Offloading and Quantizing Llama-3.1-8B-Instruct for Resource-Constrained Inference on NVIDIA RTX 3060 Ti

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Abstract

Large language models (LLMs) like **Llama-3.1-8B-Instruct** present substantial memory constraints, limiting deployment on resource-constrained hardware. We explore strategies to enable efficient inference of Llama-3.1-8B-Instruct on an **NVIDIA RTX 3060 Ti GPU(8G RAM)**, which lacks sufficient VRAM for standard model execution.

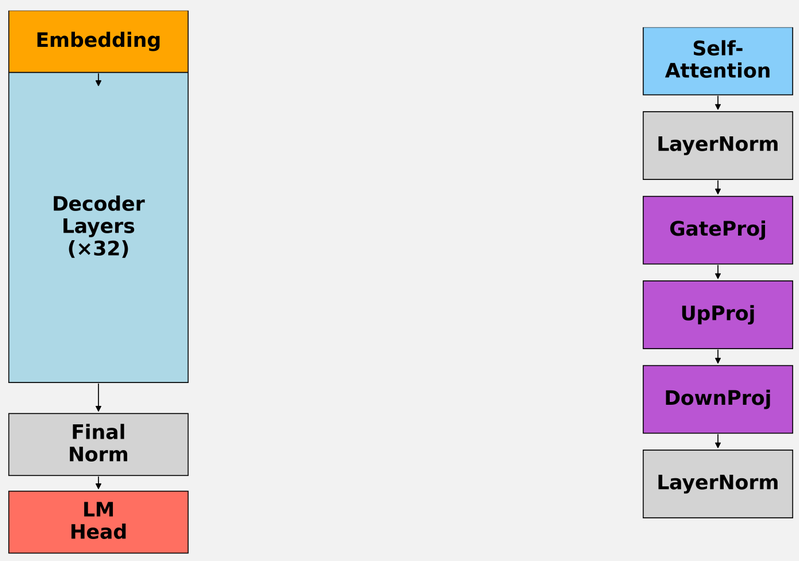
We begin by attempting to load the model in full precision, which immediately triggers **Out-of-Memory (OOM)** errors. To address this, we apply:

- **Post-training quantization**: Compressing the model by reducing weight precision (e.g., from FP32 to INT8 or INT4) without retraining.
- **Mixed-precision quantization**: Using different bit-widths (e.g., 8-bit for critical layers, 4-bit elsewhere) to balance efficiency and accuracy.
- **Dynamic offloading**: Actively transferring non-critical tensors (e.g., key-value cache) between GPU VRAM and CPU RAM/disk to fit large models on limited-memory GPUs.

Figure 1: Illustration of dynamic offloading across memory hierarchies during inference.

Model Architecture

- **Model**: Llama-3.1-8B-Instruct
- **Architecture**: Transformer-based architecture with 8 billion parameters
- **Layers**: 32 transformer layers
- **Hidden Size**: 5120
- **Activation Function**: GeLU (Gaussian Error Linear Unit)



(a) The overview of Llama-3.1-8B-Instruct architecture.

(b) Layer-wise parameter distribution in Llama-3.1-8B-Instruct.

Figure 2: Llama-3.1-8B-Instruct architecture and layer-wise parameter distribution.

References

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[2] Amir Gholami et al., "A Survey of Quantization Methods for Efficient Neural Network Inference," arXiv:2103.13630, 2021.

[3] Ying Sheng et al., "FlexGen: High-Throughput Generative Inference of Large Language Models with a Single GPU," arXiv:2303.06865, 2023.

[4] Woosuk Kwon et al., "Efficient Memory Management for Large Language Model Serving with PagedAttention," arXiv:2309.06180, 2023.

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Preliminary Attempt

We attempted to load the full-precision Llama-3.1-8B-Instruct on RTX 3060 Ti immediately triggered CUDA OOM errors, confirming that direct inference is infeasible without optimization.

```
True
0
NVIDIA GeForce RTX 3060 Ti
Loading checkpoint shards:   0%|
[00:00<?, ?it/s]Killed
```

Figure 3: Llama-3.1-8B-Instruct model architecture and parameter distribution.

Experiment

To evaluate the impact of quantization and offloading strategies on Llama-3.1-8B-Instruct inference, we conduct experiments on an NVIDIA 3060 Ti GPU. We assess performance based on:

- **OOM(Out of memory) Error**: The system (usually CPU or GPU) runs out of available memory to store or compute data
- **Inference Time**: Time taken to process a batch of inputs (in seconds)
- **Perplexity**: Language model evaluation metric (lower is better)

Table 1. Performance metrics for Llama-3.1-8B-Instruct with base configurations.

Configuration	OOM Error	Inference Time (s)	Perplexity
Full-precision Model (FP32)	Yes	N/A	N/A
Baseline (PTQ with INT8)	No	33.320	7.293

Mixed-Precision Quantization

Table 2. Performance metrics for model with mixed-precision configurations.

Configuration	OOM Error	Inference Time (s)	Perplexity
Baseline (PTQ with INT8)	No	33.320	7.293
Mixed Precision (8b L4 & L7, 4b elsewhere)	No	13.141	7.291

Mixed-Precision Quantization With Offloading

Table 3. Performance metrics for model with best performance configurations.

Configuration	OOM Error	Inference Time (s)	Perplexity
HuggingFace's Offloading	No	205.508	9075.724
Our Offloading Strategy	No	159.728	7.234
Our Offloading Strategy with Mixed Precision	No	149.051	7.291

Conclusion

We explored the feasibility of running the Llama-3.1-8B-Instruct model on limited GPU resources using quantization and offloading techniques. These results highlight the practicality of combining quantization and offloading for resource-constrained environments.

Future Improvements

We aim to extend our work along several directions:

- **Larger Model Experiments**
  - Test Llama-3.1-13B model with quantization and offloading.
- **Hardware Deployment**
  - Re-run all experiments directly on other GPU-insufficient hardware, like embedded systems.
  - Take more different configure and compare their speed, memory usage, and performance.