Grouped-Query Attention (GQA)

Comprehensive Demo and Analysis

GQA reduces KV cache memory by sharing key/value heads
across groups of query heads. This unifies MHA, GQA, and MQA
along a single axis: the number of KV heads.

Used by: Llama 2 70B (8 KV heads), Mistral 7B (8 KV heads),
Llama 3, and all modern production LLMs.

Random seed: 42
Number of visualizations: 6
Examples: 6

Generated by demo.py

Summary of Findings

1. MHA vs GQA vs MQA: GQA with h_kv=2 saves 37.5% of KV projection parameters and reduces KV cache by 4x. MQA achieves maximum 7/8 savings but at the cost of representational diversity.

2. KV Cache Memory: Cache scales linearly with h_kv and L. Llama 2 70B uses 1.25 GB for KV cache (8x reduction vs hypothetical MHA at 10 GB). Mistral 7B uses 1.0 GB at 8K context. All values B=1, FP16.

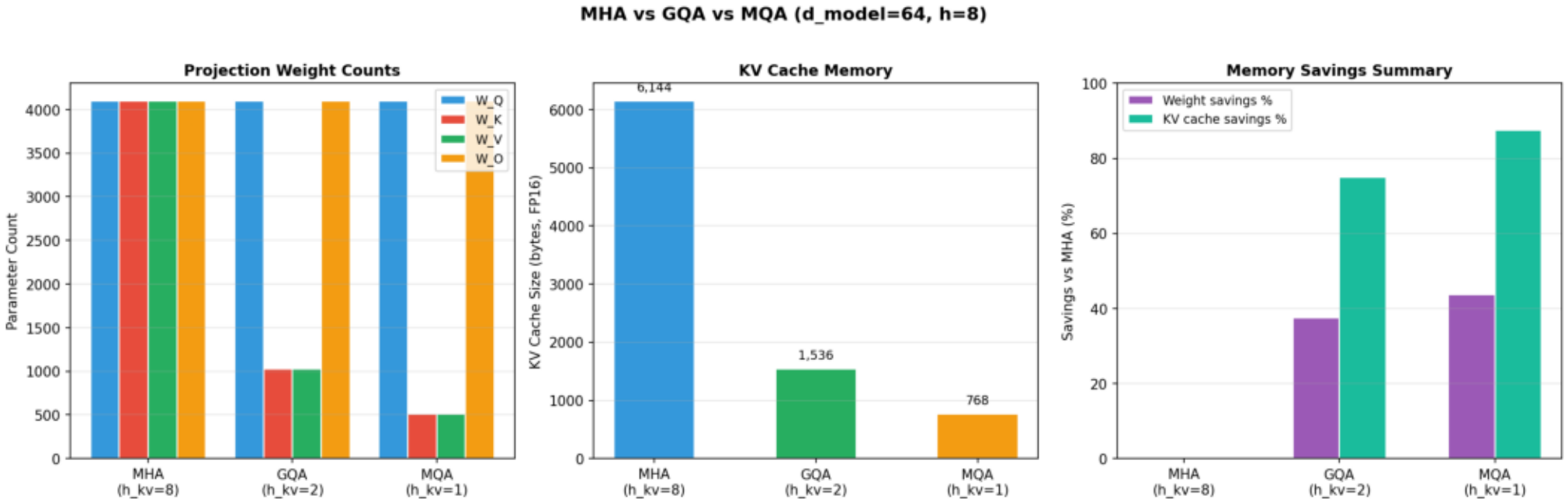
3. Attention Patterns: Heads within a GQA group share K/V but produce different attention patterns via independent Q projections. This is the key insight -- diversity comes from Q, not KV.
   CAVEAT: Shown patterns are from random init, not trained.

4. FLOPs: Attention core FLOPs (QK^T, softmax, AV) are IDENTICAL across MHA/GQA/MQA since all h query heads still compute attention. Only projection FLOPs differ. At long sequences, variants converge.

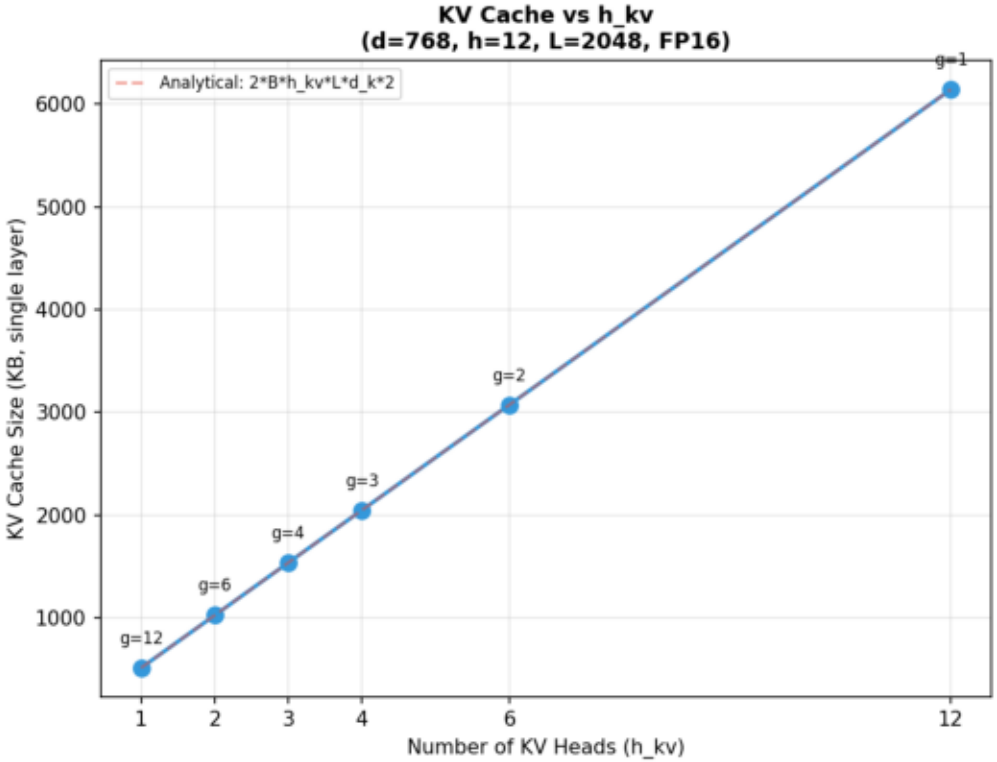
5. Gradient Flow: Per-KV-head gradients increase with group size because reduce_kv_grad sums g gradient contributions. Scaling is superlinear, exceeding sqrt(g) due to correlations from shared K/V.
   Backward correctness verified via numerical gradient check.

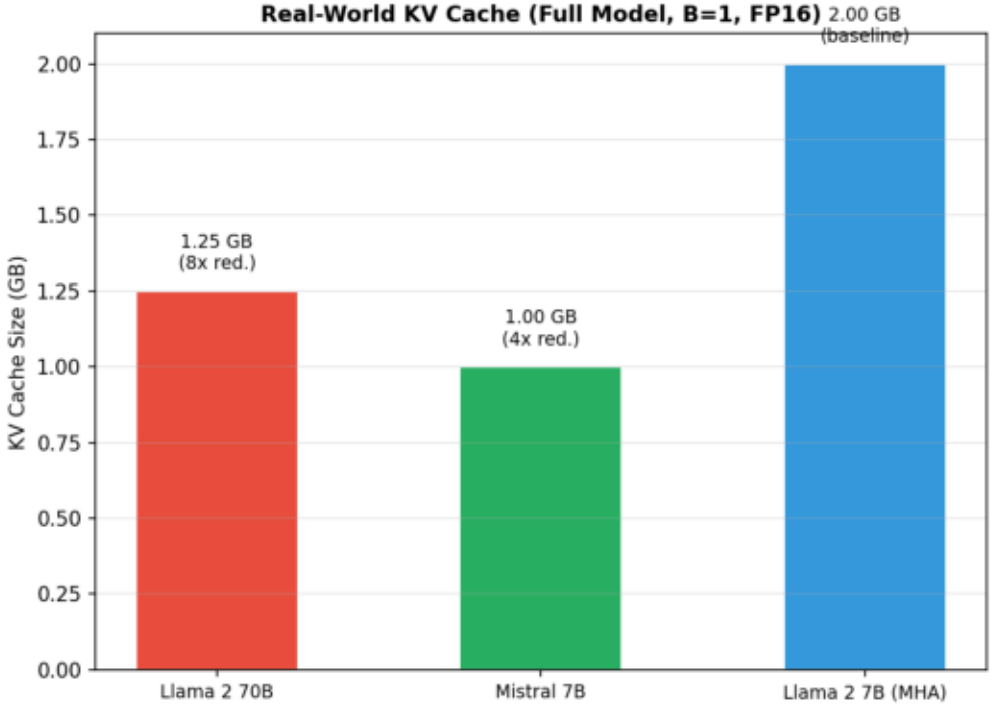
6. Scaling: KV cache is the key bottleneck for long-context inference. With h_kv=8, a 32-layer model can handle 320K+ tokens within 80GB. MHA (h_kv=32) would be limited to ~160K tokens in the same budget.

Example 1: MHA vs GQA vs MQA -- Parameters and KV Cache

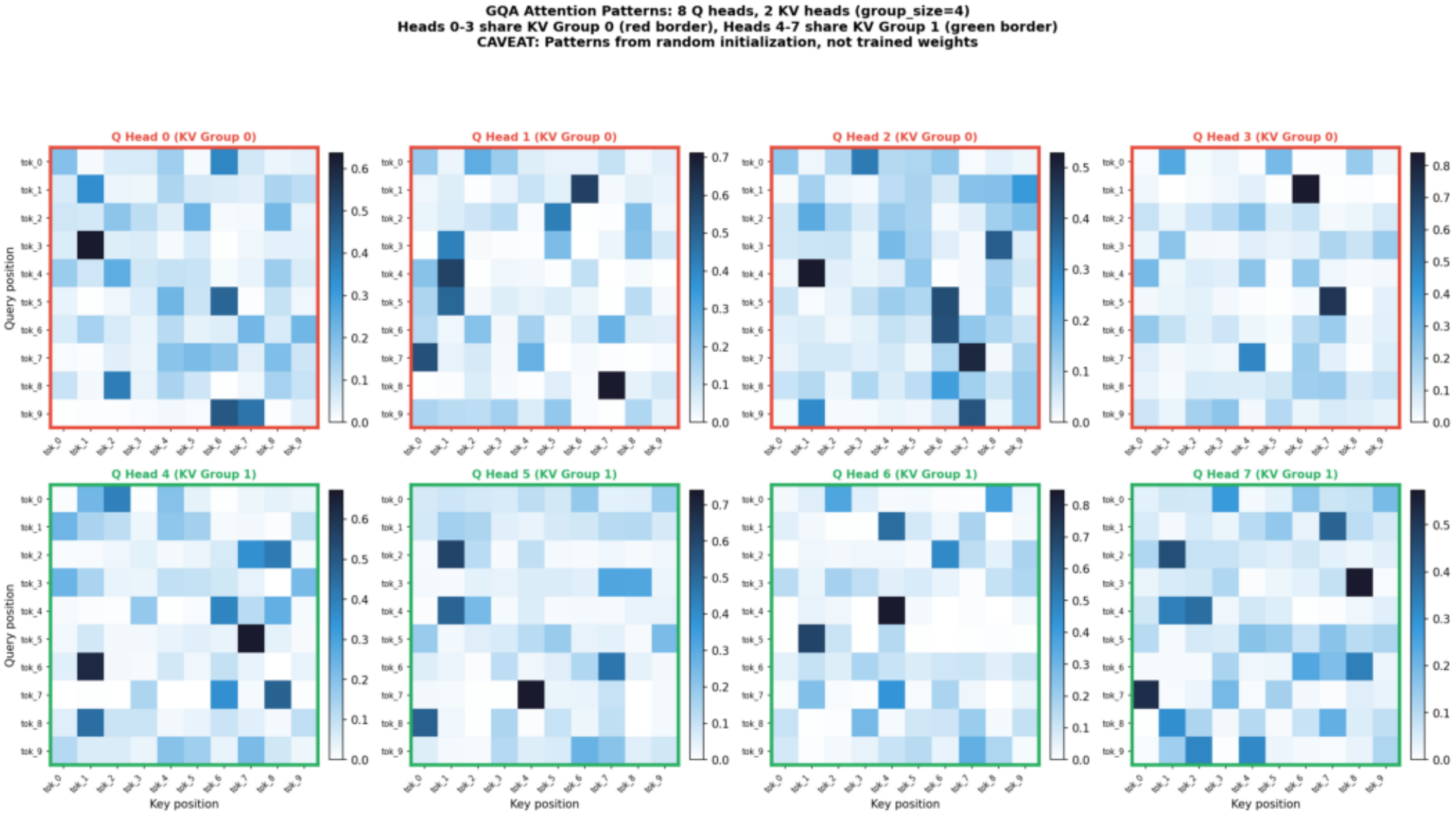


Example 2: KV Cache Memory Analysis with Real-World Configs

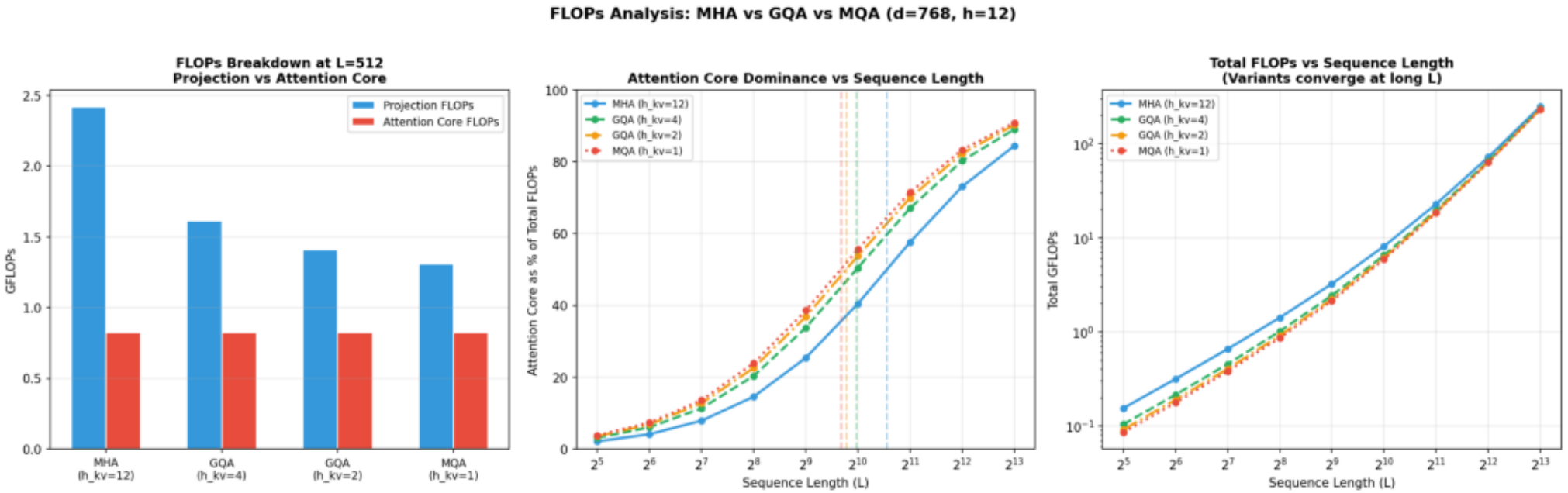




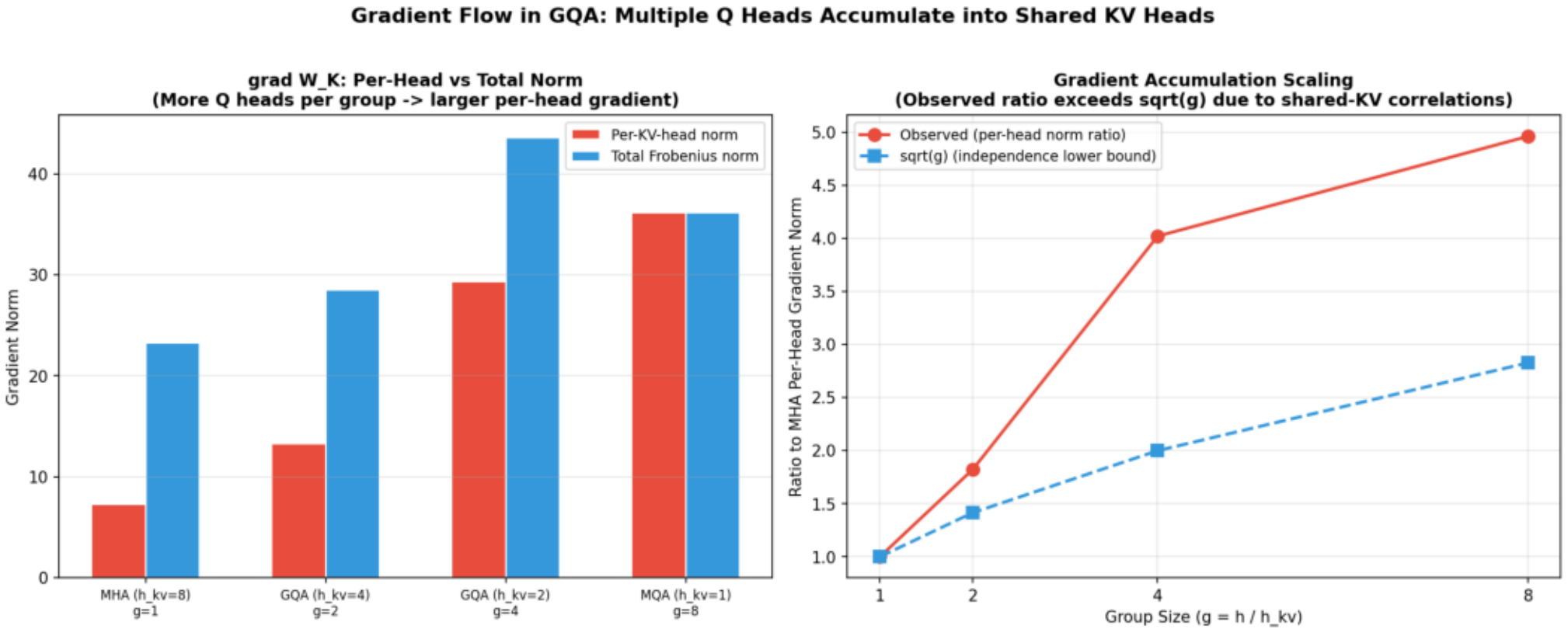
Example 3: GQA Attention Patterns (Shared KV Groups)



Example 4: FLOPs Breakdown -- Projection vs Attention Core



Example 5: Gradient Flow and Accumulation Verification



Example 6: Scaling Analysis -- Memory Heatmap and Recommendations