	41.3 tok/s	3.2 tok/s	33.2 tok/s	46.4 tok/s
tinygrad	16.6 tok/s	25.4 tok/s	27.5 tok/s	2.8 tok/s

**Note:** Results from Llama-3.2-1B-Instruct on MacBook (Metal). Performance varies with context length and workload.

# Challenges Encountered

## Software Compatibility

- Different backends for ARM vs x86
- MLC-LLM build complexity

## Implementation

### Inconsistencies

- Quantization standards differ across backends
- Leads to performance discrepancies

## Engineering Challenges

- Creating durable benchmarking suite
- Handling device-specific configurations

## Android Setup

- SSH into Pixel devices
- OpenCL library path configuration



# Contributions

## Reproducible Framework

- Open-source benchmarking toolkit
- Standardized data format
- Easy to extend to new devices

## Public Codebase

- MIT licensed
- Well-documented
- GitHub repository

## Empirical Results

- Cross-device performance data
- Quantization trade-off analysis
- Downstream accuracy evaluation

## Community Benefit

- Others can benchmark their devices

- Append results to shared data bank

## Future Work

- **Enterprise GPUs:** Extend benchmarks to A100, H100
- **More Models:** Phi-3 mini, Qwen2.5-3B, Llama-3.1-8B
- **Energy Profiling:** Watt/token measurements
- **KV-Cache Quantization:** INT8/INT4 cache strategies
- **Longer Contexts:** Prefill tokens 256, 1024, 2048

## Potential Extensions

- Automated setup script (curl | sh)
- CI/CD backend for continuous benchmarking
- Public data aggregation platform

# Conclusion

- **Quantization enables practical edge LLM deployment**
  - 4-bit models run on smartphones with acceptable performance
- **Trade-offs are workload-dependent**
  - Memory-constrained? → INT4/NF4
  - Accuracy-critical? → INT8 or FP16
- **Framework enables reproducible research**
  - Standardized benchmarks across diverse hardware
  - Community can contribute additional results

**Code:** [github.com/spikedoanz/t-eai-project](https://github.com/spikedoanz/t-eai-project)

# References

1. **llama.cpp** – Georgi Gerganov et al. High-performance LLM inference in C/C++.  
<https://github.com/ggerganov/llama.cpp>
2. **tinygrad** – George Hotz et al. A simple deep learning framework.  
<https://github.com/tinygrad/tinygrad>
3. **MLC-LLM** – Machine Learning Compilation for LLMs.  
<https://github.com/mlc-ai/mlc-llm>
4. **Verifiers** – Prime Intellect. LLM evaluation framework.  
<https://github.com/PrimeIntellect-ai/verifiers>
5. **QLoRA** – Dettmers et al. (2023). Efficient Finetuning of Quantized LLMs.
6. **GPTQ** – Frantar et al. (2022). Accurate Post-Training Quantization.
7. **AWQ** – Lin et al. (2023). Activation-aware Weight Quantization.

# Thank You!

Questions?

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[github.com/spikedoanz/t-eai-project](https://github.com/spikedoanz/t-eai-project)

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