Understanding and Harnessing Sparsity for Unified Multimodal Models

Anonymous authors
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Abstract

Large multimodal models have achieved remarkable progress in both understanding and generation. Recent unified multimodal models integrate heterogeneous components so that a single framework can support both capabilities. This unification, however, can introduce inference inefficiency: a given task or sample may require only a subset of the model's full capacity. How this inefficiency differs across the understanding and generation components remains underexplored. In this work, we analyze unified multimodal model components with training-free pruning probes, covering both depth pruning and width reduction. We find that the understanding component is compressible for both understanding and generation tasks, with substantially greater tolerance in generation. In contrast, generation components are highly sensitive to static compression, with performance degrading sharply even at moderate compression ratios. Motivated by the dynamic activation patterns observed across samples, we propose Mixture-of-Experts (MoE) Adaptation for the generation component. The method partitions MLP neurons into experts and sparsely activates them to recover generation quality under a reduced active parameter budget. We first validate sparse activation through expert-frozen tuning and then show that fully trainable adaptation provides additional gains. On BAGEL and GenEval, the adapted model achieves performance comparable to the dense baseline while activating about half of the generation-component neurons; we further report latency and memory measurements to characterize realized efficiency rather than relying on activated-parameter counts alone. The code will be released upon acceptance.

1 Introduction

Large-scale multimodal models have recently achieved strong results in both multimodal understanding (Liu et al., 2023; Li et al., 2023; Dai et al., 2023; Lu et al., 2024; 2023) and generation (Ramesh et al., 2021; Saharia et al., 2022a; Peebles & Xie, 2023). Traditionally, these two tasks were studied through separate model families: *understanding models* for vision-language reasoning with textual outputs, and *generative models* for image synthesis. While effective for task-specific purposes, this separation limits the ability of a single model to reason over multimodal inputs and generate multimodal outputs within the same system. Recent research has therefore explored unified multimodal models (Wu et al., 2024; Chen et al., 2025; Deng et al., 2025; Liang et al., 2025; AI et al., 2025), which integrate heterogeneous components such as vision encoders (Dosovitskiy et al., 2021), language backbones (Dubey et al., 2024; Yang et al., 2024), and image decoders (Peebles & Xie, 2023; AI et al., 2025). These architectures support both understanding and generation in a single framework, making them a promising direction for general-purpose multimodal intelligence.

However, this unification comes at a substantial ***efficiency cost***, because many tasks or input samples may require only a subset of the unified model's capacity Frankle & Carbin (2018); Xu et al. (2021). Three observations suggest that this inefficiency should be studied at the component, task, and input levels: (1) ***Component-wise redundancy***: the understanding and generation components follow distinct computation patterns and serve different functional roles, leading to different levels of redundancy. (2) ***Family-specific activation***: inputs from different task families tend to activate only a limited subset of parameters during inference, leaving much of the shared capacity underutilized Kudugunta et al. (2021); Sarkar et al. (2023).

(3) ***Input variability***: even within the same task, different input queries can activate different portions of the model, further complicating efficient compute allocation Liu et al. (2024); Luo et al. (2025).

Motivated by these factors, we systematically analyze how unified multimodal models allocate and use parameters across components, tasks, and inputs. We first adopt ***training-free pruning*** as a probing methodology (Gromov et al., 2025; Men et al., 2024; He et al., 2024; Ma et al., 2023; Xia et al., 2023), which lets us infer structural importance by removing structures and measuring the resulting performance change. We begin by analyzing the understanding components, which serve as shared modules that process inputs from multiple modalities and produce language representations or embeddings that guide the generation components. Our results demonstrate that the understanding components are highly compressible in multimodal generation tasks but less so in understanding tasks. We also observe clear family-specific activation patterns: understanding and generation inputs predominantly activate different model partitions, underscoring the need for family-aware activation.

In contrast, generation components (e.g., image generators) are far less tolerant to static compression. Their activation patterns vary substantially across samples and timesteps, so static pruning cannot accommodate the required activation shifts and leads to a sharp drop in generated image quality. To address this issue, we propose ***Mixture-of-Experts (MoE) Adaptation***, where MLP neurons are partitioned into experts so that the model can selectively activate different neuron subsets for different inputs. To align the model with sparsely routed inference, we first introduce expert-frozen tuning, which freezes all experts and updates the router and other remaining parameters. Building on this initialization, we further perform end-to-end MoE training, yielding additional improvements. We validate this full training-aware adaptation as a BAGEL/GenEval case study: the adapted BAGEL model (Deng et al., 2025) matches the performance of the dense baseline while activating about half of the generation-component neurons. We additionally report measured latency and memory to distinguish reduced activated parameters from realized system speedup. Our contributions are threefold:

- We show that the understanding component in unified multimodal models has substantial structural redundancy and can be compressed more aggressively when it supports generation tasks.
- We introduce a training-free neuron partition analysis that uncovers family-specific activation patterns and redundancy within the understanding component, providing a basis for family-aware compression.
- To address the high compression sensitivity of the generation component, we design MoE Adaptation and validate it on BAGEL, preserving generation quality under sparse activation while reporting runtime and memory behavior.

2 Related Work

Multimodal Models for Understanding and Generation Early multimodal research typically treated understanding and generation as separate tasks, leading to distinct architectural paradigms (Li et al., 2023; Dai et al., 2023; Zhu et al., 2023). On the one hand, multimodal large language models (MLLMs) extend language models to handle input tokens from multiple modalities, such as LLaVA (Liu et al., 2023), which augments the LLaMA backbone (Touvron et al., 2023a) with visual tokens for vision–language understanding. On the other hand, multimodal generative models use dedicated generators to synthesize high-fidelity visual outputs (Ramesh et al., 2022; Saharia et al., 2022b; Chang et al., 2023). For instance, Diffusion Transformers (DiT) (Peebles & Xie, 2023) show that iterative denoising with transformer-based backbones can generate high-quality images guided by natural language. More recently, several works aim to unify understanding and generation within a single framework (Wu et al., 2024; Chen et al., 2025; Zhang et al., 2025). BAGEL (Deng et al., 2025) employs a mixture-of-transformers design (Liang et al., 2025) to separate understanding and generation modules, while Ming-Omni (AI et al., 2025) uses a mixture-of-experts backbone with multimodal understanding and modality-specific decoders for generation. Although these unified models are versatile, their architectural complexity creates new efficiency challenges that remain underexplored.

Model Compression toward Parameter Efficiency As large language models continue to scale, their size introduces substantial redundancy and raises practical challenges for deployment. Network pruning (Liu et al., 2019; Cheng et al., 2024) identifies and removes redundant structures, improving parameter efficiency

and reducing inference cost. For instance, (Gromov et al., 2025) demonstrated that many deep layers in large language models are relatively unimportant and that comparable performance can still be maintained after removing them. Within individual layers, *width compression* provides a complementary way to reduce parameter count by shrinking intermediate or hidden dimensions (Ma et al., 2023; Xia et al., 2023). While unimodal compression techniques can be transferred to vision-language models that take multimodal inputs and produce language responses (Sung et al., 2024; Lin et al., 2024; He et al., 2025b), it remains unclear how such methods behave in unified models that contain both understanding and generation components. Building on prior efforts, we study redundancy in unified multimodal models where heterogeneous components play distinct roles. This component-aware perspective motivates compression and sparse activation strategies aligned with both multimodal understanding and generation.

3 Preliminaries: Unified Multimodal Models

Unified multimodal models integrate multimodal understanding and generation within a single framework.

Understanding Given a unified multimodal model, let $\mathbf{x}$ denote the multimodal input, and $\mathbf{y}$ denote the corresponding output. For understanding tasks, the model predicts textual outputs in an autoregressive manner:

$$p(\mathbf{y}_{\text{und}} \mid \mathbf{x}; \theta_{\text{und}}) = \prod_{t=1}^{T} p(y_t \mid y_{<t}, \mathbf{x}; \theta_{\text{und}}) \,, \tag{1}$$

where θ_{und} denotes the parameters of the understanding component and $\mathbf{y}_{\text{und}} = (y_1, y_2, \ldots, y_T)$ denotes the output token sequence.

Generation For generation tasks, the unified model uses the understanding component to process an instructional input $\mathbf{x}_{\text{inst}}$ (e.g., text prompts and reference images), producing conditional features $f_{\text{und}}(\mathbf{x}_{\text{inst}}; \theta_{\text{und}})$. The generation component, parameterized by θ_{gen}, synthesizes the output $\mathbf{y}_{\text{gen}}$ conditioned on these features and an additional generative input $\mathbf{z}$ (e.g., random noise in diffusion models):

$$\mathbf{y}_{\text{gen}} \sim p(\mathbf{y}_{\text{gen}} \mid f_{\text{und}}(\mathbf{x}_{\text{inst}}; \theta_{\text{und}}), \mathbf{z}; \theta_{\text{gen}}) \,, \tag{2}$$

In unified multimodal models, the understanding component processes inputs from multiple modalities, while the generation component operates on non-text outputs such as image or audio synthesis. Because these components have different objectives and computational pathways, they can respond differently to compression.

4 Methodology

We first introduce training-free pruning techniques for probing architectural redundancy, then propose a training-aware MoE adaptation that uses dynamic sparsity to preserve performance under sparse activation. Figure 1 summarizes the two strategies.

4.1 Training-free Compression Strategies

Depth Pruning via Layer Dropping Transformer-based large language models consist of multiple layers, and increasing depth is an effective way to improve performance. However, depth can also introduce structural redundancy. Following (Gromov et al., 2025; Men et al., 2024; He et al., 2024), we measure the redundancy of a layer as:

$$S_l = \text{CosineSim}(\mathbf{x}_l, \mathbf{y}_l), \tag{3}$$

where $\mathbf{x}_l$ and $\mathbf{y}_l$ are the input and output of the l-th layer. Higher similarity indicates that the layer applies a smaller transformation and is therefore more redundant. This metric has been effective in unimodal LLMs such as Mistral (Jiang et al., 2023) and LLaMA (Touvron et al., 2023b; Dubey et al., 2024); here we use it to probe unified multimodal models.

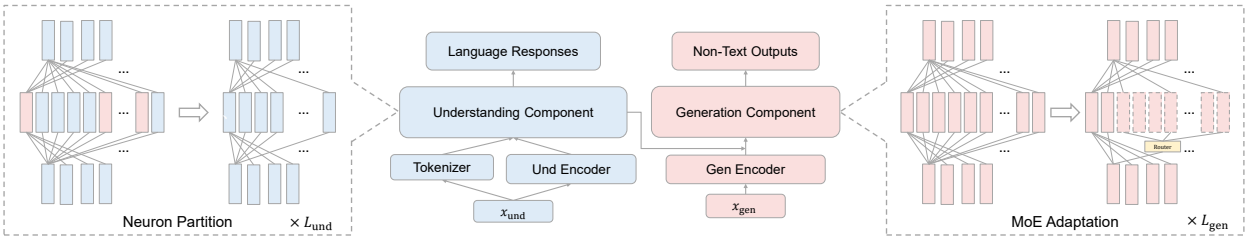


Figure 1: Overview of our training-free compression and training-aware MoE adaptation strategies.

Width Reduction via Neuron Partition In addition to depth, width, particularly in MLP layers, is a major source of model capacity. In Transformer MLP layers, the input is expanded from dimension d to dm, activating dm hidden neurons before being projected back to d. This expansion increases capacity but can also introduce neuron-level redundancy. We therefore propose neuron partitioning, which separates hidden neurons into important and less important subsets, preserves the former, and prunes the latter for structured width reduction.

To measure neuron importance, we take inspiration from Wanda (Sun et al., 2024), which combines weight magnitudes and activation statistics, and extend it from unstructured weight-level pruning to a structured neuron-level metric. Given an input $x \in \mathbb{R}^{s\times d}$, the hidden activations $h \in \mathbb{R}^{s\times dm}$ and output $y \in \mathbb{R}^{s\times d}$ of a Gate-Up-Down MLP are:

$$h = \left(\mathrm{SiLU}(xW_g^\top)\right) \odot (xW_u^\top), \qquad y = hW_d^\top, \tag{4}$$

where $W_g, W_u \in \mathbb{R}^{dm\times d}$ are the gate-projection matrix and up-projection matrix, $h \in \mathbb{R}^{s\times dm}$ is the gated activation, and $W_d \in \mathbb{R}^{d\times dm}$ is the down-projection matrix. The contribution of the i-th neuron to the final output is:

$$\Delta y_i = h_i W_{d,i}^\top, \tag{5}$$

with $W_{d,i}$ being the i-th column vector of W_d. If the i-th neuron is pruned, the induced output error norm can be approximated by:

$$\|\Delta y\|_2 \approx \|h_i W_{d,i}^\top\|_2. \tag{6}$$

Given all inputs from the calibration dataset $\mathcal{D}$, the expected accumulated error of each neuron is used as its importance metric:

$$s_i = \mathbb{E}_{x\sim\mathcal{D}}\left[|h_i| \cdot \|W_{d,i}^\top\|_2\right], \tag{7}$$

where $|h_i|$ measures the average activation magnitude of the i-th neuron and $\|W_{d,i}\|_2$ quantifies its amplification effect on the output. Neurons with larger scores are retained, while those with smaller scores are removed. Unlike unstructured pruning, which zeros individual weights, our approach removes entire neurons. Concretely, this removes column i from W_d and row i from both W_u and W_g, yielding a structured reduction.

Unified models integrate diverse task families within a single architecture, and different families can activate different neuron subsets. Figure 2 illustrates the distinct neuron partitions within the understanding component. We first identify the top 50% of neurons by importance score for understanding and generation, respectively. We then measure the overlap subset between the two top-50% sets and report this overlap share relative to all neurons in the layer. Since the two top-50% sets have the same size, the one-side non-overlap share is simply 50% minus the overlap share. The relatively low overlap share suggests that understanding and generation inputs activate distinct neuron subsets within the understanding component. We therefore align calibration samples with the target task family before applying the neuron-level importance metric, which improves the identification of family-relevant neurons.

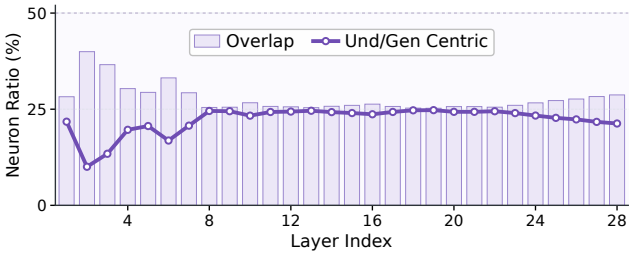


Figure 2: Top-50% neuron-set overlap between understanding and generation calibration.

4.2 Training-Aware MoE Adaptation

Figure 3 visualizes active neurons (those consistently ranked within the top 50% by activation score) and inactive neurons (those that never enter the top 50%) across layers of the generation component over multiple prompts and time steps. Only a small subset of neurons remains consistently active throughout inference, while most neurons exhibit sample-dependent activation patterns. This input-dependent activation aligns with the motivation for Mixture-of-Experts (MoE) architectures. We leverage it through two stages: *Expert Partition* and *MoE Adaptation*.

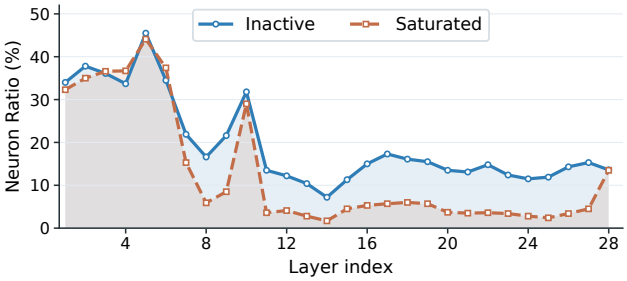


Figure 3: Inactive and saturated neurons in the generation component across layers.

Expert Partition To separate universal and sample-specific capacity (He et al., 2023; Dai et al., 2024), we partition MLP neurons into shared and routed experts using cumulative importance over calibration samples. For each neuron, we compute its cumulative importance score using Equation 7. Neurons with scores above a threshold are selected as shared experts E_s, preserving features that consistently benefit multiple samples. The remaining neurons, whose relative importance is more sample-dependent, are allocated to routed experts $E_r^{(1)}, \ldots, E_r^{(n)}$ by ranked importance. Specifically, neurons are sorted in descending importance order and assigned to experts in alternating forward and reverse order (i.e., $E_r^{(1)}$ to $E_r^{(n)}$, then $E_r^{(n)}$ back to $E_r^{(1)}$), balancing total importance across experts.

MoE Adaptation After expert partition, we insert one router per layer to dynamically select routed experts for each input. The MoE layer output is:

$$\mathrm{MoE}(x) = f_{\mathcal{S}}(x) + \sum_{j \in \text{Top-}k(\mathcal{G})} \mathcal{G}_j \cdot f_{\mathcal{R}_j}(x), \tag{8}$$

where $\mathcal{G}$ denotes the gating function, and $f_{\mathcal{S}}$ and $f_{\mathcal{R}}$ are the transformations of the shared and routed experts. The original MLP layer is a special case of Equation 8, where all experts are selected and their gating scores are uniformly set to 1. To smooth the transition from dense to sparse activation, we relax the constraint that gating scores sum to 1 and reparameterize them as $(1 + \mathrm{Router}(x))$, with the router initialized to zero. The conversion partitions the original MLP weights into experts rather than duplicating a full dense MLP for every expert, so the main additional parameters come from lightweight routers instead of multiple complete expert copies. To adapt the model to sparse routed inference, we perform Expert-Frozen Tuning as a cold-start phase of MoE Adaptation, where experts remain fixed while the router and other parameters are trainable. This stage preserves pretrained expert knowledge while establishing an initial routing policy. We then release the freezing constraint for full MoE Adaptation.

5 Experiments

5.1 Experimental Setup

Models We evaluate three representative open-source unified models: BAGEL (Deng et al., 2025), Ming-Omni (AI et al., 2025), and Qwen-Image (Wu et al., 2025). For the understanding component, BAGEL and Qwen-Image rely on a VLM derived from Qwen-Instruct (Yang et al., 2024), whereas Ming-Omni employs an MoE-based backbone (Team, 2025). Their generation components differ more substantially: BAGEL employs a Mixture-of-Transformers (MoT) (Liang et al., 2025) design and reuses an LLM decoder for generation; Qwen-Image incorporates an MMDiT-based generator (Esser et al., 2024); and Ming-Omni adopts a multi-scale DiT block architecture. Table 1 compares these model families and lists the generator-side MLP blocks targeted by our component analysis.

We vary the number of experts per MoE layer among 16, 32, and 64. Following (Dai et al., 2024; DeepSeek-AI et al., 2025), we include shared experts that constitute one-sixteenth of the total number of experts. The

Table 1: Summary of evaluated unified models, component sizes, and generator-side MLP targets.

Model	Und. type	Und. Param.	Gen. type	Gen. Param.	Gen. MLP targets
Qwen-Image	Dense VLM	7.62B	diffusion transformer	20.42B	`img_mlp`, `txt_mlp`
Ming-Omni	MoE VLM	17.12B	diffusion transformer	2.51B	`ff`, `ff_context`, connector MLP
BAGEL	Dense VLM	7.62B	autoregressive decoder	7.62B	generation MLP stack

overall activation ratio is set to 50% per layer. We exclude the first and last layers from MoE conversion, as they are important for preserving input encoding and output generation quality (Dai et al., 2024).

Datasets For calibration in training-free compression, we use a small number of examples drawn from the target task, which is sufficient for training-free compression (Frantar et al., 2022; Lin et al., 2023; Men et al., 2024; He et al., 2024). Note that these samples are used solely to compute activation scores, so no ground-truth annotations are required and no label leakage occurs. When calibration samples are drawn from the same benchmark prompt distribution as the evaluation set, we explicitly treat this as a task-calibrated or transductive compression protocol rather than as a standard held-out generalization setting. For MoE adaptation, we additionally incorporate high-quality image–text pairs, complemented by a small amount of synthetic data generated by existing text-to-image models.

Concretely, each task uses eight label-free calibration samples drawn from the same domain. For MoE Adaptation, each converted MLP layer has one router with per-token top-k routed expert selection. The exact total/shared/top-k settings are reported with the corresponding result tables.

Unless otherwise specified, the main BAGEL adaptation converts layers 1–27 with an approximately 50% active-neuron budget. We use relaxed gates, $(1 + \mathrm{Router}(x))$, initialized at zero so sparse layers start close to dense computation. Adaptation uses AdamW with a constant scheduler, betas 0.9/0.95, epsilon 10^{-15}, weight decay 0, and gradient clipping 1.0. Router/expert-frozen tuning uses learning rate 10^{-8}; full MoE Adaptation uses 10^{-5} and an auxiliary load-balancing loss.

5.2 Redundancy of Understanding Components

Depth Reduction Works for Generation but Fails for Understanding Because the understanding component is not directly responsible for the generated pixels, we first examine its effect on generation performance through depth reduction. Specifically, we remove transformer blocks, MLP layers, and attention layers. As shown in Figure 4, removing 50% of layers from the understanding component is effective for BAGEL and Qwen-Image, but less effective for Ming-Omni. We attribute this difference to architecture: Ming-Omni's generation component is relatively smaller and therefore depends more heavily on precise features encoded by the understanding component.

Figure 4: Overall GenEval performance after depth reduction in the understanding component.

However, depth pruning substantially degrades understanding capability. For instance, removing half of the MLP layers causes performance on MME (Fu et al., 2023) to drop from 1684.8 to 304.5 in perception and from 696.7 to 127.1 in cognition. These results suggest that depth reduction fails to preserve the performance of unified multimodal models on understanding tasks. Understanding tasks rely on autoregressive decoding, which is inherently an error-accumulation process: deviations in early generated tokens propagate through subsequent steps and ultimately cause the output to collapse.

Neuron Partition on Understanding Components: Effective in Both Understanding and Generation We next evaluate neuron partition on understanding components by compressing MLP layers to target ratios using a small calibration set. As shown in Table 2, Ming-Omni and Qwen-Image largely maintain performance even at aggressive compression ratios (50% and 70%), whereas BAGEL shows a larger

Table 2: GenEval performance after applying Neuron Partition to the understanding component. Since only the **understanding component** is compressed, the reported parameter counts and speedups correspond to this part rather than the full model size.

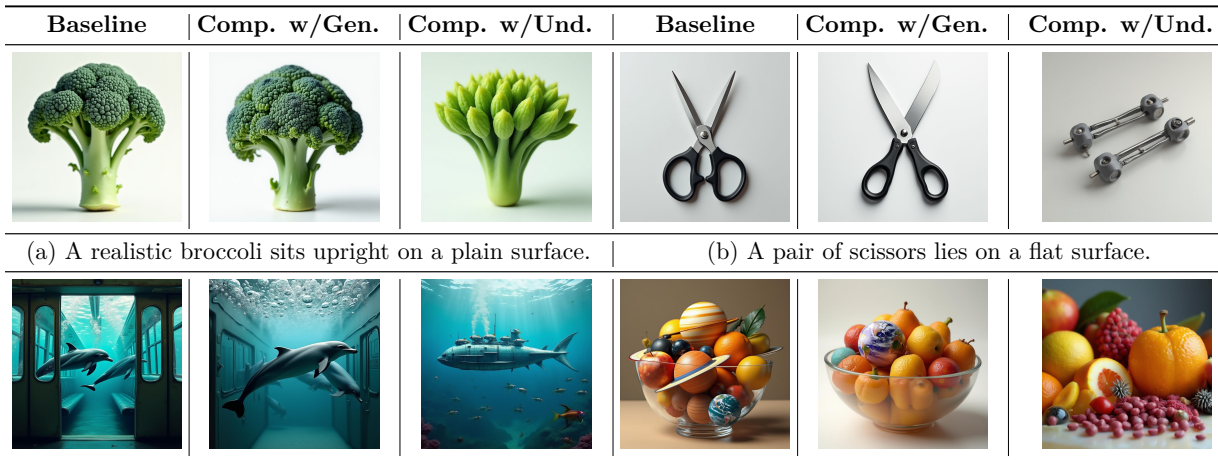
Model	Sparsity	Params.	Speedup	Single Obj.	Two Obj.	Counting	Colors	Position	Color Attri.	Overall↑
BAGEL	0%	7.62B	1.00×	0.99	0.94	0.81	0.95	0.72	0.77	**0.86**
	50%	4.76B	1.60×	0.94	0.63	0.62	0.77	0.47	0.34	**0.63**
Qwen-Image	0%	7.62B	1.00×	0.99	0.98	0.91	0.94	0.80	0.89	**0.92**
	50%	4.76B	1.60×	0.99	0.94	0.94	0.93	0.76	0.87	**0.90**
	70%	3.62B	2.10×	0.97	0.88	0.85	0.91	0.60	0.71	**0.82**
Ming-Omni	0%	17.12B	1.00×	0.97	0.95	0.67	0.92	0.71	0.71	**0.82**
	50%	8.55B	2.00×	0.97	0.92	0.66	0.89	0.61	0.70	**0.79**
	70%	5.61B	3.05×	0.96	0.81	0.58	0.86	0.49	0.56	**0.71**

Table 3: Performance of neuron partitioning on understanding tasks at compression ratios of 25% and 50%.

Model	Sparsity	MME-P	MME-C	MMMU	MMBench	MMVP
Qwen-Image	–	1711.6	611.8	50.0	87.8	75.7
	25%	1574.6	458.2	39.7	83.9	70.3
	50%	1165.9	271.1	29.9	77.4	62.0
Ming-Omni	–	1584.3	670.4	66.7	86.7	54.6
	25%	1578.5	560.4	56.7	81.2	51.3
	50%	1269.0	317.9	51.7	81.0	46.0
BAGEL	–	1684.8	696.7	65.0	88.1	69.6
	25%	1558.1	681.7	60.1	85.7	68.7
	50%	1392.6	528.9	56.7	79.2	56.0

degradation. This difference is likely due to BAGEL's mixture-of-transformers architecture (Liang et al., 2025), in which components interact through cross-attention at every layer. Similarly, the neuron partition strategy can be extended to attention heads, and this extension remains effective when compressing the understanding component for generation tasks (see Appendix B).

As shown in Table 3, neuron partition consistently outperforms layer dropping across understanding tasks. Although some layers exhibit substantial redundancy, removing entire layers also discards the smaller set of weights that remain critical to task performance (Yu et al., 2025). In contrast, neuron partition preserves important neurons within each layer, yielding more fine-grained and reliable compression. Nevertheless, since the understanding component directly governs textual outputs, its compression ratio should remain more conservative in understanding tasks than in generation tasks.



(a) A realistic broccoli sits upright on a plain surface. (b) A pair of scissors lies on a flat surface.

(c) Dolphins swim through abandoned subway cars. (d) A fruit bowl consisting of fruits and miniature planets.

Figure 5: Impact of calibration data selection on neuron partition. Each triplet shows the unmodified model, image-generation calibration, and understanding calibration.

Figure 6: Generation-side width reduction degrades visual quality. The compressed model uses 50% generator width reduction for the prompt "The word START."

Calibration Data Affects the Activated Parameters Neuron partition uses calibration samples to estimate neuron importance and prune neurons that are less critical for the target behavior. Figure 2 shows that understanding and generation families activate different neurons, suggesting that calibration data can change which weights are retained and therefore affect downstream performance. To assess how different calibration datasets affect parameter retention and downstream performance, we conduct an ablation study using samples from understanding tasks (MME) and generation tasks (GenEval).

We find that aligning calibration data with target tasks consistently improves performance. For instance, using generation samples for calibration degrades MMBench from 79.2 to 74.8. The generation results in Figure 5 further highlight this trend. When calibrated with image generation samples, the outputs remain faithful to the prompts, producing broccoli, scissors, dolphins, and fruit bowls with correct structures. In contrast, calibration with understanding samples introduces distortions and mismatches. This demonstrates that family-aligned calibration data yields better performance, while mismatched data degrades generation quality. The effect is especially important for unified models, where inputs and outputs can vary across modality combinations.

5.3 Dilemma of Generation Component Compression

We next investigate how compression influences generation quality by applying neuron partition to the generation components. Unlike understanding-side compression, generation-side compression presents a clear dilemma. Figure 6 shows that a 50% width reduction substantially degrades output fidelity and coherence, producing distorted structures and unrealistic textures.

These findings are consistent with the depth and attention reduction experiments in Appendix E. Together, they highlight a component-level asymmetry: understanding components can often tolerate compression, while generation components are highly sensitive to static compression.

Generation-side MLPs are also not homogeneous. Appendix Tables 10 and 11 separate the generator targets from Table 1 and report both their target FLOPs and their compression sensitivity. In Qwen-Image, compressing only `txt_mlp` retains much higher GenEval performance than compressing `img_mlp` (0.75 vs. 0.11), while compressing all generator MLPs falls to 0.05. Appendix Figure 13 provides a qualitative example of this text/context-side robustness. Ming-Omni remains broadly fragile, with the image-stream `ff` path collapsing to 0.00. Janus-Pro shows a similar component-dependent pattern: the generation head retains nontrivial quality, while compressing the AR backbone MLP collapses GenEval (0.47 vs. 0.00); Appendix Table 12 provides the corresponding scoped AR-generation ablation.

5.4 MoE Adaptation for Generation Component Sparsity

Static compression conflicts with the dynamic activation patterns required across tasks and samples, leading to substantial degradation in generation components. To mitigate this issue, we apply MoE Adaptation, which enables dynamic activation and restores representational capacity under sparse inference.

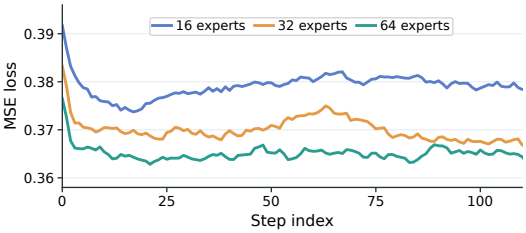


Figure 7: Expert-Frozen Tuning curves.

Warmup via Expert-Frozen Tuning MoE Adaptation begins with Expert-Frozen Tuning, a cold-start phase that

Table 4: Performance across stages of MoE Adaptation. We compare training-free Expert Partition, Expert-Frozen (E.F.) Tuning, and full MoE Adaptation. Activated parameters are reported as "Und. Param. & Gen. Param."

Method	Adapt. Comp.	Activated Params.	Single Obj.	Two Obj.	Counting	Colors	Position	Color Attri.	Overall↑
Baseline	N/A	7.62B + 7.62B	0.99	0.94	0.81	0.95	0.72	0.77	**0.86**
Expert Partition	*Gen.*	7.42B + 4.96B	0.90	0.70	0.49	0.74	0.53	0.34	**0.62**
Dense Finetuning			0.97	0.88	0.75	0.91	0.67	0.71	**0.82**
E.F. Tuning			0.99	0.94	0.62	0.93	0.69	0.54	**0.78**
MoE Adaptation			**0.99**	**0.95**	**0.85**	**0.95**	**0.75**	**0.79**	**0.88**
Expert Partition	*Und. & Gen.*	4.96B + 4.96B	0.69	0.18	0.23	0.45	0.10	0.05	**0.28**
Dense Finetuning			0.97	0.89	0.76	0.91	0.70	0.64	**0.81**
E.F. Tuning			0.94	0.63	0.62	0.77	0.47	0.34	**0.63**
MoE Adaptation			**0.99**	**0.96**	**0.78**	**0.95**	**0.70**	**0.72**	**0.85**

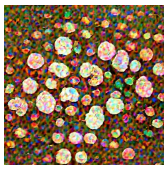
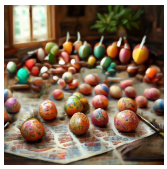
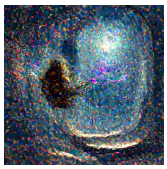
Prompt	Baseline	Zero-shot w/o SE	Zero-shot w/ SE	E.F. Tuning	MoE Adapt.
A famous flower that symbolizes wealth in China.					
Traditional activity during Easter in Western countries.					
Old analog picture of parked car on side street, quiet night.					
A lone astronaut paints swirling galaxies onto a massive canvas in a vast space station.					

Figure 8: Visual comparison across stages of MoE Adaptation. Columns show the dense baseline, zero-shot expert partition with or without shared experts, Expert-Frozen Tuning, and full MoE Adaptation.

trains the model to use partitioned experts effectively. This strategy mitigates catastrophic forgetting and encourages expert selection while preserving pretrained knowledge (Houlsby et al., 2019; Qiao & Mahdavi, 2024; He et al., 2025a).

We compare 16, 32, and 64 experts, with training loss curves shown in Figure 7. After a small number of expert-frozen tuning steps, the loss declines substantially, indicating that the model can exploit a subset of experts to recover performance. Finer-grained expert partitioning also enables more flexible activation combinations, leading to lower training loss.

The overall GenEval score improves from 0.62 to 0.78, reflecting more coherent and visually faithful outputs. As illustrated in Figure 8, before tuning, the model generates noisy, low-detail images that fail to capture fine-grained semantics. Expert-Frozen Tuning improves image fidelity and strengthens alignment between generated content and instructions. This indicates that subsets of generation parameters, although difficult to compress statically, can still support high-quality generation when routed and tuned appropriately.

Table 5: Measured inference efficiency for dense, pruned, and MoE execution. Rows use matched hardware, precision, workload, and converted-layer ranges within each model. Target FLOPs report affected MLP/FFN compute, not full-pipeline FLOPs.

Model	Config	Target FLOPs	Dense			Pruned			MoE			MoE Speedup
			Lat.	Thr.	Mem.	Lat.	Thr.	Mem.	Lat.	Thr.	Mem.	
Qwen-Image	4e/1s/k1	765.36→306.14 TF	51.638 s	0.019/s	61.13 GB	44.912 s	0.022/s	53.83 GB	45.007 s	0.022/s	54.04 GB	1.147×
Ming-Omni	8e/2s/k2	36.84→14.74 TF	1.691 s	0.591/s	43.72 GB	1.212 s	0.825/s	42.99 GB	1.363 s	0.734/s	43.73 GB	1.241×
BAGEL	16e/2s/k6	186.88→93.44 TF	3.311 s	0.302/s	25.704 GB	2.584 s	0.387/s	21.220 GB	3.081 s	0.325/s	25.676 GB	1.074×

Effectiveness of MoE Adaptation After Expert-Frozen Tuning, we lift the restriction on frozen expert parameters to further improve performance. Beyond applying MoE adaptation only to the generation component, we also explore extending it to the understanding component to reduce the number of activated parameters while maintaining task effectiveness. To preserve fidelity in understanding tasks, the experts in the understanding component are kept frozen. They remain fully activated for understanding and are only sparsely activated for generation, since generation tasks are more tolerant to sparsity in this component. In summary, we consider two configurations of MoE adaptation: (1) *Gen.*: Expert partitioning and adaptation are applied only to generation experts; and (2) *Und. & Gen.*: Both understanding and generation experts are partitioned, but only the generation experts are adapted while the understanding experts remain frozen.

These additional training stages allow experts to refine their internal representations and develop stronger specialization, improving both structural coherence and semantic consistency in generated outputs. As shown in Table 4 and Figure 8, generation quality improves after Expert-Frozen Tuning and improves further after full MoE Adaptation. This demonstrates that allowing experts to adapt beyond static partitioning enhances both representational capacity and task alignment. We keep this quality comparison separate from inference speed measurements: adding a speedup column to Table 4 would require matched whole-generation timing for every checkpoint and adaptation scope, including both *Gen.* and *Und. & Gen.* partitioned settings.

Efficiency Measurement Table 5 reports measured latency, throughput, and peak memory for dense, pruned, and MoE execution. Latency is wall-clock time per generation workload, throughput is the reciprocal workload rate, and memory is end-to-end peak CUDA memory. The results show consistent end-to-end MoE speedups in the tested implementations. Pruned dense execution remains faster because it removes parameters without routing overhead. Together, the multi-model pruning results and runtime measurements support the broader component-level diagnosis, while Table 4 provides the training-aware MoE adaptation quality study on BAGEL GenEval. Appendix Table 9 gives the component-level target-FLOP context for these measurements, and Appendix Table 13 reports single-layer diagnostics that connect local sparse-compute savings to the end-to-end results.

We also evaluate the sensitivity of the expert design. Appendix F reports that BAGEL GenEval quality remains close across several total/shared/top-k granularities at a fixed active-neuron budget. However, finer expert partitioning makes routed matrix multiplications smaller and more fragmented, which can be less favorable for kernel dispatch and practical optimization.

6 Conclusion

This work studies component-level redundancy and activation sparsity in unified multimodal models. Using training-free pruning as a probe, we find that the understanding component is substantially more compressible than the generation component, especially when it is used to support generation. In contrast, static compression of the generation component can severely degrade visual quality, indicating that generation relies on more input-dependent activation patterns. To address this asymmetry, we introduce Mixture-of-Experts (MoE) Adaptation, which dynamically activates generation parameters and restores generation quality under sparse activation on BAGEL. Together, the analysis and adaptation results show that unified multimodal models contain meaningful efficiency opportunities, but that effective compression must respect the distinct roles of understanding and generation components and be validated with measured runtime behavior.

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Appendix

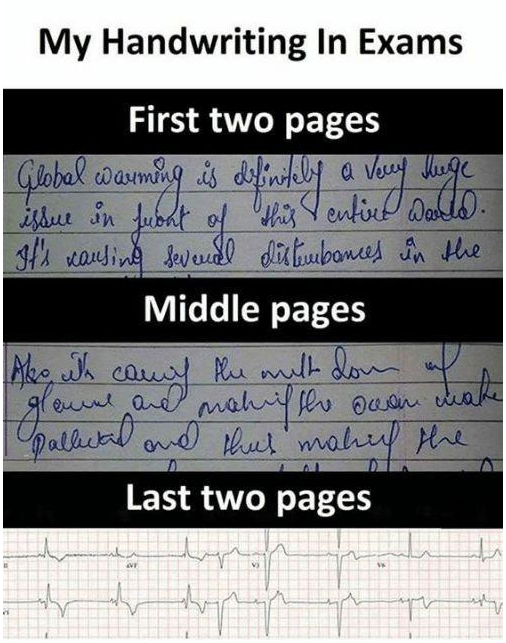
A Depth Reduction on Understanding Tasks

Depth reduction in the understanding component can have only a limited impact on some generation tasks, but it is brittle for multimodal understanding. Table 6 shows that removing whole layers sharply degrades MME, MMMU, MMBench, and MMVP. This is distinct from the neuron-partition results in Table 3, where fine-grained neuron selection is substantially more reliable.

Figure 9 illustrates the failure mode. The depth-reduced model starts to answer the visual question but quickly collapses into repetition, suggesting error accumulation during autoregressive decoding.

Table 6: Depth reduction degrades understanding performance. Whole-layer removal is less reliable than neuron partition.

Model	Sparsity	MME-P	MME-C	MMMU	MMBench	MMVP
Ming-Omni	–	1584.3	670.4	66.7	86.7	54.6
	50%	1197.2	308.2	51.7	81.2	46.0
Qwen-Image	–	1711.6	611.8	50.0	87.8	75.7
	50%	7.0	1.4	10.6	12.8	30.3
BAGEL	–	1684.8	696.7	65.0	88.1	69.6
	50%	304.5	127.1	16.7	18.6	23.1



Meme: "My Handwriting In Exams"

Question: Can someone explain what's funny about this meme?

Neuron Partition:
The joke comes from the exaggerated shift in handwriting style as the exam progresses. The text starts out neat and legible, then becomes increasingly messy, reflecting the student becoming more stressed and less focused.

Depth Reduction:
The depth-reduced model produces degenerate repetition instead of a coherent explanation, making the answer unreadable and unhelpful.

Figure 9: Neuron partition preserves coherent answers, while depth reduction causes repetition. Both methods use a 50% compression ratio.

B Attention Head Partition

Our main experiments focus on MLP width reduction because MLP layers account for most parameters. The same score construction can also be applied to attention heads by measuring head-level importance. Table 7 shows that attention-head partition is still viable on the understanding component, although the quality drop is larger than for MLP neuron partition.

Table 7: Attention-head partition on the understanding component at 50% sparsity.

Model	Compressed Layers	Single Obj.	Two Obj.	Counting	Colors	Position	Color Attri.	Overall↑
BAGEL	N/A	0.99	0.94	0.81	0.95	0.72	0.77	0.86
	3-27	0.97	0.87	0.66	0.88	0.33	0.31	0.67
	4-27	0.98	0.91	0.72	0.89	0.41	0.40	0.72

C Comparison with Compression Methods

Neuron partition uses reconstruction errors to estimate neuron importance without labels or gradients. As a reference point, Table 8 compares it with gradient-based pruning metrics in the style of LLM-Pruner (Ma et al., 2023) and with AWQ 4-bit quantization. Neuron partition is competitive while remaining training-free and avoiding explicit gradient computation.

Table 8: Neuron partition compared with gradient-based pruning and 4-bit quantization on the understanding component.

(a) Gradient-based pruning comparison.

Model	Metrics	Single Obj.	Two Obj.	Counting	Colors	Position	Color Attri.	Overall↑
Ming-Omni	LLM-Pruner	0.96	0.82	0.72	0.85	0.47	0.55	0.70
	Neuron Partition	0.96	0.81	0.58	0.86	0.49	0.56	0.71

(b) Quantization comparison.

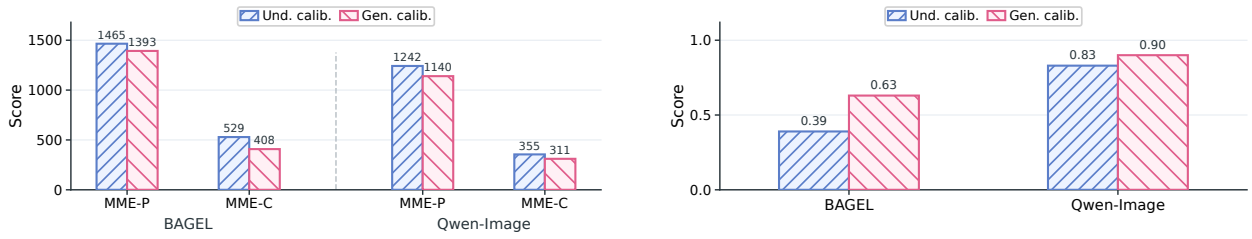
Model	Single Obj.	Two Obj.	Counting	Colors	Position	Color Attri.	Overall↑
Qwen-Image	0.99	0.98	0.91	0.94	0.80	0.89	0.92
w/ 4-bit quantization	0.99	0.97	0.93	0.92	0.79	0.70	0.88
w/ 50% neuron partition	0.99	0.94	0.94	0.93	0.76	0.87	0.90

For Qwen-Image, we apply AWQ to the understanding component, namely the Qwen-VL backbone. Neuron partition reaches 0.90 GenEval overall at 50% compression, compared with 0.88 for 4-bit quantization. This contrasts with traditional LLM compression settings, where pruning at similar ratios is often substantially weaker than 4-bit quantization.

D Calibration Data for Neuron Partitioning

Calibration data determine which activations are measured and therefore which neurons are retained. We ablate this effect using MME samples for understanding calibration and GenEval samples for generation calibration. The resulting models are evaluated on MME and GenEval in Figures 10a and 10b.

Task-aligned calibration consistently performs better. This suggests that unified models rely on different neuron partitions for different modality families. It also explains why our test-time few-shot compression can adapt to downstream tasks by using a few target-task samples for calibration.



(a) Understanding tasks. **(b)** Generation tasks.

Figure 10: Family-aligned calibration consistently yields better performance.

E Additional Generation Component Compression

Generation components are more sensitive to static compression than understanding components. Beyond neuron partition, we examine depth reduction and attention-layer compression. Removing entire generation layers produces severe visual degradation, as shown in Figure 11. Attention compression is also fragile: reducing more than 10% of attention capacity leads to visible quality drops in Figure 12.

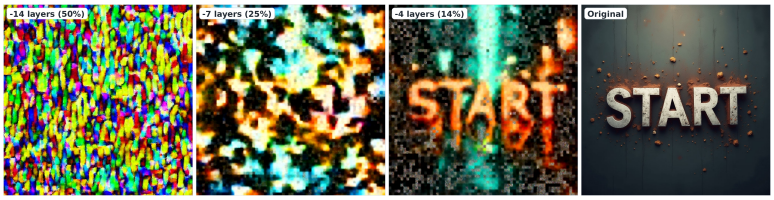


Figure 11: Generation depth reduction. Removing 14, 7, or 4 generation layers progressively degrades the generated images.

(a) Depth reduction. **(b)** Width reduction.

Figure 12: Attention-layer compression in generation components. Both depth and width reduction substantially degrade generation quality.

F Additional System and AR-Generation Results

Table 9 reports the component-level compute context for the MLP/FFN blocks targeted by our compression and sparse-routing experiments. FLOPs count only MLP/FFN matrix multiplications. They should therefore be read as target-component compute rather than full-pipeline compute, which also includes attention, image decoders, sampling, routing, and framework overhead.

We also check expert-count sensitivity for BAGEL MoE Adaptation under a matched active-neuron budget. GenEval remains close across the tested total/shared/top-k settings, staying around 0.89 rather than improving with finer expert partitioning. This supports quality robustness, but it also exposes a systems trade-off: more experts make the routed matrix multiplications smaller and more fragmented, which is harder for GPU kernels and dispatch paths to optimize.

Table 9: Component-level MLP/FFN compute context. Sparse FLOPs are activated target-component FLOPs under the listed sparse method.

Model	Component family	Target params	Dense FLOPs	Sparse method	Sparse FLOPs	E2E speedup
BAGEL	image-decoder MLP stack	5.70B	186.88 TF	MoE 16e/2s/k6	93.44 TF	1.074×
Qwen-Image	MMDiT image/text FFNs	9.06B	765.36 TF	MoE 4e/1s/k1	306.14 TF	1.147×
Ming-Omni	multi-scale DiT FFNs	0.90B	36.84 TF	MoE 8e/2s/k2	14.74 TF	1.241×

The generator-side target is not homogeneous across models. BAGEL uses a diffusion-style image generator whose main converted target is the image-decoder MLP stack. Qwen-Image uses a dual-stream MMDiT with separate image-stream and text/context-stream MLPs. Ming-Omni separates image, context, and connector MLPs. Table 10 breaks down the dominant generator-side MLP/FFN FLOPs for Qwen-Image and Ming-Omni. Janus-Pro uses a shared AR language backbone together with a generation head and aligner, so we report it as an applicability boundary rather than part of the MoE efficiency table.

We further isolate generation-side MLP streams with 50% structural compression. Table 11 shows that text/context-side generator MLPs can be less sensitive than image-stream MLPs, although the degree of robustness is model-dependent. Qwen-Image preserves much more GenEval performance when only `txt_mlp` is

Table 10: Generator-subcomponent FLOPs under the measured workload. These rows identify which MLP/FFN subcomponents dominate target compute.

Model	Component	Role	Dense FLOPs
Qwen-Image	`img_mlp`	image stream	626.21 TF
	`txt_mlp`	text/context stream	139.16 TF
Ming-Omni	`ff`	image stream	27.83 TF
	`ff_context`	context stream	8.75 TF
	connector MLP	LLM-to-diffusion connector	0.25 TF

compressed. Ming-Omni remains broadly fragile, but `ff_context` is still less damaging than the latent/image `ff` stream. For Janus-Pro, the generation head is substantially more compressible than the AR backbone MLP or the generation aligner.

Table 11: Generator-subcomponent sensitivity at 50% compression. GenEval is measured after compressing only the listed component.

Model	Compressed component	Role	GenEval
Qwen-Image	all generator MLPs	image + text streams	0.05
	`img_mlp`	image stream	0.11
	`txt_mlp`	text/context stream	0.75
Ming-Omni	all generator MLPs	image + context streams	0.00
	`ff`	image stream	0.00
	`ff_context`	context stream	0.19
	`ff`+`ff_context`	image + context streams	0.00
	VAE decoder conv	decoder convolution	0.02
Janus-Pro	AR backbone MLP	image-token generator	0.00
	generation aligner	VQ-token embedding adapter	0.06
	generation head	image-token prediction head	0.47

Table 12 gives a scoped Janus-Pro AR-generation ablation. It is not a direct MoE Adaptation claim because Janus-Pro shares an AR language backbone for understanding and image-token generation. The result marks a boundary case: mild AR-language MLP compression preserves much of GenEval quality, while generation-head interventions retain nontrivial quality despite targeting a smaller module.

Table 12: Janus-Pro AR generation ablation on GenEval. Retention is measured relative to the dense baseline.

Target	Method	Setting	GenEval	Retention
dense baseline	dense	none	0.76	100%
AR language MLP	compression	keep 0.80	0.69	91%
	compression	keep 0.75	0.65	86%
generation head	compression	keep 0.50	0.47	62%
	partition	16/8/0	0.46	61%

As shown in Table 11, Figure 13 gives a simple Qwen-Image case where text/context-side compression preserves visual coherence while more fragile image-stream interventions collapse.

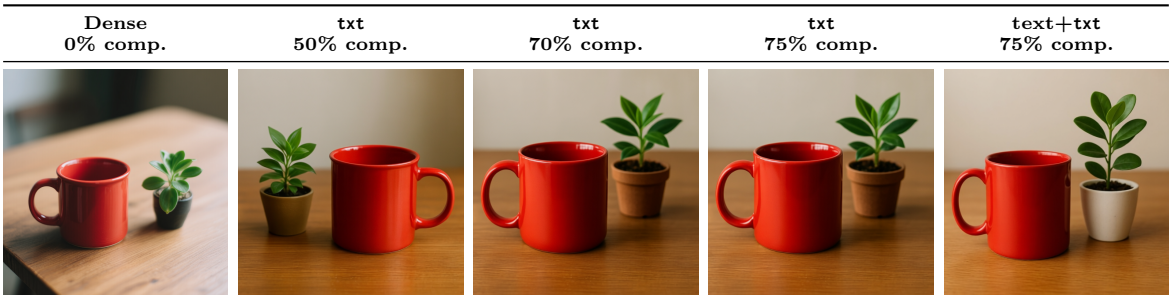


Figure 13: Qwen-Image text/context compression on a simple object prompt. Percentages denote the compressed fraction, not the kept fraction.

Table 13 complements the end-to-end timing in Table 5 with single-layer latency diagnostics at matched sparse FLOPs. These measurements isolate kernel behavior from full-pipeline overhead.

Table 13: Single-layer FFN/MLP latency at matched sparse FLOPs. BAGEL uses one generation MLP layer; Qwen-Image and Ming-Omni use one MMDiT FFN layer.

Model	Module	Tokens	Dense baseline	Method	Configuration	Sparse FLOPs	Latency	Speedup
BAGEL	generation MLP	4,096	8.397 ms	Pruned	50% width	0.55 TF	4.219 ms	1.990×
				MoE	14e/2s/k6	0.55 TF	6.782 ms	1.237×
		8,192	17.704 ms	Pruned	50% width	1.11 TF	8.540 ms	2.073×
				MoE	14e/2s/k6	1.11 TF	12.495 ms	1.420×
		16,384	36.733 ms	Pruned	50% width	2.22 TF	17.573 ms	2.090×
				MoE	14e/2s/k6	2.22 TF	25.169 ms	1.460×
Qwen-Image	MMDiT FFN	32,768	25.335 ms	Pruned	50% width	2.47 TF	13.090 ms	1.935×
				MoE	6e/2s/k2	2.47 TF	17.915 ms	1.414×
		65,536	51.378 ms	Pruned	50% width	4.95 TF	27.151 ms	1.892×
				MoE	6e/2s/k2	4.95 TF	39.431 ms	1.303×
Ming-Omni	MMDiT FFN	32,768	6.897 ms	Pruned	50% width	0.62 TF	3.279 ms	2.103×
				MoE	6e/2s/k2	0.62 TF	6.224 ms	1.108×
		65,536	14.307 ms	Pruned	50% width	1.24 TF	7.289 ms	1.963×
				MoE	6e/2s/k2	1.24 TF	12.949 ms	1.105×

G Limitations and Broader Impact

Limitations Our results separate the breadth of the diagnosis from the scope of the trained adaptation. The pruning and neuron-partition analyses cover BAGEL, Qwen-Image, and Ming-Omni. The full training-aware MoE Adaptation result is evaluated as a BAGEL/GenEval case study. Extending trained MoE adaptation to Qwen-Image, Ming-Omni, and autoregressive generators remains future work.

Activated-parameter reduction should not be interpreted as a deployment speedup by itself. Realized latency depends on workload size, expert granularity, routing overhead, kernel dispatch, and hardware implementation.

Broader Impact Improving the efficiency of unified multimodal generation models can reduce serving cost and broaden access to creative tools. It may also lower the barrier for large-scale synthetic-content generation. Potential risks include misinformation, deepfake-like misuse, biased or harmful visual outputs, and copyright-sensitive generation. Responsible deployment should therefore pair efficiency improvements with provenance or watermarking mechanisms, safety classifiers, dataset filtering, and careful release practices for model weights and code.