Multiple Noises in Diffusion Model for Semi-Supervised Multi-Domain Translation

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Abstract

In this work, we address the challenge of multi-domain translation, where the objective is to learn mappings between arbitrary configurations of domains within a defined set (such as $(D_1, D_2) \rightarrow D_3$, $D_2 \rightarrow (D_1, D_3)$, $D_3 \rightarrow D_1$, etc. for three domains) without the need for separate models for each specific translation configuration, enabling more efficient and flexible domain translation. We introduce Multi-Domain Diffusion (MDD), a method with dual purposes: i) reconstructing any missing views for new data objects, and ii) enabling learning in semi-supervised contexts with arbitrary supervision configurations. MDD achieves these objectives by exploiting the noise formulation of diffusion models, specifically modeling one noise level per domain. Similar to existing domain translation approaches, MDD learns the translation between any combination of domains. However, unlike prior work, our formulation inherently handles semi-supervised learning without modification by representing missing views as noise in the diffusion process. We evaluate our approach through domain translation experiments on BL3NDT, a multi-domain synthetic dataset designed for challenging semantic domain inversion, the BraTS 2020 dataset, and the CelebAMask-HQ dataset. The code for MDD and all data are publicly available[1].

1 Introduction

A domain is a set of tensors drawn from the same probability distribution $p(x)$, characterized by both shared features, common across related domains, and domain-specific features, that distinguish it from other domains. We define domain translation as a function $f_{S_i,S_j} : S_i \rightarrow S_j$ that projects the data representations from a set of source domains S_i to a set of target domains S_j.

In a scenario with L domains denoted by $\mathcal{D} = \{D_1, ..., D_L\}$, we aim to obtain a model performing all translations f such that $f_{S_i,\bar{S}_i} : S_i \rightarrow \bar{S}_i$ with $S_i \in \mathcal{P}(\mathcal{D})$, where $\mathcal{P}(\mathcal{D})$ represents the power set of $\mathcal{D}$, and $\bar{S}_i = \mathcal{D} - S_i$ is the complement of S_i within $\mathcal{D}$. Our goal is to develop a model that is not limited to a specific translation direction, either during training or inference. Any domain should be available to serve as a condition, while all remaining domains must be part of the generation. Given that S_i can be any subset of $\mathcal{D}$, there are 2^L possible translation functions. Figure 1 illustrates this scenario when $L = 3$ using the CelebA-HQ (Karras et al., 2018) dataset, where D_1, D_2, and D_3 represent an image, a sketch, and its segmentation map, respectively. Specific instances $x^{(i)}$, such as a face $x^{(1)}$, are referred to as a view, and combinations of related views as a data point $x = [x^{(1)}, x^{(2)}, x^{(3)}]$.

Some translation configurations can be viewed as conditional generation tasks (*e.g.* face generation, where multiple faces can be considered valid given a unique sketch). In contrast, others can be viewed as regression or classification tasks (*e.g.* a unique semantic segmentation is expected given a face). This paper primarily focuses on generation and conditional generation configurations.

The MDD framework leverages the noise-removal property of diffusion models (Ho et al., 2020; Song et al., 2022; Rombach et al., 2022) and, like other frameworks, concatenate the domains in the input (Wolleb et al., 2021). In contrast to other frameworks, MDD uniquely models semi-supervised information using higher

[1]Our code is provided in supplementary materials.

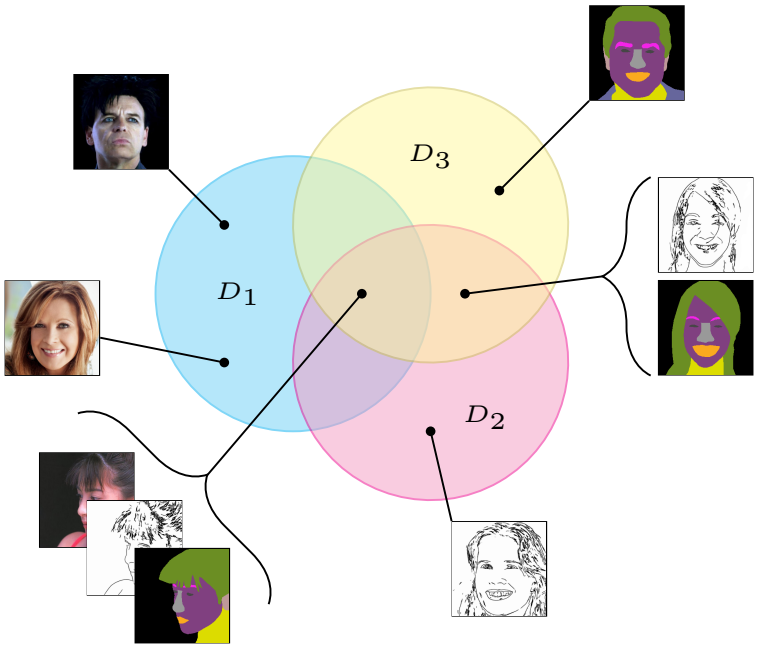

Figure 1: This example considers three domains: photographs of faces, sketches, and semantic segmentation. Supervision scenarios include full supervision (all domain samples available) and semi-supervised (some samples missing). As the number of domains increases, achieving full supervision becomes more challenging. This task can be challenging and tedious, especially when human intervention is required, such as obtaining a sketch and segmentation for each face. Semi-supervised multi-domain translation aims to reduce the data collection burden by allowing missing samples.

noise levels for unavailable views and further models different noise levels per domain. During training, views with higher noise levels, indicating less information, will encourage the model to rely more on less noisy views to enhance its reconstruction capabilities. This approach transforms the task from simple reconstruction to complex domain translation learning based on the joint data distribution.

Our main contributions are summarized as:

- We introduce the MDD framework, which incorporates multiple noise levels for each domain. This diffusion-based framework enables learning in a semi-supervised setting, allowing mapping between multiple domains.
- We investigate how the noise formulation in MDD can be used to condition the generation process on missing modalities, given a set of available views.
- We conduct a comprehensive evaluation of MDD's performance on different datasets with different modalities, using both quantitative and qualitative assessments.

2 Related Works

2.1 Domain Translation

Domain translation research has explored various generative models, including GANs (Goodfellow et al., 2014), VAEs (Kingma & Welling, 2022), normalizing flows (Rezende & Mohamed, 2016; Grover et al., 2019; Sun et al., 2019), and diffusion models (Sohl-Dickstein et al., 2015). Although approaches like Pix2Pix (Isola et al., 2018), CycleGAN (Zhu et al., 2020), and others (Mayet et al., 2022; Liu et al., 2018; Huang et al., 2018; Lee et al., 2018; 2019) have demonstrated promising results, they face limitations in multi-modal settings and exhibit reduced scalability as the number of domains increases. Moreover, both CycleGAN and StarGAN are designed for unsupervised settings, neglecting the potential benefits of supervised examples. StarGAN (Choi et al., 2018) enables translation between domain pairs using a single network for each configuration.

However, it does not address multi-modal settings, where multiple modalities can be utilized as conditions simultaneously.

2.2 Domain Translation Using Diffusion Models

Diffusion models offer various conditional generation paradigms. These methods can be broadly categorized into two groups: those operating in the original high-dimensional pixel space and those operating in the latent space. Models working in pixel space project the condition onto the target manifold of a pre-trained model using forward diffusion on the condition (Li et al., 2023; Meng et al., 2022a). These approaches leverage the fact that, for specific translation tasks, condition and generation domain can be visually close (*e.g.* CBCT to CT (Li et al., 2023)). Methods operating in the pixel space face several limitations, including the need to have conditions and targets close together in the input space, not allowing multiple conditions, and requiring a careful balance between condition fidelity and generation realism (Meng et al., 2022a). Models working in latent space use a similar approach. They embed the condition into the latent space of the target domain, allowing the use of a pre-trained diffusion model (Wang et al., 2022; Ramesh et al., 2022; Lin et al., 2023). However, they do not address the issue of multiple conditions and target domains. Recent work on guided diffusion (Dhariwal & Nichol, 2021; Ho & Salimans, 2022; Wang et al., 2023; Cross-Zamirski et al., 2023) has explored ways to enhance adherence to condition semantics, but shares similar limitations in multi-modal settings.

2.3 Conditional Diffusion Models Using Concatenation

Recent approaches have attempted to address the use of multiple conditions or targets simultaneously through their concatenation (Xie et al., 2023; Cross-Zamirski et al., 2023; Saharia et al., 2022; Lyu & Wang, 2022; Saharia et al., 2021). However, they primarily focus on one-way translation with fixed domains. They do not address the defined multi-domain translation setting, where any domain can serve as input or output during generation. Two main approaches have emerged to overcome these limitations: noisy condition and clean condition methods. **Noisy condition:** To allow a unified framework without a fixed configuration of condition and target domains, this class of approaches (Lugmayr et al., 2022; Sasaki et al., 2021; Mariani et al., 2024) introduces the concept of adding noise to the condition. During training, the condition is degraded using the same forward diffusion process, enabling the model to learn to reverse the diffusion process for all domains using the joint data distribution. For example, RePaint (Lugmayr et al., 2022) applies a matching noise level between condition and generation and designs a jumping mechanism to maintain generation faithful to the condition while significantly increasing the generation time.

Multi-Source Diffusion Models for Simultaneous Music Generation and Separation (MSDM) MSDM (Mariani et al., 2024) presents an innovative approach utilizing noisy conditions. The method proposes applying an equivalent amount of noise to both the condition domain and the generated target domain, enabling multi-domain translation learning in a supervised setting. While this formulation has demonstrated success in music generation, related applications (Lugmayr et al., 2022; Meng et al., 2022a; Chung et al., 2022; Corneanu et al., 2024) have highlighted the limitations of noisy conditions and the necessity for additional mechanisms to synchronize the condition and target domains.

These limitations motivate the exploration of alternative approaches, such as UMM-CSGM, which investigates the use of clean conditioning.

Clean Condition: In contrast, clean condition approaches (Xie et al., 2023; Cross-Zamirski et al., 2023; Saharia et al., 2022; Lyu & Wang, 2022; Saharia et al., 2021) keep the condition clean during both training and generation. This scheme allows for learning a one-way translation conditioned on a specific domain and produces successful results. However, it falls short in a multi-domain translation setting, where any domain can become an input or an output at generation time. **Unified Multi-Modal Conditional Score-based Generative Model (UMM-CSGM):** Recently, UMM-CSGM (Meng et al., 2022b) has alleviated the problems of clean and noisy conditioning. It aims to learn a multi-domain medical image completion task using a multi-in multi-out conditional score network. UMM-CSGM adopts the concept of clean conditioning and incorporates a code to indicate the conditional configuration by partitioning the domain into noisy targets or clean conditions.

While this formulation enables multi-domain translation in a fully supervised context, our work adopts a different approach by embedding information about conditions and target domains directly into the noise level modeling during training. Our proposed method inherently facilitates the configuration of missing modalities and aims to overcome the limitations of previous methods in addressing flexible multi-domain translation scenarios.

3 Multi-Domain Diffusion (MDD) Method

3.1 Diffusion Model

Diffusion models learn a data distribution from a training dataset by inverting a noising process. During training, the forward diffusion process transforms a data point x_0 into Gaussian noise $x_T \sim \mathcal{N}(0, \mathbf{I})$ in T steps by creating a series of latent variables $x_1, ..., x_T$ using the following equation

$$q(x_t|x_{t-1}) = \mathcal{N}(x_t; \sqrt{1-\beta_t}x_{t-1}, \beta_t\mathbf{I}) \tag{1}$$

Where β_t is the defined variance schedule. With $\alpha_t = 1 - \beta_t$, $\bar{\alpha}_t = \prod_{i=1}^{t} \alpha_i$, and $\epsilon \sim \mathcal{N}(0, \mathbf{I})$, x_t can be marginalized at a step t from x_0 using the reparametrization trick

$$x_t = \sqrt{\bar{\alpha}_t}x_0 + \sqrt{1-\bar{\alpha}_t}\epsilon. \tag{2}$$

The reverse denoising process $p_\theta(x_{t-1}|x_t, t)$ allows generation from the data distribution by first sampling from $x_T \sim \mathcal{N}(0, \mathbf{I})$ and iteratively reducing the noise in the sequence $x_T, ..., x_0$. The model $\epsilon_\theta(x_t, t)$ is trained to predict the added noise ϵ to produce the sample x_t at time step t using mean square error (MSE):

$$\mathcal{L} = \mathbb{E}_{\epsilon\sim\mathcal{N}(0,\mathbf{I}),x_0,t}\|\epsilon_\theta(\sqrt{\bar{\alpha}_t}x_0 + \sqrt{1-\bar{\alpha}_t}\epsilon, t) - \epsilon\|_2^2. \tag{3}$$

3.2 Existing Issues With Noisy Conditional Diffusion Models

We focus on noisy conditional diffusion models that concatenate different modalities as input to ϵ_θ, as detailed in Sec. 2.3. These models face challenges due to the shared noise level t during forward and backward diffusion processes across all domains. The core issue is the discrepancy between noise levels of available and unavailable views during training and inference. During training, unavailable views are replaced with pure noise, while other domains contain a different noise level. Consequently, t no longer accurately models the noise level. This discrepancy propagates to the backward diffusion process during inference, where the condition must be degraded to match the target domain's noise level. When the time step is close to T, the condition is extremely noisy, containing minimal information. This degradation causes the generation of the target domain to deviate from the intended semantic. RePaint (Lugmayr et al., 2022) encounters a similar issue, which it addresses by implementing a jumping mechanism. This solution involves looping through the same generation steps multiple times to increase the semantic consistency, but at the cost of increased time and computational complexity.

3.3 Noise Modeling for Semi-Supervised Multi-Domain Translation

To address these interconnected problems, MDD introduces an augmented forward and backward diffusion process. It employs a vector $\mathcal{T}$ of size L, assigning a separate $t^{(i)}$ for each of the L domains. This approach allows for more accurate modeling of noise levels across different domains, removing the discrepancy between noise levels in training and issues of semantic deviation during inference.

The goal of MDD is to remove constraints on predefined conditional domains for semi-supervised domain translation. During training, x denotes the ground truth data point. Here, $x \odot m$ represents available supervised views, while $x \odot (1 - m)$ represents unavailable views. The binary mask m indicates which domains are supervised or not.

Algorithm 1 MDD training process

1: **repeat**
2: $x_0 \sim q(x_0)$
3: m_{sup} the supervision mask
4: $m_{\text{c}} \in \{0,1\}^L$ a random conditional mask
5: $\mathcal{T}_{\text{sup}} \sim \text{Uniform}(\{1,...,T\})^L$
6: $\epsilon \sim \mathcal{N}(\mathbf{0},\mathbf{I})$
7: $\mathcal{T} := T \odot (1 - m_{\text{sup}}) + \mathcal{T}_{\text{sup}} \odot m_{\text{sup}}$
8: $\mathcal{T} := 0 \odot (1 - m_{\text{c}}) + \mathcal{T} \odot m_{\text{c}}$
9: $x_{\mathcal{T}} := \sqrt{\bar{\alpha}_{\mathcal{T}}} x_0 + \sqrt{1 - \bar{\alpha}_{\mathcal{T}}}\epsilon$
10: Training with loss: $\mathcal{L} := \|\epsilon - \epsilon_\theta(x_{\mathcal{T}}, \mathcal{T})\|_2^2$
11: **until** convergence

For generation, $x \odot m$ denotes views in the condition, while $x \odot (1 - m)$ represents generated views. During training, different noise levels are sampled for each domain:

$$\mathcal{T}_{\text{sup}} \sim \text{Uniform}(\{1,...,T\})^L \tag{4}$$

encouraging learning the joint data distribution by using less noisy domains to reconstruct noisier ones. For missing samples in semi-supervised settings, $\mathcal{T}$ is masked by replacing t where a domain is missing with T

$$\mathcal{T} = T \odot (1 - m_{\text{sup}}) + \mathcal{T}_{\text{sup}} \odot m_{\text{sup}} \tag{5}$$

The forward diffusion process is applied independently for each view according to $\mathcal{T}$:

$$x_{\mathcal{T}} = \sqrt{\bar{\alpha}_{\mathcal{T}}} x_0 + \sqrt{1 - \bar{\alpha}_{\mathcal{T}}}\epsilon \tag{6}$$

In the implementation, missing views are replaced with Gaussian noise, and the loss is computed only on available domains. The training process is illustrated in Fig. 2. Unless specified otherwise, in addition to Eq. (5), MDD training includes an additional step where a subset of domains is randomly selected as clean, with their associated t set to 0 (*cf*. Algorithm 1, line 8).

Algorithm 2 MDD generation process

1: $x_T \sim \mathcal{N}(\mathbf{0},\mathbf{I})$
2: **for** $t := T, ..., 1$ **do**
3: $\epsilon \sim \mathcal{N}(0,\mathbf{I})$
4: $z \sim \mathcal{N}(0,\mathbf{I})$ if $t > 1$, else $z = 0$
5: $x_{\text{cond},\phi(t)} = \sqrt{\bar{\alpha}_{\phi(t)}} x_{\text{cond}} + \sqrt{1 - \bar{\alpha}_{\phi(t)}}\epsilon$
6: $\mathcal{T} := t \odot (1 - m) + \phi(t) \odot m$
7: $x_{\mathcal{T}} := x_t \odot (1 - m) + x_{\text{cond},\phi(t)} \odot m$
8: $x_{t-1} := \frac{1}{\sqrt{\bar{\alpha}_{\mathcal{T}}}} \left(x_{\mathcal{T}} - \frac{\beta_{\mathcal{T}}}{\sqrt{1-\bar{\alpha}_{\mathcal{T}}}} \epsilon_\theta(x_{\mathcal{T}}, \mathcal{T}) \right) + \sigma_{\mathcal{T}} z$
9: **end for**
10: **return** x_0

This modification allows the network to recognize unavailable views as having a maximum noise level (modeled by T) and replaced by noise. During training, the model sees views with different noise levels, encouraging it to exploit more inter-domain dependencies for reconstruction. The training procedure is detailed in Algorithm 1. This modification also allows MDD to take input with different noise levels for direct generation using a clean condition, differing from other work where conditions must have the same noise level as the target domain or where condition and target domain are predefined. The new generation process is described in Algorithm 2 and illustrated in Fig. 3, where $\phi(t)$ controls the amount of information in the condition during backward diffusion. Unless specified otherwise, $\phi(t)$ is set to $\phi(t) = 0$ in our results. We

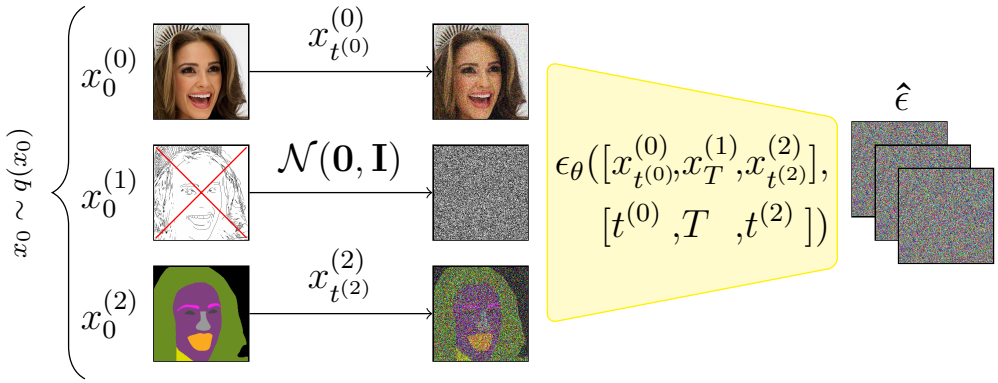

Figure 2: **Training procedure of MDD** in a semi-supervised setting on 3 domains with here d_1 missing. The network receives Gaussian noise for the missing domain, and $t^{(i)}$ is set to T.

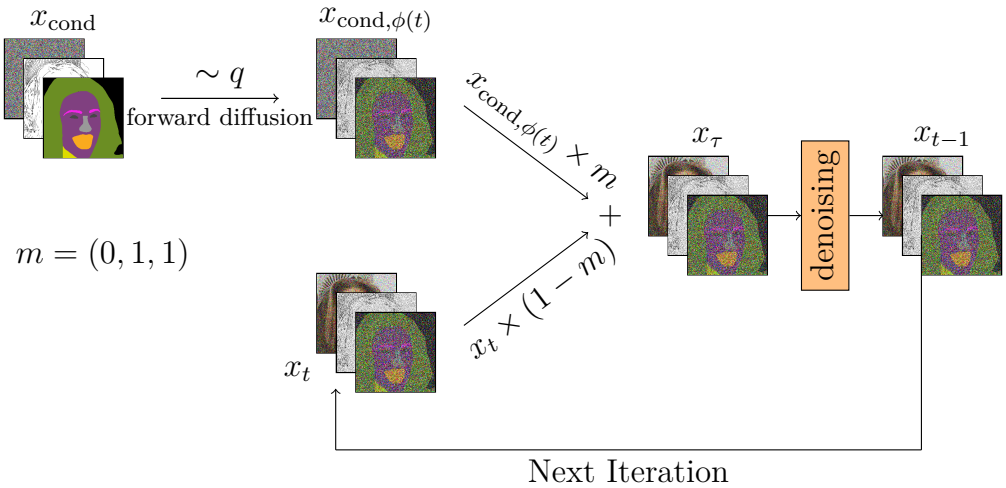

Figure 3: **Conditional generation procedure of MDD** in a setting with three domains. The first domain is missing and is considered a target domain, while the other two domains are available and are considered a condition. m is the mask indicating missing and available domains, and $\phi(t)$ controls the noise added to the condition.

investigate different functions for $\phi(t)$ in Appendix B.1. Intuitively, if $\phi(t)$ results in a function producing a higher noise level, the generation will drift further away, allowing it to produce more diverse results at the cost of less fidelity to the condition.

The MDD approach addresses the multi-domain semi-supervised translation task by modeling an independent noise level for each domain. The design of sampling independent noise levels aims to transform the reconstruction task of noisy condition models into a translation task, wherein cleaner views are utilized to predict noisier views. This formulation inherently accommodates the semi-supervised setting by representing missing views as noise. As all views are concatenated in the model input and the model simultaneously generates all modalities, it eliminates the need for duplications across various input or output configurations.

4 Experiments

4.1 Datasets

We validate MDD on three datasets, each containing more than two domains: 1) our proposed BL3NDT synthetic dataset, 2) the BraTS 2020 (Menze, 2014; Spyridon Bakas et al., 2017; et al., 2019; 2017) medical dataset with missing modality completion task, and 3) CelebAMask-HQ (Lee et al., 2020) dataset of face photos and masks, augmented with generated sketches.

Each dataset is evaluated under varying levels of supervision. Model performance is assessed by removing a specific number of views from a data point and subsequently regenerating them.

4.1.1 BL3NDT Synthetic Dataset

The Blender 3 Domain Translation (BL3NDT) dataset provides a testbed for multi-domain translation frameworks with deterministic mapping. Generated using the open-source 3D software Blender[2], it consists of 64x64 image triplets across three domains (cube, pyramid, iscosphere), each containing domain-specific and common features (Fig. 4). Each domain represents an object (cube, pyramid, or icosphere) placed before two walls and a floor, with controllable viewing angles. Generation parameters include object type, 3D position, camera angle, object color, floor color, and wall colors. Some parameters are common across domains, while others (position, camera angle, object color) exhibit semantic inversion between domains (Tab. 1). By swapping generative parameters between domains, pixel-to-pixel mapping is eliminated, compelling the model to learn underlying generative parameters and increasing task difficulty. The dataset comprises 40,500 randomly generated image triplets.

We study the BL3NDT setting with different amounts of supervised data. A percentage of the dataset, denoted as N%, is considered supervised data points, with the remaining (100-N)% divided equally between pairs of domains, with $N \in \{100, 70, 10, 0\}$. For example, if $N = 40\%$, 40% of the data is fully supervised, 20% is (cube, pyramid), 20% is (pyramid, icosphere), and 20% is (cube, icosphere). In addition, the *bridge setting* divides the dataset into 50% (cube, pyramid) and 50% (pyramid, icosphere) pairs, by removing the icosphere from half the data and removing the cube from the other half of the data. We call it *bridge translation* as there is never a cube and a corresponding icosphere together. Therefore, producing an icosphere from a cube requires using a bridge domain: the pyramids. Generation is evaluated using the Mean Average Error (MAE).

Table 1: Parameters controlling BL3NDT dataset generation. Position, Camera angle, and Object color semantics are swapped between domains, while floor and wall colors are shared.

	Position	Camera angle	Object color	Floor color	Wall 1 color	Wall 2 color
Cube	p1, p2, p3	α	α, color1, color2	r1, g1, b1	r2, g2, b2	r3, g3, b3
Pyramid	p2, p3, p1	$1-\alpha$	color1, color2, α	r1, g1, b1	r2, g2, b2	r3, g3, b3
Icosphere	p3, p1, p2	$(\alpha+0.5)\%1$	color2, α, color1	r1, g1, b1	r2, g2, b2	r3, g3, b3

4.1.2 CelebAMask-HQ Dataset Augmented With Sketches

Evaluations are conducted on the CelebAMask-HQ dataset at 256x256 resolution. To obtain a setting with more than two domains, each face is augmented with a corresponding sketch computed using a pre-trained model (Chen et al., 2018).

The evaluation focuses on face-conditioned generation, as MDD is designed for generation rather than discriminative tasks (*e.g.* classification, regression, segmentation *etc.*).

The same supervision settings as BL3NDT is used with N=100% and N=0%. The quality of face generation is evaluated using established metrics from image-to-image translation, the Learned Perceptual Image Patch

[2] https://www.blender.org/

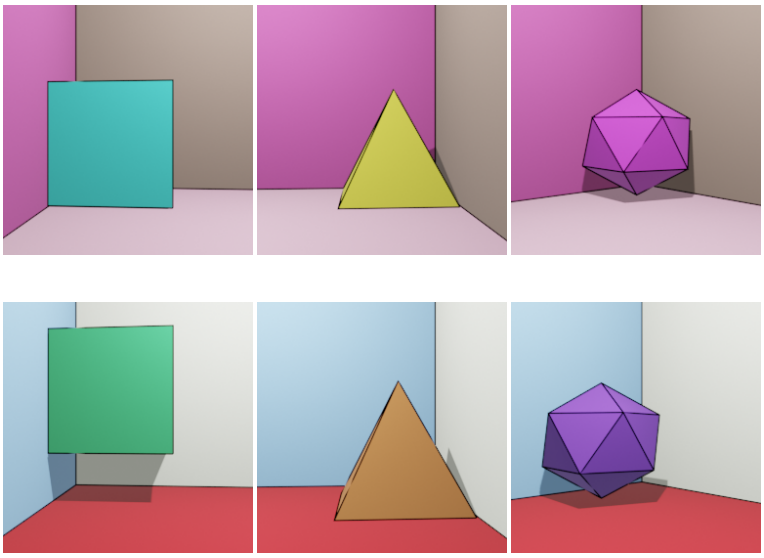

Figure 4: Two data points from BL3NDT dataset which provides a synthetic domain translation setup.

Similarity (Zhang et al., 2018)(LPIPS) and the Structural Similarity Index Measure (Wang et al., 2004) (SSIM).

4.1.3 BraTS 2020 Medical Dataset

Evaluations are conducted on the BraTS 2020 (Menze, 2014; Spyridon Bakas et al., 2017; et al., 2019; 2017) dataset comprising four MRI modalities (FLAIR, T1, T1ce, and T2), and 3D tumor segmentations. We use 2D slices (256x256) with linear normalization [0,1] and binary semantic segmentation.

As for CelebAMask-HQ, the evaluation focuses on scans generation conditioned on other modalities, since MDD is designed for generation rather than discriminative tasks.

For BraTS 2020, we evaluate three supervision settings: P100% (fully supervised), P80% (80% probability of keeping each view $x_j^{(i)}$), and P50% (50% probability of keeping each view $x_j^{(i)}$), and a minimum of two views are retained for each data point. Removing random scans simulates a realistic scenario where not all patients have complete scan sets. In the P50% setting, only 3% of the data retain all five modalities, 16% miss one modality, and 81% lack two or more modalities. This heterogeneous setting presents a more complex and realistic challenge compared to the BL3NDT dataset. Missing modality completion on the BraTS 2020 dataset is evaluated using the standard metrics for this task (Meng et al., 2022b; Li et al., 2023; Xie et al., 2023): Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity Index Measure (Wang et al., 2004) (SSIM). For segmentation generation, the Jaccard Index (Jaccard) is reported.

4.2 Implemented Models

Comparison with State-of-the-Art Methods (sota) For evaluation, MDD is compared with two multi-domain translation paradigms, clean and noisy conditions, which do not specify a condition domain. For the clean condition paradigm, UMM-CSGM (Meng et al., 2022b) training scheme is used as described in Sec. 2.3. The MSDM (Mariani et al., 2024) training scheme is used for the noisy condition paradigm, which has shown competitive quantitative results in music generation and separation. UMM-CSGM uses binary vectors for flexible conditions and target domain definitions, applying forward diffusion only to the target domain and keeping the condition domain clean. MSDM applies the forward diffusion process to all domains during training, bringing them to the same noise level. In MSDM, conditional generation is performed by applying noise to the condition to match the noise level in the target domains. Since MSDM was initially designed

Table 2: MAE↓ error (values are given in e-1 order) for different amounts of supervision on the BL3NDT dataset for cube→(pyramid, icosphere) translation. 'sota' refers to the original state-of-the-art methods without modifications, while 'ad.' refers to our adapted versions of these methods modified to handle semi-supervised scenarios.

	BL3NDT MAE↓	100%	70%	40%	10%	0%	Bridge
sota	MSDM†	1.962	2.028	2.186	2.925	-	-
sota	UMM-CSGM	0.359	0.503	0.852	4.601	-	-
ad.	MSDM†[N]	1.976	1.944	1.971	2.060	2.321	3.036
ad.	UMM[N]	0.353	0.422	0.443	0.544	3.324	3.444
	MDD	**0.316**	**0.338**	**0.361**	**0.399**	**0.434**	**1.199**

for music generation, we kept only the noise scheduling for each domain and referred to it as MSDM†. We refer to these models as 'sota' in the different results tables. In a semi-supervised setting, 'sota' methods are only trained on the supervised examples, ignoring semi-supervised data.

Comparison with Uni-Directional Domain Translation Methods In addition to multi-domain methods, we conduct comparisons with state-of-the-art diffusion translation models that are restricted to a specific translation direction ($f_{S_i,\bar{S}_i} : S_i \to \bar{S}_i$) using ControlNet (Zhang et al., 2023) in Appendix B.3. While ControlNet does not strictly fit the introduced multi-domain translation setting, as it operates only on fixed, predefined translation directions, we include these comparisons for the sake of completeness.

Adaptation of State-of-the-Art Methods to Semi-Supervised (ad.) To our knowledge, only UMM-CSGM, MSDM, and the like, are capable of addressing the defined multi-modal domain translation setting. To evaluate performance in both supervised and semi-supervised scenarios, we note that UMM-CSGM, MSDM, and ControlNet do not inherently support semi-supervised training. Therefore, we propose modified variants of each model (UMM[N], MSDM†[N], and ControlNet[N]) that handle missing views by substituting them with noise. The different results tables refer to these adapted models as 'ad.'.

Multi-Domain Diffusion Ablations (ours) To extensively test MDD capabilities, further ablation is provided by removing the contribution of Eq. (4), MDD training scheme is adapted to noisy conditions (named MDD[NOISY]). $\mathcal{T}$ is set as $\mathcal{T} = [t, t, t]$ during training. During generation, missing domains are replaced with noise and their t with T as specified in Eq. (5). Ablation of the additional step in Algorithm 1, line 8 is also provided (named MDD[RAND]). The different results tables refer to these adapted models as 'ours' and are analyzed in Appendix B.2.

Additional training details are provided in Appendix A.

4.3 BL3NDT Results

In this section, we demonstrate that MDD effectively performs domain translation on datasets without strong pixel-to-pixel correspondence between domains. We examine three distinct supervision settings: (1) the fully-supervised setting, where all data views are available; (2) the semi-supervised setting, where some views are missing from data points; and (3) the bridge data setting, where certain domains are never simultaneously present in the training samples.

In Tab. 2, MDD is compared to the different baselines. For all amount of supervision considered, MDD outperforms every baseline. The lower the supervision (lower N), the more MDD outperforms other baselines.

Supervised performances: For $N = 100\%$, UMM-CSGM, UMM[N], and MDD exhibit comparable low MAE errors. In contrast, MSDM† and MSDM†[N] demonstrate notably higher MAE error. The similarity in results for UMM-CSGM, UMM[N], and MDD is expected, as they all utilize a clean condition during the generation process, and the full supervision allows learning the translation task. The higher MAE errors observed in MSDM† and MSDM†[N] can be attributed to their noisy condition: the condition is degraded to the same level as the generation. This creates a disharmony between condition and generation, as the

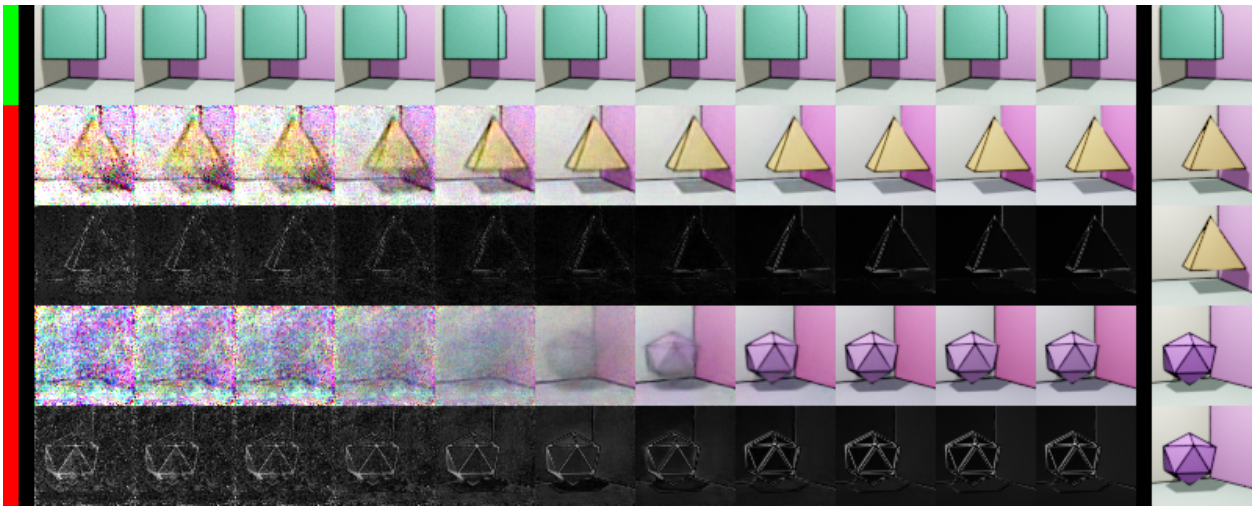

Figure 5: **Bridge translation on cube→(pyramid, icosphere).** The left row shows the condition in green and the generation in red. The right column shows the ground truth. Each row represents, from top to bottom, for each time in the backward diffusion process, the cube condition, the current pyramid translation, the current pyramid L1 map with the ground truth, the current iscophere translation, and the current icosphere L1 map with the ground truth.

model cannot leverage the condition during earlier steps. This shows how using a clean condition guides the generation in the right direction from the start of the diffusion process, resulting in more faithful generations.

Semi-supervised performances: As N decreases, an increase in MAE is observed across all models. This trend is particularly pronounced for the supervised models UMM-CSGM and MSDM†, which do not utilize samples with missing views. In contrast, it is worth noting that MDD performances only slightly decrease for $N \in \{70, 40, 10\}$. The semi-supervised adaptation MSDM†[N] shows similar results to its original formulation as N decreases, indicating that the noisy formulation is not well-suited for producing highly faithful results. For UMM[N], the performance decrease is more substantial than for MDD, suggesting that the clean condition is not the sole factor contributing to MDD performances. At $N = 0\%$, all methods except MDD fail to learn the task. It is possible that sampling t according to Eq. (4) may serve as an additional form of data augmentation.

Bridge Translation: The cube→(pyramid,icosphere) translation proves challenging, as can be seen in the qualitative images in Fig. 5, where the L1-map shows some shift of the object position, and in the Tab. 2 where the Bridge column has the highest error of all supervision setting. Two factors may explain this: in the early stages of the backward diffusion process, the pyramid translation is suboptimal and subject to significant noise. In addition, the semantic inversion makes the generation more sensitive to noise, *e.g.* a wrong prediction in the pyramid color will also affect the prediction of the camera angle (see α in Tab. 1). While this issue impacts the MAE on BL3NDT, the usual domain translation tasks do not expect a one-to-one mapping (*e.g.* face↔sketch translation), which mitigates the problem in real-world applications.

4.4 CelebAMask-HQ Results

To assess MDD's capability in generating realistic views for challenging domain-to-domain translation tasks, we evaluated domain translation between face, sketch, and segmentation mask on the CelebAMask-HQ dataset. This section considers the (sketch, mask)→face translation and shows that MDD can generate realistic faces.

The diversity of face generation, sketch generation, and segmentation generation is evaluated in Appendix B.5 along with additional quantitative and qualitative results.

As shown by Tab. 3, MDD closely matches LPIPS of UMM[N] in the different supervision settings and improves on SSIM. MDD significantly outperforms all other methods on both LPIPS and SSIM. In some instances, the UMM[N] method seems to produce oversaturated results but generally performs better than MSDM†[N]. This aligns with findings from other datasets, where the noisy condition paradigm consistently underperforms compared to the clean condition paradigm.

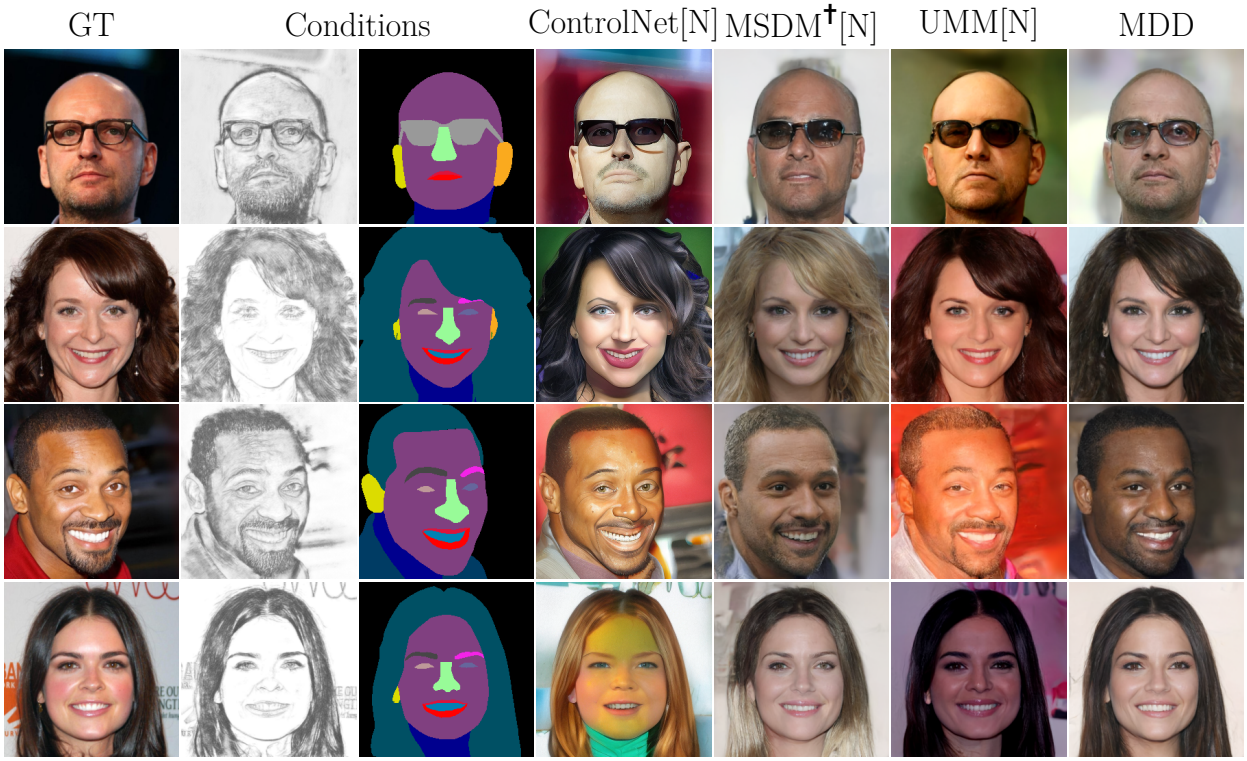

Figure 6: Generated faces given a sketch, mask condition, and the corresponding GT for N=0%.

Table 3: Evaluation metrics for (sketch, segmentation)→face on the CelebAMask-HQ dataset. 'ad.' refers to our adapted versions of state-of-the-art methods modified to handle semi-supervised scenarios.

	CelebAMask-HQ	LPIPS↓		SSIM↑	
	Face	100%	0%	100%	0%
ad.	MSDM†[N]	0.3814	0.3785	0.1483	0.1306
ad.	UMM[N]	0.2930	0.3500	0.2902	0.2177
	MDD	**0.2305**	**0.3023**	**0.4385**	**0.3381**

4.5 BraTS 2020 Results

4.5.1 Missing Modalities Completion

To demonstrate MDD's flexibility, we evaluate its performance in regenerating each modality on the BraTS 2020 dataset, establishing that a single trained MDD model successfully handles the generation of all modalities.

Table 4 presents quantitative results for PSNR and SSIM metrics, while Fig. 7 provides qualitative visual results. Additional quantitative analysis using other metrics (MSE, MAE) is provided in Appendix B.4. We focus primarily on T1 scan generation analysis and observe that our findings generalize to other modalities (Tab. 4) using only one model, highlighting the flexibility of multi-domain diffusion models compared to fixed diffusion models, which would require at least one model for each domain.

Table 4: Evaluation metrics for T1, T1ce, T2, and Flair, modalities completion on the BraTS 2020 dataset for different levels of supervision PN%, where N% indicates the probability of keeping a view. 'sota' refers to the original state-of-the-art methods without modifications, while 'ad.' refers to our adapted versions of these methods modified to handle semi-supervised scenarios.

		T1						T1ce					
		PSNR↑			SSIM↑			PSNR↑			SSIM↑		
		P100%	P80%	P50%	P100%	P80%	P50%	P100%	P80%	P50%	P100%	P80%	P50%
sota	MSDM†	21.623	18.583	11.077	0.883	0.735	0.146	**27.159**	25.971	19.067	**0.911**	0.840	0.135
sota	UMM-CSGM	22.806	17.769	13.280	0.894	0.680	0.064	26.947	26.488	26.558	0.910	0.898	0.892
ad.	MSDM†[N]	21.486	21.608	21.456	0.883	0.886	0.822	27.056	24.513	16.943	0.887	0.699	0.060
ad.	UMM[N]	22.467	21.720	22.188	0.880	0.891	0.874	26.956	27.136	26.680	0.892	0.888	0.880
	MDD	**23.004**	**23.373**	**22.928**	**0.902**	**0.903**	**0.892**	27.052	**27.567**	**27.285**	0.894	**0.909**	**0.892**
		T2						Flair					
		PSNR↑			SSIM↑			PSNR↑			SSIM↑		
		P100%	P80%	P50%	P100%	P80%	P50%	P100%	P80%	P50%	P100%	P80%	P50%
sota	MSDM†	24.679	21.485	15.844	0.824	0.775	0.090	22.801	18.829	17.764	0.872	0.785	0.229
sota	UMM-CSGM	24.706	24.241	23.980	0.813	0.874	0.805	22.809	22.603	22.059	0.871	0.860	0.833
ad.	MSDM†[N]	25.249	20.895	12.321	**0.891**	0.701	0.029	23.491	21.649	12.366	0.839	0.753	0.042
ad.	UMM[N]	24.726	24.843	24.036	0.882	0.887	0.861	23.110	23.384	22.726	0.845	0.840	0.827
	MDD	**25.383**	**25.716**	**24.788**	0.875	**0.894**	**0.877**	**24.173**	**24.103**	**23.663**	**0.876**	**0.879**	**0.868**

The existing formulations, MSDM† and UMM-CSGM, demonstrate significant performance degradation under reduced supervision conditions. Specifically, UMM-CSGM's PSNR on T1 generation decreases substantially from 22.81 to 13.28 when supervision is reduced from P100% to P50%, highlighting the inherent difficulty of this task with limited training data (Table 4). As illustrated in Fig. 7, these methods fail to generate clinically acceptable images outside the fully supervised setting. Our adaptation of these formulations (MSDM†[N] and UMM[N]) improves their resilience to supervision reduction, with both methods maintaining more stable performance metrics when supervision decreases, as evidenced in Tab. 4. Notably, MDD consistently outperforms the adapted UMM[N], despite the latter being specifically designed for missing scan completion tasks.

4.5.2 Flexibility in the Number of Inputs

MDD demonstrates flexibility in handling both missing modality completion and varying numbers of condition domains during inference. We explore this adaptability through two experiments: missing modalities completion (focusing on T1 scan generation results here) and semantic segmentation (Appendix B.4), each with a gradually decreasing number of input modalities.

We gradually remove modalities in the order [Segmentation, T1ce, T2, Flair] and regenerate the missing domains, focusing on T1 scan generation. Qualitative results are presented in Fig. 8 and quantitative results in Tab. 5.

Models with noisy conditions demonstrate limitations in this setup. MSDM†[N]'s PSNR decreases by approximately 13% when the number of domains used drops from 4 to 1, compared to only a 4% decrease for MDD (Tab. 5). Generated T1 scans from MSDM†[N] are inconsistent when varying the number of condition domains, as observed in Fig. 8.

Conversely, models with clean conditions perform well. MDD not only outperforms UMM[N] but also maintains consistency as the number of available scans decreases. While UMM[N]'s PSNR shows a slight drop between four scans and one scan, its generation can be less consistent than MDD when the number of condition domains becomes very small.

The superior performance of MDD demonstrates how using different t per domain allows for learning better data fusion compared to using a binary code (UMM[N]) or no code at all (MSDM†[N]). MDD effectively learns the relative information in different domains at each step, extracting data from less noisy domains to reconstruct the more noisy ones. These results indicate that MDD adapts well to varying numbers of inputs, particularly when condition domains become scarce. This suggests that MDD could be effectively used for

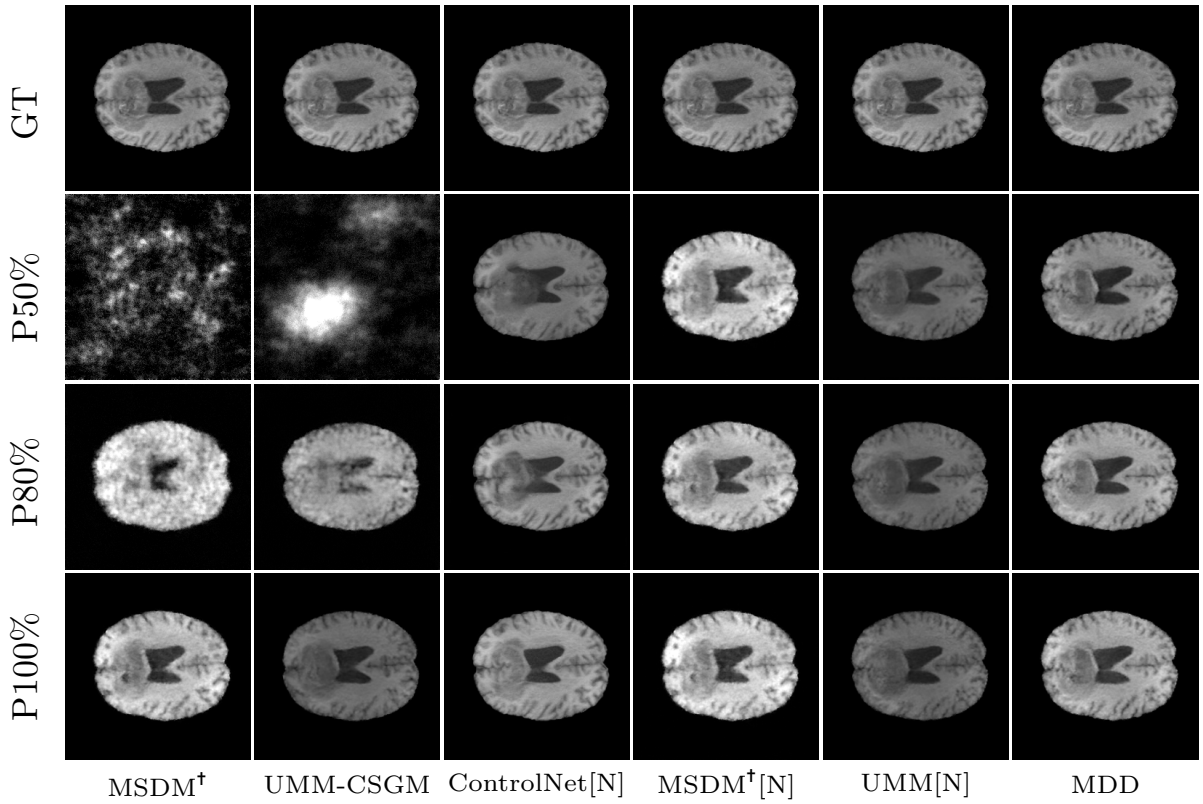

Figure 7: Generated T1 scan given all remaining modalities and the corresponding GT for different supervision levels.

multimodal data fusion in situations where modalities may be missing during inference, offering a robust solution for diverse medical imaging scenarios.

Table 5: Evaluation metric for T1 scan generation on the BraTS 2020 dataset while varying the number of input domains. 'ad.' refers to our adapted versions of state-of-the-art methods modified to handle semi-supervised scenarios.

	BraTS 2020	PSNR↑				SSIM↑			
	T1 P50%	4 dom	3 dom	2 dom	1 dom	4 dom	3 dom	2 dom	1 dom
ad.	MSDM†[N]	21.456	21.336	20.615	18.711	0.822	0.817	0.806	0.752
ad.	UMM[N]	22.188	22.175	22.055	21.758	0.874	0.878	0.870	0.852
	MDD	**22.928**	**22.934**	**22.503**	**22.075**	**0.892**	**0.896**	**0.887**	**0.864**

5 Limitations

In this section, we discuss some of the potential areas for improvement of MDD.

While MDD effectively handles the fusion of information from multiple domains (Sec. 4.5.2), the scalability of combining information from an increasing number of domains within a single latent vector could become a bottleneck. As the number of domains grows, the efficient integration and representation of multi-domain information may present computational and architectural challenges. The current architecture could benefit from more advanced data fusion strategies, particularly those designed for semi-supervised and imbalanced settings involving numerous domains (Han et al., 2024). Such advanced fusion mechanisms could enhance the model's ability to handle heterogeneous data distributions and varying levels of annotation across domains.

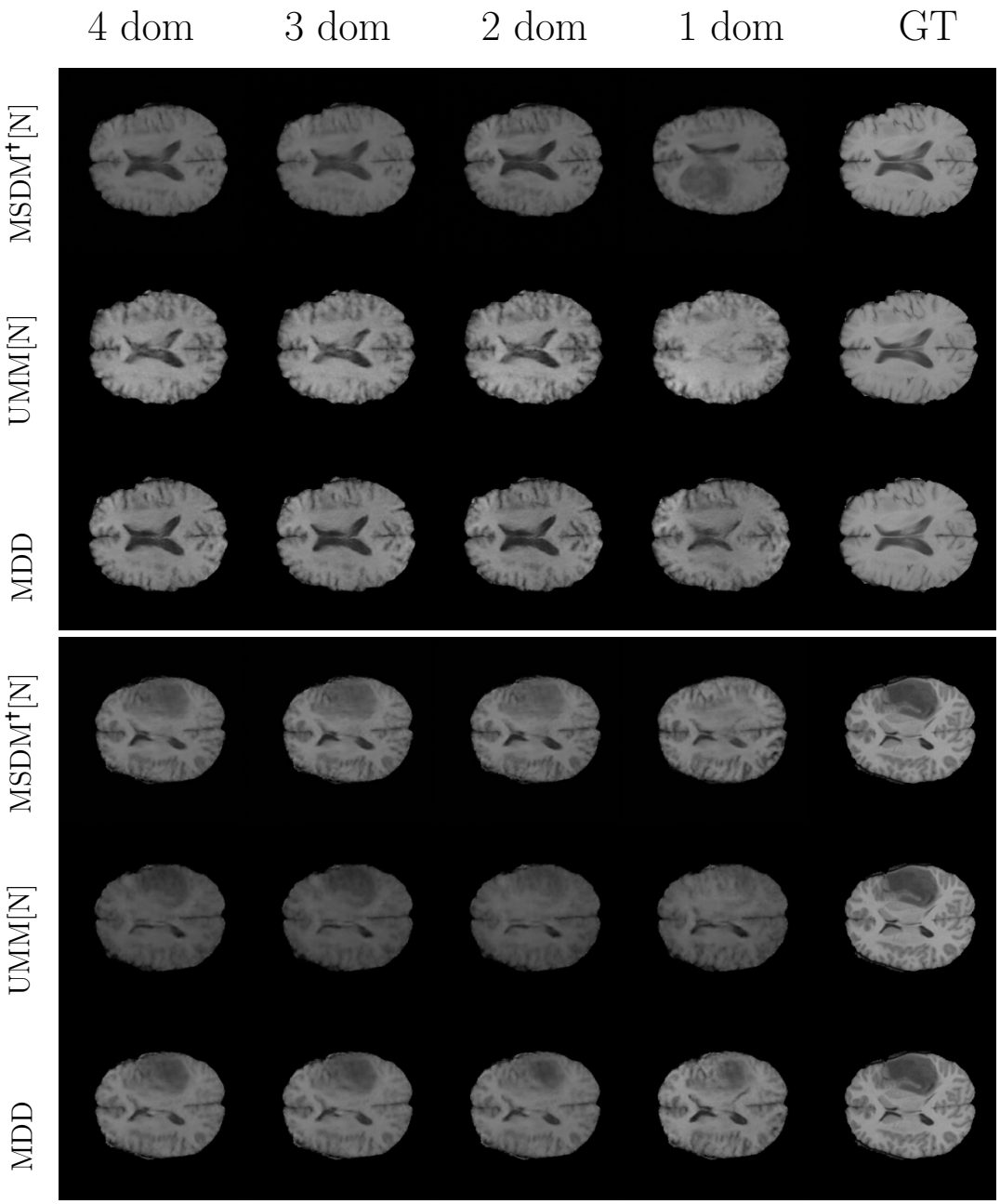

Figure 8: Generated T1 scans given multiple numbers of scans as input for P50%. Zoom in for better details.

Another limitation of this study lies in the evaluation methodology. Although we employed diverse metrics that are widely accepted in the field, the incorporation of human preference evaluations could have provided additional valuable insights. However, such studies can be challenging to implement due to the need for humain annotators and standardized evaluation protocols.

6 Broader Impact Statement

As MDD is a generative framework requiring training datasets, it raises several important ethical considerations. These include concerns regarding image privacy, the inclusiveness of generated images which may exhibit biases, and the potential for memorization and reproduction of training examples.

MDD leverages synthetic datasets (Sec. 4.1.1) containing geometric forms, which inherently circumvents issues related to data privacy, biases, and inclusiveness. The additional datasets employed in this research are publicly available, thereby mitigating certain data rights and privacy concerns. Nevertheless, several critical aspects require careful attention, including potential biases in image generation, demographic representation, and training data memorization and reproduction.

To address these challenges, we recommend the following measures: First, it is crucial to ensure proper data usage rights and permissions for all training images. Second, the training dataset should be carefully curated to represent diverse populations and scenarios, avoiding demographic or contextual biases. Third, thorough analysis of the generated image distribution should be conducted to detect and address any learned biases or potential privacy breaches. Additionally, regular auditing of the model's outputs and systematic evaluation of its societal impact should be performed to ensure responsible deployment of the technology.

7 Conclusions

We demonstrate that the MDD framework effectively learns multi-modal, multi-domain translation in a semi-supervised setting by modeling domain-specific noise levels. This approach facilitates domain translation learning without requiring the definition of a specific condition domain.

Unlike existing frameworks, MDD can handle a significant number of modalities without substantially increasing model size. Moreover, it exhibits superior information fusion from different modalities, making it particularly suitable for tasks with a large number of domains.

Our research elucidates how MDD unifies various approaches to applying noise to the condition in domain translation tasks. We found that maintaining a clean condition during generation yields excellent results, as it allows leveraging the condition from the start of the diffusion process. Using a noisy condition is particularly detrimental when tasks involve deterministic mapping, especially when the target domain is a semantic segmentation map. We attribute this issue to the diffusion model's need to generate a mean image without condition information at the start of the generation process, and subsequently correct erroneous predictions.

Our work integrates seamlessly with existing literature on diffusion frameworks that aim to learn multi-modal domain translation without defining a specific translation path (Meng et al., 2022b; Bao et al., 2023; Mariani et al., 2024) and by applying different noise levels per modality (Meng et al., 2022b; Mariani et al., 2024). Extending these existing works, we demonstrate that the proposed formulation allows for semi-supervised conditional domain translation. This can reduce the data burden in settings where data is difficult to acquire, such as the medical field, and allow for flexible translation with different inputs.

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Supplementary Material

A Implementation Details

A.1 Diffusion Model

During training, we use a linear noise schedule or $(1e-4, 2e-2)$ and the noise prediction function described in Sec. 3.1. The maximum number of diffusion steps T is 1 000. During generation, DDIM (Song et al., 2022) with 100 steps is used for BL3NDT, DDPM (Ho et al., 2020) with 1000 steps for BraTS 2020, and DDPM with 1000 steps for CelebAMask-HQ when faces are part of the generation; otherwise, DDIM with 250 steps for the other CelebAMask-HQ modalities.

A.2 Training Details

A.2.1 Multi-Domain Translation Models

For all multi-domain translation models (MSDM†, UMM-CSGM, and MDD), we employ consistent hyperparameter settings within each dataset. We utilize the Adam optimizer with an initial learning rate of 7×10^{-5} for BraTS 2020 and 2×10^{-5} for both BL3NDT and CelebAMask-HQ datasets. The Adam parameters β_1 and β_2 are set to 0.9 and 0.999, respectively. For BL3NDT and BraTS 2020, we implement a learning rate decay strategy, multiplying the rate by 0.75 every 10 epochs. We employ batch sizes of 256 for BL3NDT, and 64 for both BraTS 2020 and CelebAMask-HQ. All models are trained with Exponential Moving Average (EMA) on model parameters with a decay rate of 0.9999. For BL3NDT, we implement early stopping with a patience of 40 epochs and a maximum computational budget of 240 epochs. For BraTS 2020, all models are trained for 200 epochs, while for CelebAMask-HQ, training continues for 2000 epochs.

A.2.2 Uni-Direction Translation Models

For ControlNet implementations (Zhang et al., 2023), we use the publicly available code repository and select each model based on its best validation metrics. For the BL3NDT dataset, we train with an unlocked decoder for 1000 epochs with a batch size of 256. For BraTS 2020, training proceeds with an unlocked decoder for 700 epochs using a batch size of 128. For CelebAMask-HQ, we conduct training for 2000 epochs with a batch size of 1024.

A.3 Data Normalization

For BL3NDT, images are linearly normalized between [-1,1], and no data augmentation is applied.

For BraTS 2020, each 3D scan is independently linearly normalized between [0,1], and the semantic segmentation classes are merged to create a binary segmentation and are one hot encoded with one channel. The bottom 80 and top 26 slices are removed. Each resulting 3D volume is sliced in the axial axis and resized to (224, 224).

For CelebAMask-HQ, faces and sketches are linearly normalized in [-1,1], and the 19 classes are one hot encoded. We resize each modality in (256,256) and use random horizontal flips as data augmentation.

A.4 Model Architecture and Adaptation to Multiple Domains

All models use the same U-Net architecture based on (Ho et al., 2020) with some modifications to accommodate multiple domains and times. We call E the U-Net encoder, B its bottleneck, and D its decoder. In a setting with L domains, the encoder and decoder are duplicated L-times and function as in the classical single-domain diffusion setting, *i.e.* the encoder $E^{(l)}$ takes as input the modality $x^{(l)}$ and the time $\mathcal{T}^{(l)}$ and produces its embedding $e^{(l)}$ and a list of skip connections skips$^{(l)}$. The list of embeddings $[e^{(1)}, ..., e^{(L)}]$ and times $\mathcal{T}$ is then processed by a bottleneck adapted for multi-domain multi-time, which we will describe later, to produce the processed embedding *emb*. Each decoder $D^{(l)}$ takes as input the processed embedding *emb*,

the list of skips connections $\text{skips}^{(l)}$ and time $\mathcal{T}^{(l)}$, and predicts the noise map for the modality $x^{(l)}$ as in the classical single-domain diffusion setting.

To accommodate multiple domains, an aggregation network is added before the bottleneck, taking as input the list of embeddings $[e^{(1)}, ..., e^{(L)}]$ each of shape (b, c, h, w) and times $\mathcal{T}$. The embeddings are concatenated on the channel dimension before going through a ConvNextBlock which reduces their dimension from $c \times L$ back to c. They are then processed through the bottleneck layers as the original U-Net would.

Each layer that uses the entire $\mathcal{T}$ is modified. The $\mathcal{T}$ of shape (b, L) is embedded once at the beginning of the forward pass using the initial time-embedding MLP into a tensor of shape $(b, L, tdim)$, then reshaped into shape $(b, L \times tdim)$. Then, each bottleneck ConvNextBlock time MLP input dimension is modified to take as input a vector of shape $(b, L \times tdim)$ instead of taking a vector of shape $(b, tdim)$.

B Additional Experiments

B.1 Exploring the Noise on Condition Strategy

During MDD training, there is no domain identified as a condition domain or as a target domain, so the question is how to use the condition during the generation process: should the condition be kept clean (using $x_{\text{cond},0}$, see Algorithm 2) or should it contain the same level of noise as in generation (using $x_{\text{cond},t}$, see Algorithm 2). We experiment on BL3NDT dataset to compare the effect of different noise levels during the generation process and define four noise strategies for the condition described in Fig. 9. We define $\phi_\gamma(t)$ as the function that allows to obtain the noise level in the condition domains according to the noise level present in the generated domains.

Approaches that learn the joint distribution apply the same noise level on each modality during training (Mariani et al., 2024) and thus also during generation. This strategy is called Vanilla noise because it closely follows the original backward diffusion process. When a condition domain is identified, it is often kept clean during training and generation (Xie et al., 2023; Cross-Zamirski et al., 2023; Saharia et al., 2022; Lyu & Wang, 2022). We identify this strategy as Constant Noise, which can be parameterized by a noise level, a clean condition is identified as Constant Noise(0). We also explore two additional strategies: Skip Noise, which is vanilla noise, where the noise applied to the condition is less than that applied to the generation, and Constant Noise Fading, where the noise remains constant until it catches up with the generation.

For the BL3NDT dataset with the Bridge data setting, we found that the higher the γ, the lower the MAE. This is not surprising, as the higher the γ, the less noisy the condition, allowing the model to use information from the condition early in the generation process and avoid drifting too far from the correct semantic. Interestingly, the ϕ Skip Noise function has a low MAE even for a relatively high level of γ. We speculate that this noise scheme still allows the diffusion model to focus first on the low-level frequency that is erased from the condition and, later on, the high-level frequency details.

B.2 Ablation Study

To extensively test MDD capabilities, further ablation is provided by removing the contribution of Eq. (4), MDD training scheme is adapted to noisy conditions (named MDD[NOISY]). $\mathcal{T}$ is set as $\mathcal{T} = [t, t, t]$ during training. During generation, missing domains are replaced with noise and their t with T as specified in Eq. (5). Ablation of the additional step in Algorithm 1, line 8 is also provided (named MDD[RAND]). The different results tables refer to these adapted models as 'ours'.

Noisy generation: MDD[NOISY]. Using a noisy condition instead of a clean condition significantly increases the translation error, as shown in Tab. 6. This is more true for the BL3NDT dataset than for the other datasets, because the BL3NDT dataset expects a specific output with challenging variable inversions between domains. For other datasets, such as BraTS 2020, MDD also consistently outperforms MDD[NOISY], as shown in Tabs. 10 to 13.

For translation tasks where the target is semantic segmentation, MDD[NOISY] fails the task as shown in Tabs. 14 and 16 by producing realistic segmentation but unaligned with the condition, which is consistent

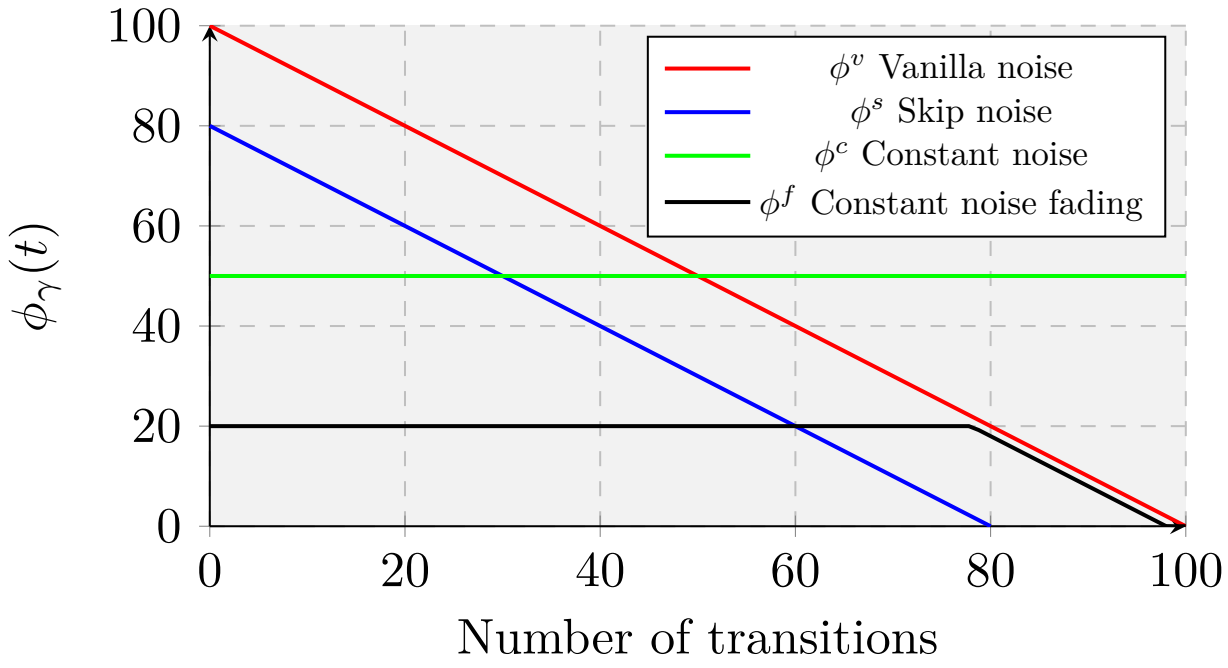

Figure 9: **Illustration of different $\phi_\gamma(t)$ functions.** Evolution of the noise applied to the condition as a function of the number of transitions made for the target domain. Vanilla diffusion steps have the drawback of not properly preserving semantic information of the condition and requiring multiple jumps. Skip Noise diffusion removes information of the condition in the same way as the Vanilla diffusion step, but allows a cleaner condition at the start, therefore better preserving semantic information from the condition. Constant noise continuously removes the same amount of information at each step. We found this solution to work best in practice with a low amount of 20% of the total number of time steps. We also tried applying constant noise to the condition until the noise level of the target domain caught up with the condition.

with other noisy condition models such as MSDM†[N] (Fig. 18). When generating segmentation maps from other condition domains, MDD[NOISY] (and other noisy condition models) has no mechanism to distinguish which domain is part of the generation and which is part of the condition; therefore, correcting the target domain (in this case, the segmentation) becomes particularly challenging. A similar problem has been reported in other works (Lugmayr et al., 2022; Chung et al., 2022) where the current generation and condition are not well synchronized. Proposed solutions involve resampling mechanisms (Lugmayr et al., 2022; Chung et al., 2022), which increases computation time, making prediction of many images impractical for most institutions.

This validates the assumption that using a clean condition allows diffusion models to leverage the condition from the early steps of diffusion, leading to more faithful and realistic generations.

Condition vector m_c: MDD[RAND]. Tweaking the noise scheduling during training allows MDD to better follow a specific set of domains during generation. We found that this formulation is beneficial for tasks where a specific output is expected, such as the BL3NDT dataset (Tab. 6) and segmentation tasks (Tabs. 14 and 16). For other translation tasks, MDD performs better than MDD[RAND], but with a smaller metric difference (Tabs. 10 to 13).

B.3 Comparison to Model with a Fixed Configuration

We compare MDD with ControlNet (Zhang et al., 2023), a diffusion-based domain translation framework that enables translation from a fixed set of conditional domains to a specific target domain. While **ControlNet is limited to one specific configuration among the 2^n possible translation configurations**,

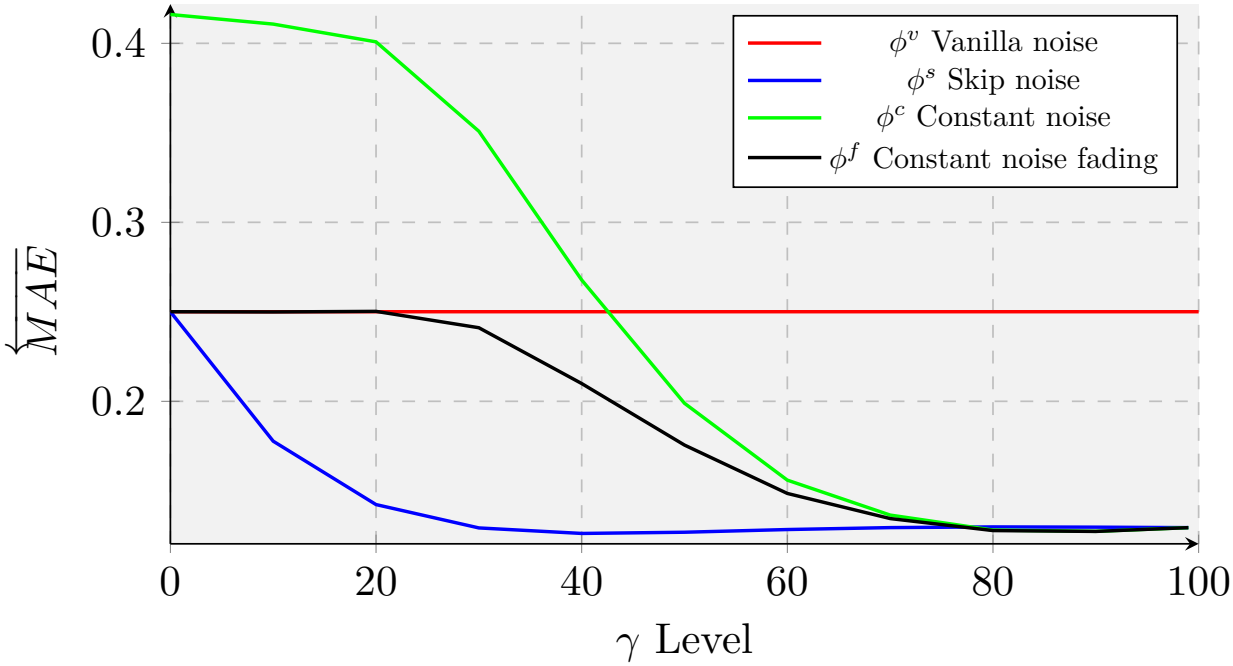

Figure 10: Comparison of the MAE↓ for different $\phi_\gamma(t)$ functions according to the γ parameter on BL3NDT dataset using the Bridge data setting. In general, the smaller the γ, the higher the MAE. The smaller γ, the noisier the condition, and the harder it is for the model to use the information within the condition in the early steps.

Table 6: BL3NDT ablation, MAE↓ error (values are given in e-1 order) for different amounts of supervision on the BL3NDT dataset for cube→(pyramid, icosphere) translation.

	BL3NDT MAE↓	100%	70%	40%	10%	0%	Bridge
ours	MDD[NOISY]	1.977	2.001	2.030	2.158	2.740	4.022
	MDD[RAND]	0.616	0.652	0.715	0.803	0.565	1.294
	MDD	**0.316**	**0.338**	**0.361**	**0.399**	**0.434**	**1.199**

making it inherently different from our framework's flexibility, we include this comparison to demonstrate the advantages of our approach.

B.3.1 Translation With Complex Semantic Inversion

The translation cube→(pyramid, icosphere) is evaluated. For this purpose, ControlNet requires training two separate models: one for cube→pyramid and another for cube→icosphere. In the bridge supervision setting (where 50% of (cube, pyramid) pairs and 50% of (pyramid, icosphere) pairs are available), two distinct models must be trained: cube→pyramid and pyramid→icosphere. Moreover, for the bridge translation scenario, using pyramid→icosphere requires generated pyramid images as conditions, which can introduce domain adaptation challenges due to potential distribution shifts between generated and real images. This demonstrates a significant limitation of ControlNet, as different models must be trained for different configurations, whereas MDD efficiently handles all configurations using a single unified model.

We report the MAE results in Tab. 7. Despite training with an unlocked stable diffusion decoder [3], ControlNet[N] fails to effectively solve the translation task. While it generates plausible and visually coherent images, it struggles significantly with semantic inversion and frequently misassigns colors (Fig. 11). Specifically, ControlNet[N] accurately positions the geometric objects but consistently applies incorrect colors to

[3] https://github.com/lllyasviel/ControlNet/blob/main/docs/train.md#sd_locked

Table 7: Evaluation of translation domain with a fixed-configuration using ControlNet. MAE↓ error (values are given in e-1 order) for different amounts of supervision on the BL3NDT dataset for cube→(pyramid, icosphere) translation.

BL3NDT MAE↓	100%	70%	40%	10%	0%	Bridge
ControlNet[N]	1.707	1.946	2.116	2.315	2.408	2.390
MDD	**0.316**	**0.338**	**0.361**	**0.399**	**0.434**	**1.199**

Table 8: Evaluation of translation domain with a fixed-configuration using ControlNet. Evaluation metrics for T1 modality completion on the BraTS 2020 dataset for different levels of supervision PN%, where N% indicates the probability of keeping a view.

BraTS 2020	PSNR↑			SSIM↑		
T1	P100%	P80%	P50%	P100%	P80%	P50%
ControlNet[N]	**24.929**	**24.665**	**23.968**	0.890	0.869	0.832
MDD	23.004	23.373	22.928	**0.902**	**0.903**	**0.892**

either the objects or the surrounding walls. Unlocking the full model (encoder, bottleneck, and decoder instead of just the decoder) resolves this issue but requires much more training time and computations; this reveals an inherent limitation in ControlNet's domain translation capabilities. These results suggest that, unlike MDD, ControlNet's capabilities are limited to tasks with strong pixel-to-pixel correspondences and may not be suitable for more complex domain translation tasks requiring semantic understanding.

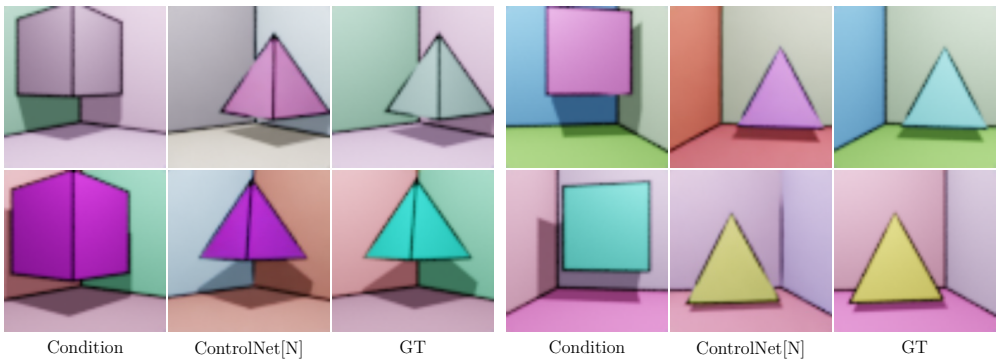

Figure 11: Evaluation of translation domain with a fixed-configuration using ControlNet. Translation on cube→pyramid for $N = 100$ on BL3NDT.

B.3.2 Missing T1 Completion on BraTS 2020

For the BraTS 2020 dataset, ControlNet[N] demonstrates strong performance (Fig. 7) when adapted to the semi-supervised setting, achieving high PSNR values but lower SSIM scores compared to MDD (Tab. 8). Since SSIM evaluates the similarity in luminance, contrast, and structural information between images, it provides a more clinically relevant assessment for medical scan evaluation, where preservation of anatomical structures is critical for diagnostic purposes.

B.3.3 Face Generation on CelebAMask-HQ

To complement our multi-domain translation evaluation (Sec. 4.4), we assess the (sketch, mask)→face translation by training one ControlNet[N] for each supervision proportion. For $N = 100\%$, ControlNet[N] generates realistic images as evidenced by low LPIPS and SSIM metrics (Tab. 9). It can be observed that MDD produces better metrics than ControlNet[N], despite ControlNet[N] leveraging powerful pre-trained model which, which show MDD capacity to fully utilize the cross-domain information during training. However, for $N = 0\%$, despite being trained in the same semi-supervised setting as MSDM†[N] and UMM[N] (with missing

samples replaced by noise), ControlNet[N] fails to adapt effectively to the translation task, as indicated by significantly higher LPIPS values and poor visual quality (Fig. 6). This highlights how fixed-domain translation conditioning mechanisms demonstrate reduced robustness in challenging low-supervision settings (when no fully supervised training data exists, unlike for the BraTS 2020 setting) without specific adaptations. In contrast, our model produces highly realistic images even under these constrained conditions (Fig. 6), demonstrating superior generalization capabilities.

Table 9: Evaluation of translation domain with a fixed-configuration using ControlNet. Evaluation metrics for (sketch, segmentation)→face on the CelebAMask-HQ dataset.

CelebAMask-HQ	LPIPS↓		SSIM↑	
Face	100%	0%	100%	0%
ControlNet[N]	0.2391	0.42780	0.4330	0.1833
MDD	**0.2305**	**0.3023**	**0.4385**	**0.3381**

B.4 BraTS 2020 Additional Missing Modalities Completion Results

Additional quantitative and qualitative results are provided for all missing modalities on BraTS 2020 for a more detailed analysis of the missing modality completion task. Additional results for T1 generation Tab. 10 and Fig. 12, results for T1ce generation Tab. 11 and Fig. 13, T2 generation Tab. 12 and Fig. 14 and Flair generation Tab. 13 and Fig. 15 are consistent with those presented in the main paper, where MDD performs strongly on metrics considered.

For segmentation generation Tab. 14 and Fig. 16, we found that noisy generation strategies (MSDM† and MSDM†[N]) are unable to perform the task even when a lot of supervision is available (Fig. 16). It is possible that at the beginning of the generation, when the condition is noisy, MSDM† and MSDM†[N] are unable to predict a meaningful "mean" due to the binary and localized nature of the segmentation maps. However, this effect may be mitigated for scan modalities as it can predict a correct mean image that better represents the scan modality distribution.

Table 10: Evaluation metrics for T1 modality completion on the BraTS 2020 dataset. To save place, SSIM values are given in e+1 order, MAE values are given in e-2 order, and MSE values are given in e-3 order. 'sota' refers to the original state-of-the-art methods without modifications, while 'ad.' refers to our adapted versions of these methods modified to handle semi-supervised scenarios.

	BraTS 2020	PSNR↑			SSIM↑			MAE↓			MSE↓		
	T1	P100%	P80%	P50%	P100%	P80%	P50%	P100%	P80%	P50%	P100%	P80%	P50%
sota	MSDM†	21.62	18.58	11.08	8.83	7.35	1.46	3.31	5.19	17.46	6.88	13.86	78.03
sota	UMM-CSGM	21.49	21.61	21.46	8.83	8.86	8.22	3.34	3.28	3.54	7.10	6.91	7.15
ad.	MSDM†[N]	22.81	17.77	13.28	8.94	6.80	0.64	2.92	5.80	14.76	5.24	16.71	46.99
ad.	UMM[N]	22.47	21.72	22.19	8.80	8.91	8.74	3.06	3.34	3.18	5.67	6.73	6.04
ours	MDD[RAND]	**23.44**	23.15	21.70	8.84	8.83	8.63	**2.72**	2.79	3.32	**4.53**	4.84	6.76
ours	MDD[NOISY]	21.85	21.99	21.61	8.85	8.80	8.78	3.19	3.18	3.30	6.52	6.32	6.91
ours	MDD	23.00	**23.37**	**22.93**	**9.02**	**9.03**	**8.92**	2.84	**2.73**	**2.87**	5.01	**4.60**	**5.10**

B.5 CelebAMask-HQ Additional Translation Results

We provide additional quantitative and qualitative results for (face, mask)→sketch translation in Fig. 17 and Tab. 15, (face, sketch)→mask in Fig. 18 and Tab. 16 translation and ()→(face, sketch, mask) generation in Fig. 19.

The diversity of face generation is evaluated in different settings: (sketch, mask)→face generation Fig. 20 and mask→(face, sketch) Fig. 21 where we calculate the Diversity Score over the generated faces Tab. 17.

Table 11: Evaluation metrics for T1ce modality completion on the BraTS 2020 dataset. To save place, SSIM values are given in e-1 order, MAE values are given in e-2 order, and MSE values are given in e-3 order. 'sota' refers to the original state-of-the-art methods without modifications, while 'ad.' refers to our adapted versions of these methods modified to handle semi-supervised scenarios.

	BraTS 2020	PSNR↑			SSIM↑			MAE↓			MSE↓		
	T1ce	P100%	P80%	P50%	P100%	P80%	P50%	P100%	P80%	P50%	P100%	P80%	P50%
sota	MSDM†	**27.16**	25.97	19.07	**9.11**	8.40	1.35	**1.69**	2.15	7.14	1.92	2.53	12.40
sota	UMM-CSGM	26.95	26.49	26.56	9.10	8.98	8.92	1.72	1.88	1.90	2.02	2.24	2.21
ad.	MSDM†[N]	27.06	24.51	16.94	8.87	6.99	0.60	1.83	2.68	10.10	1.97	3.54	20.22
ad.	UMM[N]	26.96	27.14	26.68	8.92	8.88	8.80	1.81	1.78	1.89	2.02	1.93	2.15
ours	MDD[RAND]	26.82	27.14	26.92	8.73	8.59	8.92	1.90	1.85	1.76	2.08	1.93	2.03
ours	MDD[NOISY]	26.98	26.80	26.62	9.09	9.01	**9.00**	1.74	1.81	1.84	2.01	2.09	2.18
ours	MDD	27.05	**27.57**	**27.28**	8.94	**9.09**	8.92	1.81	**1.63**	**1.73**	1.97	**1.75**	**1.87**

Table 12: Evaluation metrics for T2 modality completion on the BraTS 2020 dataset. To save place, SSIM values are given in e-1 order, MAE values are given in e-2 order, and MSE values are given in e-3 order. 'sota' refers to the original state-of-the-art methods without modifications, while 'ad.' refers to our adapted versions of these methods modified to handle semi-supervised scenarios.

	BraTS 2020	PSNR↑			SSIM↑			MAE↓			MSE↓		
	T2	P100%	P80%	P50%	P100%	P80%	P50%	P100%	P80%	P50%	P100%	P80%	P50%
sota	MSDM†	24.68	21.48	15.84	8.24	7.75	0.90	2.33	3.49	11.92	3.40	7.10	26.03
sota	UMM-CSGM	24.71	24.24	23.98	8.13	8.74	8.05	2.36	2.28	2.59	3.38	3.77	4.00
ad.	MSDM†[N]	25.25	20.89	12.32	**8.91**	7.01	0.29	**2.11**	3.82	16.26	2.99	8.14	58.60
ad.	UMM[N]	24.73	24.84	24.04	8.82	8.87	8.61	2.24	2.23	2.46	3.37	3.28	3.95
ours	MDD[RAND]	24.86	24.54	24.29	8.64	8.46	8.61	2.20	2.34	2.35	3.26	3.52	3.73
ours	MDD[NOISY]	24.01	24.12	23.59	8.76	8.70	8.42	2.34	2.34	2.59	3.97	3.87	4.38
ours	MDD	**25.38**	**25.72**	**24.79**	8.75	**8.94**	**8.77**	2.12	**1.98**	**2.23**	**2.90**	**2.68**	**3.32**

The translation results for sketch and mask generation are consistent with those presented in the main paper, and on the BraTS 2020 dataset, MDD models perform strongly. For the semantic segmentation task, MSDM†[N] performs better than on the BraTS 2020 dataset while still achieving the lowest Jaccard. This can be explained by the fact that a correct "mean" prediction is easier for the CelebAMask-HQ dataset, since the segmentations for different images are similar (the faces are centered, often have the same angles *etc.*).

Table 13: Evaluation metrics for Flair modality completion on the BraTS 2020 dataset. To save place, SSIM values are given in e-1 order, MAE values are given in e-2 order, and MSE values are given in e-3 order. 'sota' refers to the original state-of-the-art methods without modifications, while 'ad.' refers to our adapted versions of these methods modified to handle semi-supervised scenarios.

	BraTS 2020	PSNR↑			SSIM↑			MAE↓			MSE↓		
	Flair	P100%	P80%	P50%	P100%	P80%	P50%	P100%	P80%	P50%	P100%	P80%	P50%
sota	MSDM†	22.80	18.83	17.76	8.72	7.85	2.29	2.85	5.01	7.24	5.25	13.10	16.74
sota	UMM-CSGM	22.81	22.60	22.06	8.71	8.60	8.33	2.85	3.00	3.32	5.24	5.49	6.22
ad.	MSDM†[N]	23.49	21.65	12.37	8.39	7.53	0.42	2.79	3.53	16.28	4.48	6.84	57.99
ad.	UMM[N]	23.11	23.38	22.73	8.45	8.40	8.27	2.89	2.85	3.06	4.89	4.59	5.34
ours	MDD[RAND]	**24.38**	23.91	23.09	8.43	8.44	8.38	2.48	2.60	2.87	**3.65**	4.06	4.91
ours	MDD[NOISY]	22.83	22.86	22.16	8.66	8.66	8.56	2.90	2.90	3.16	5.21	5.18	6.07
ours	MDD	24.17	**24.10**	**23.66**	**8.76**	**8.79**	**8.68**	**2.45**	**2.45**	**2.61**	3.83	**3.89**	**4.30**

Table 14: Evaluation metrics for Mask modality completion on the BraTS 2020 dataset. 'sota' refers to the original state-of-the-art methods without modifications, while 'ad.' refers to our adapted versions of these methods modified to handle semi-supervised scenarios.

	BraTS 2020	Jaccard↑		
	Segmentation	P100%	P80%	P50%
sota	MSDM†	0.056	0.049	0.000
	UMM-CSGM	0.755	0.072	0.002
ad.	MSDM†[N]	0.055	0.066	0.071
	UMM[N]	0.727	0.770	0.713
ours	MDD[RAND]	0.752	0.734	0.695
	MDD[NOISY]	0.061	0.057	0.059
	MDD	**0.788**	**0.788**	**0.763**

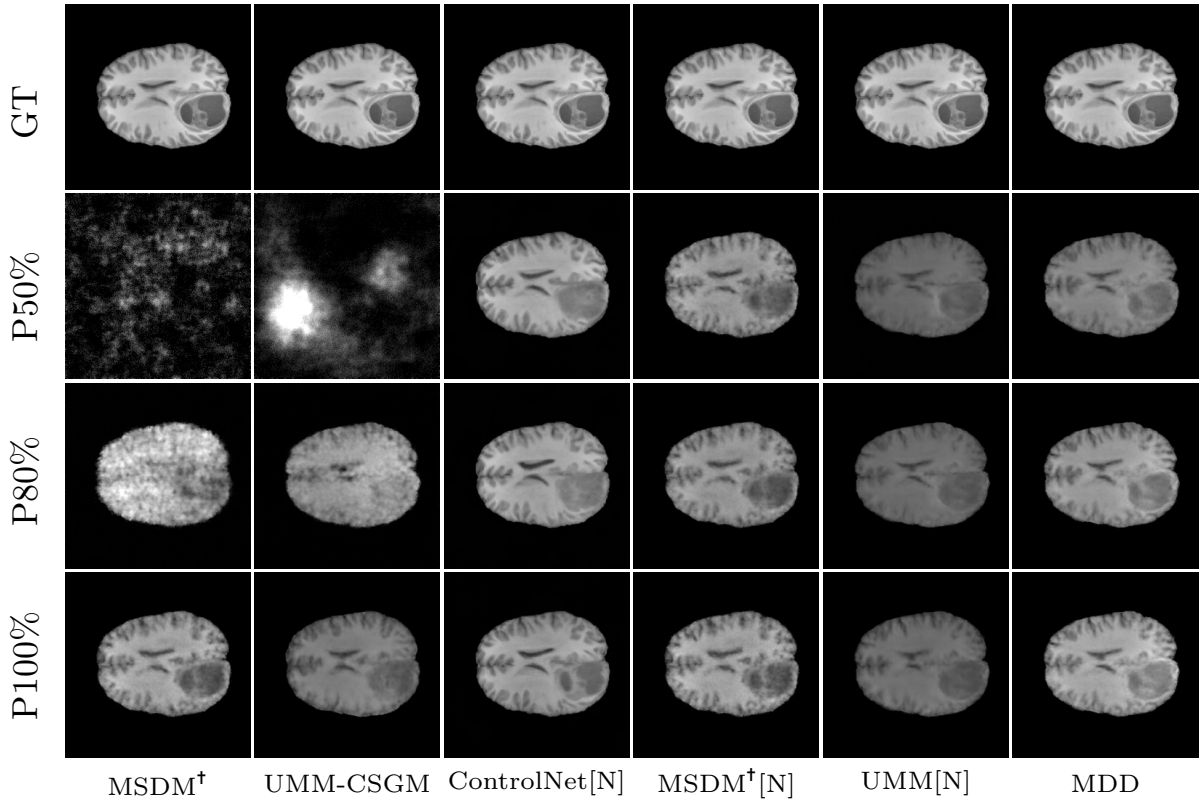

Figure 12: Examples of generated T1 scan given all remaining modalities, and the corresponding GT for different levels of supervision.

We found that the noisy condition model, MSDM†[N], has the best diversity score for the generated faces but the worst generation quality. Using a noisy condition allows the model to avoid using it at the beginning of the generation process and use a noisy condition later in the diffusion process. This allows the generated faces to drift further away from the condition, producing more diverse images. In the case of MSDM†[N], while it has the higher diversity, it also has the worst generation quality according to Tab. 3.

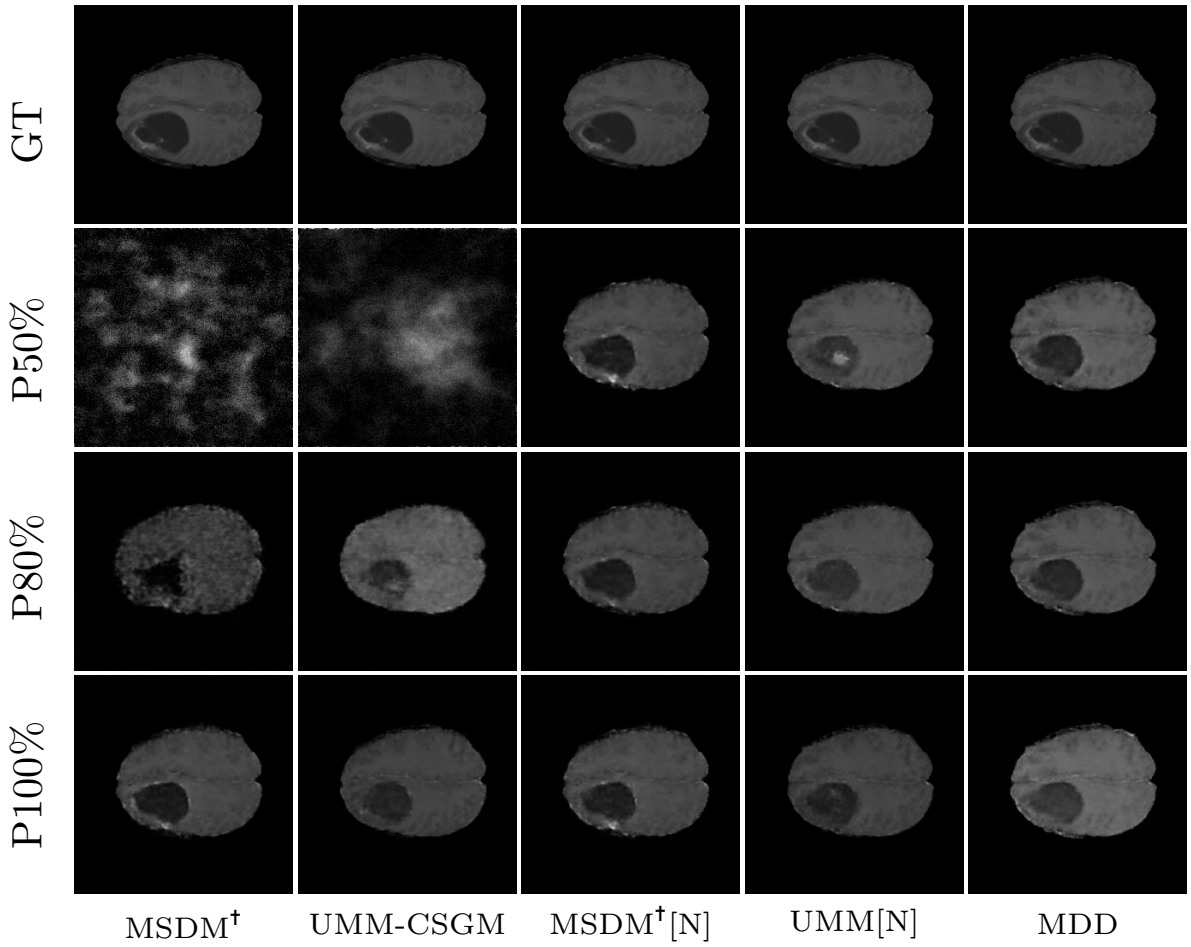

Figure 13: Examples of generated T1ce scan given all remaining modalities, and the corresponding GT for different levels of supervision.

Table 15: Evaluation metrics for (Face, Mask)→Sketch on the CelebAMask-HQ dataset. 'ad.' refers to our adapted versions of state-of-the-art methods modified to handle semi-supervised scenarios.

	CelebAMask-HQ	PSNR↑		SSIM↑	
	Sketch	100%	0%	100%	0%
ad.	MSDM†[N]	17.298	16.652	0.3875	0.3739
ad.	UMM[N]	18.576	16.872	0.4371	0.3897
ours	MDD[RAND]	17.526	17.071	0.3903	0.3715
ours	MDD	**20.402**	**18.259**	**0.5055**	**0.4219**

Table 16: Evaluation metrics for (Face, Sketch)→Mask on the CelebAMask-HQ dataset. 'ad.' refers to our adapted versions of state-of-the-art methods modified to handle semi-supervised scenarios.

	CelebAMask-HQ	Jaccard↑	
	Mask	100%	0%
ad.	MSDM†[N]	0.4476	0.4731
ad.	UMM[N]	0.7378	0.7131
ours	MDD[RAND]	0.6978	0.6704
ours	MDD	**0.7536**	**0.7133**

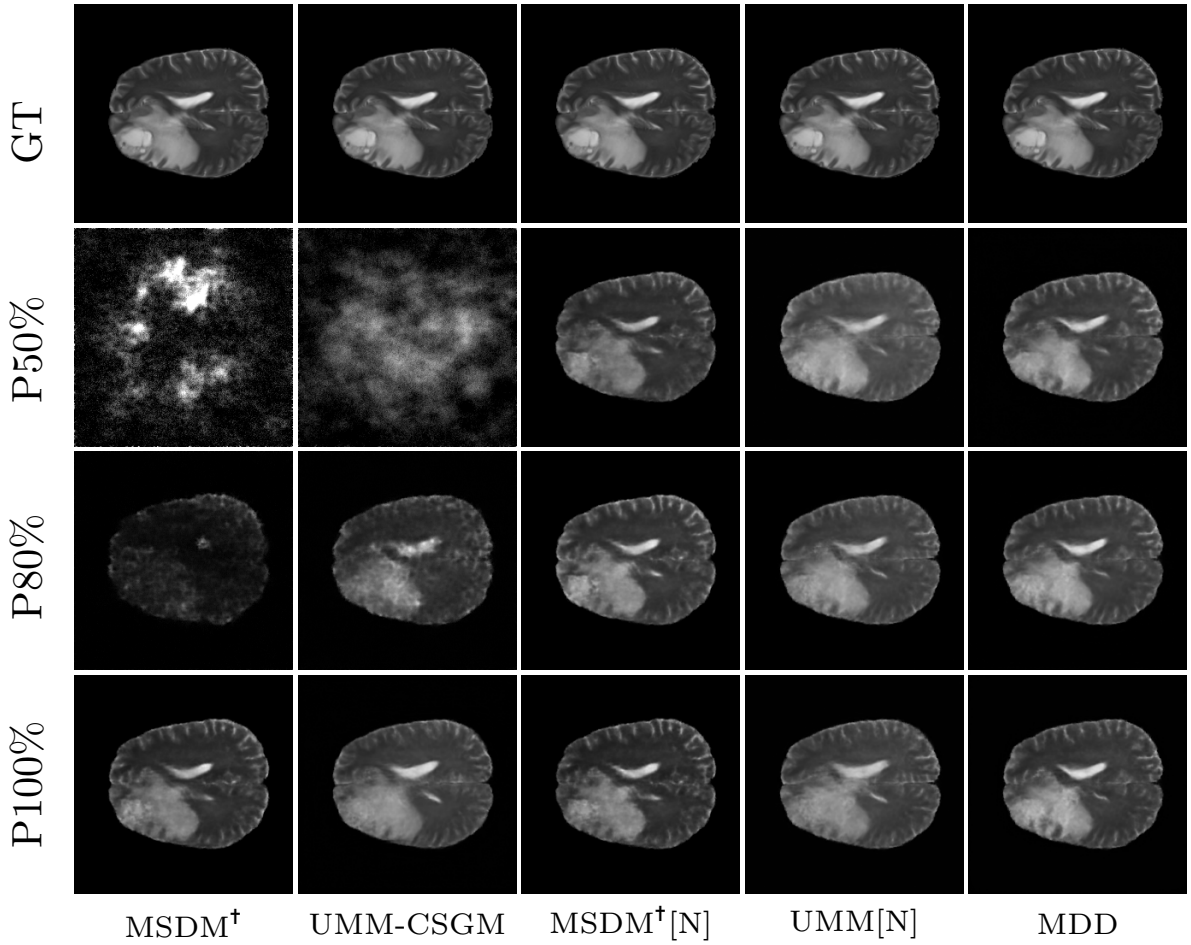

Figure 14: Examples of generated T2 scan given all remaining modalities, and the corresponding GT for different levels of supervision.

Table 17: Diversity of Face generation metrics for (Sketch, Mask)→Face generation and Mask→(Face, Sketch) on the CelebAMask-HQ dataset. 'ad.' refers to our adapted versions of state-of-the-art methods modified to handle semi-supervised scenarios.

	CelebAMask-HQ	(S,M)→(F) DS↑		(M)→(S,F) DS↑	
	Face Diversity	100%	0%	100%	0%
ad.	MSDM†[N]	19.883	18.625	19.896	18.726
ad.	UMM[N]	19.668	18.213	20.305	18.564
ours	MDD[RAND]	16.518	16.028	17.502	16.614
ours	MDD	19.524	15.842	19.177	15.786

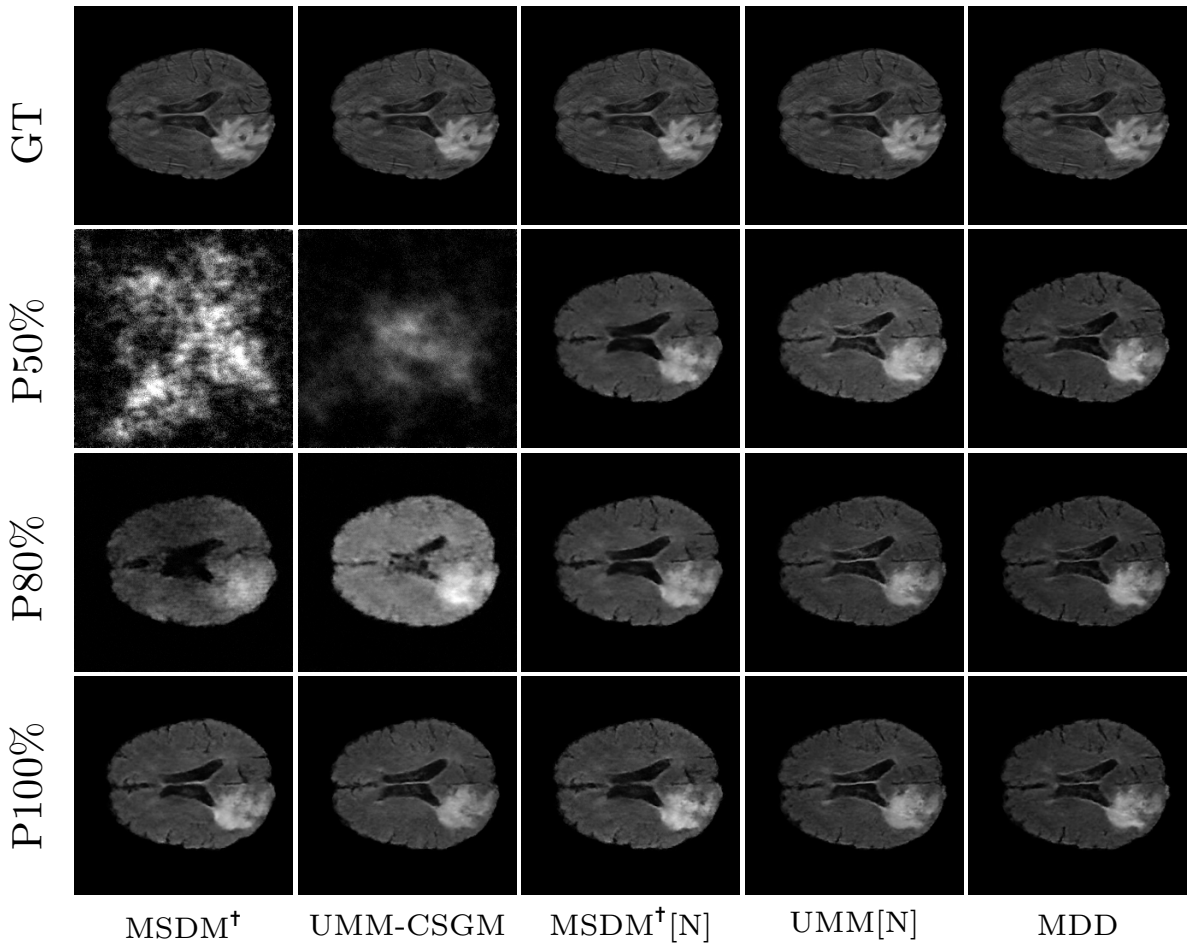

Figure 15: Examples of generated Flair scan given all remaining modalities, and the corresponding GT for different levels of supervision.

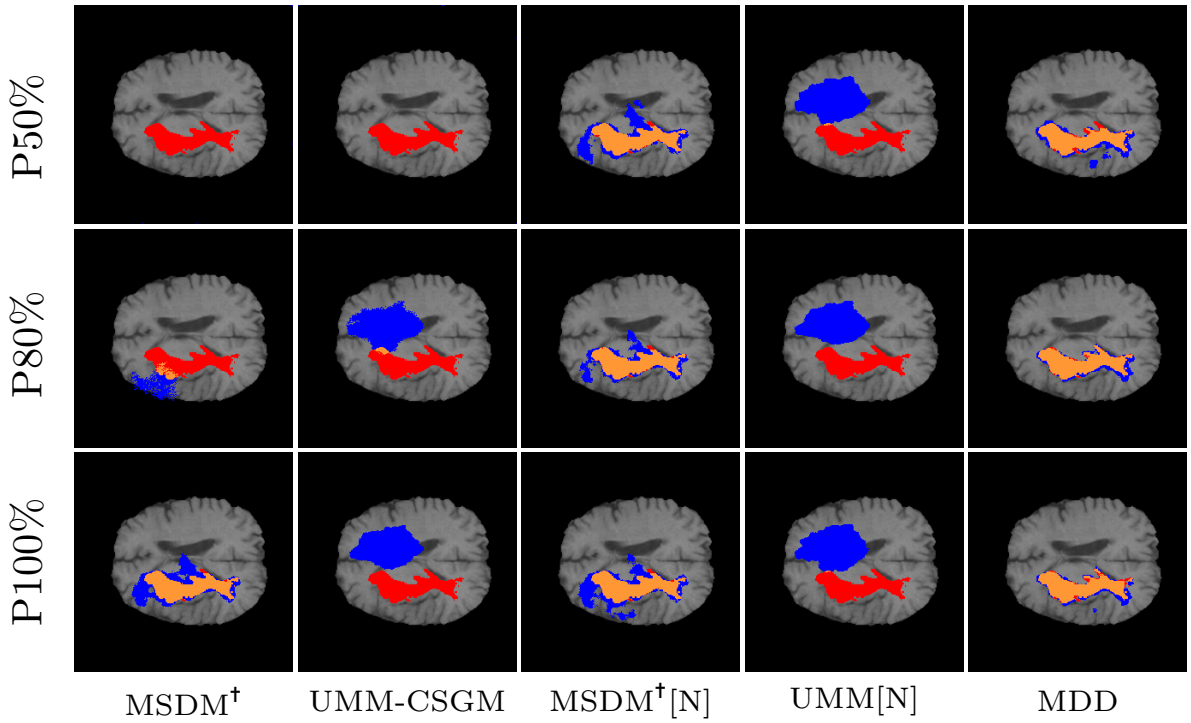

Figure 16: Generated segmentation given all remaining modalities. Orange represents true positives, red false negatives, and blue false positives.

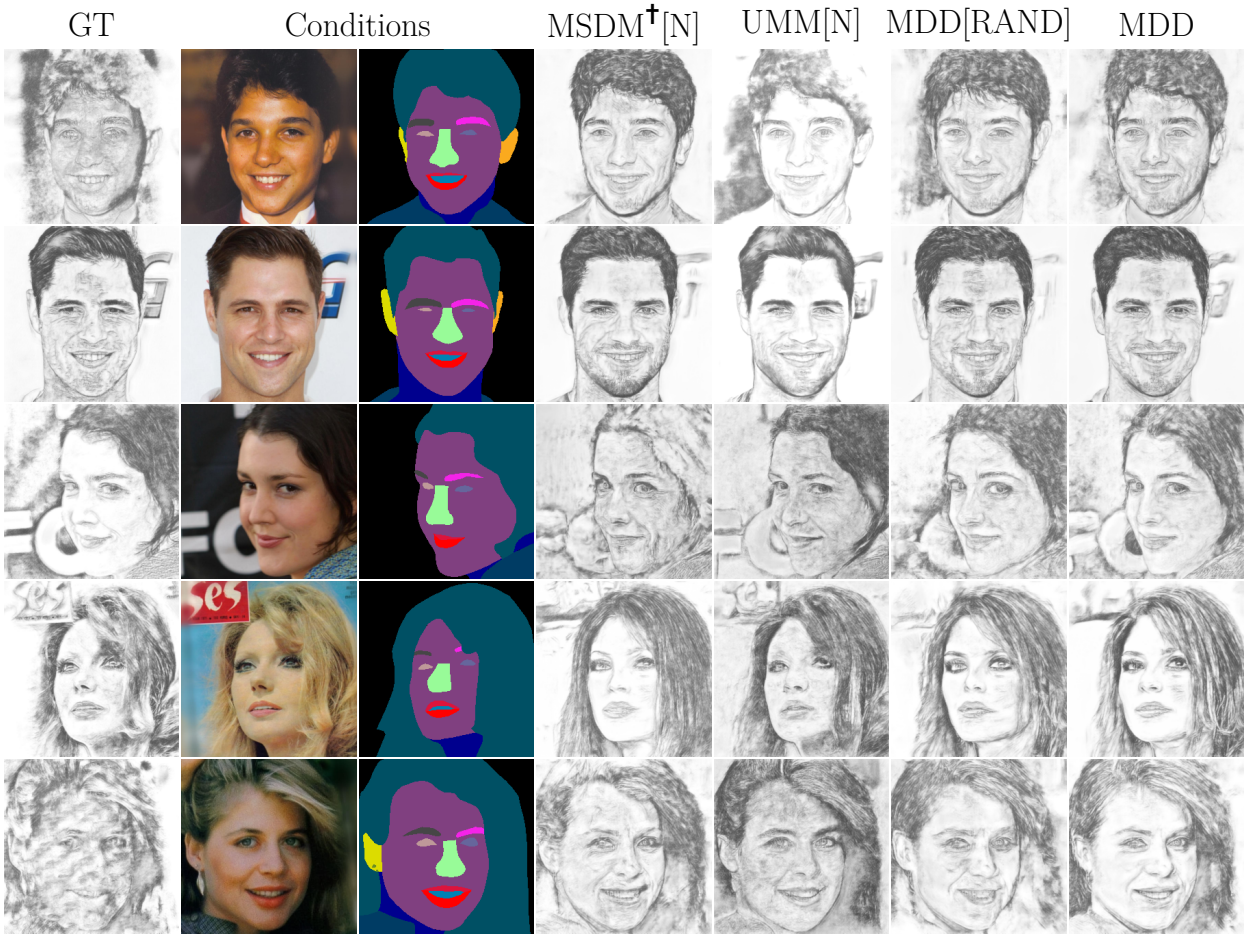

Figure 17: Examples of generated sketches given a face and a mask, and the corresponding GT for N=0%.

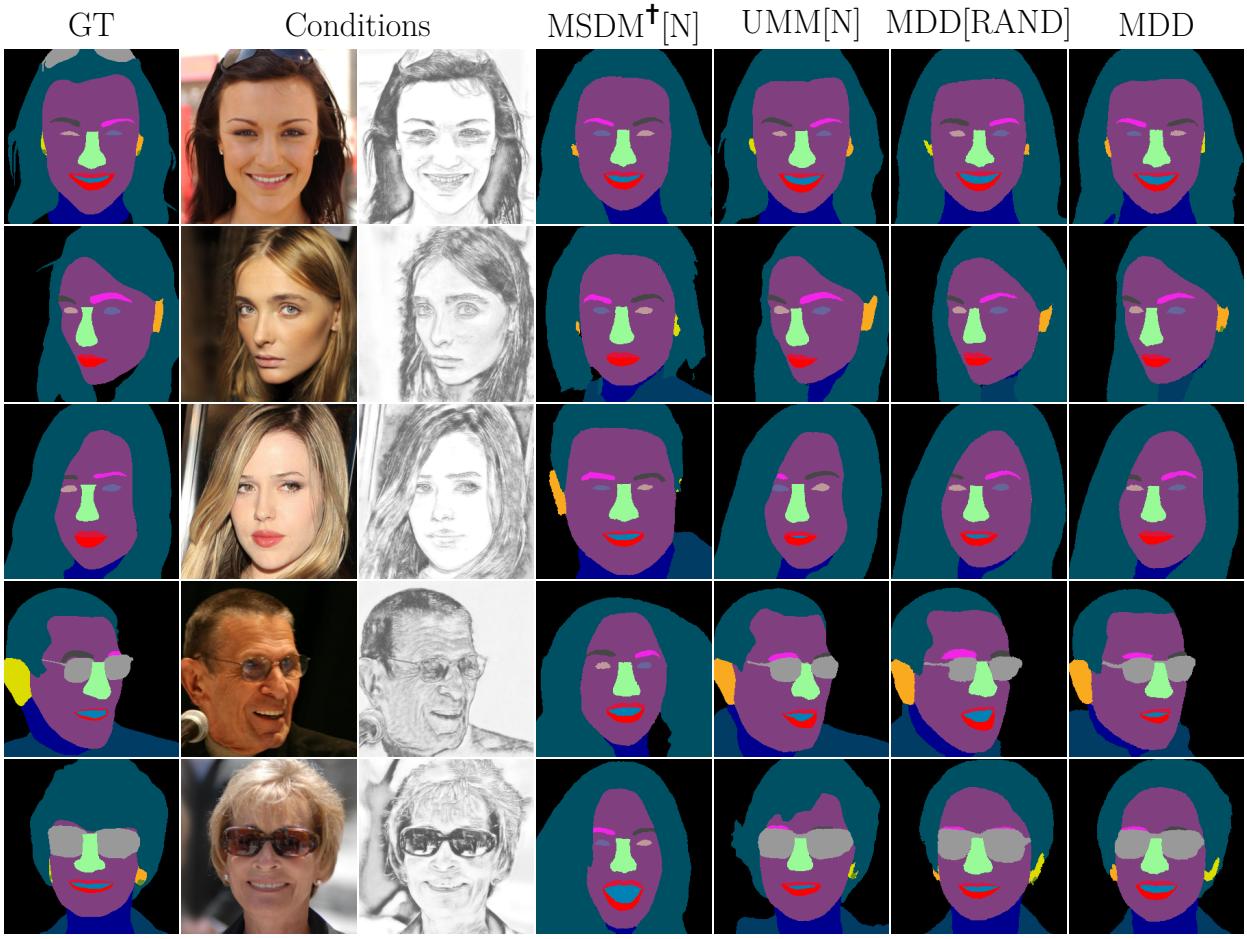

Figure 18: Examples of generated masks given a face and a sketch, and the corresponding GT for N=0%.

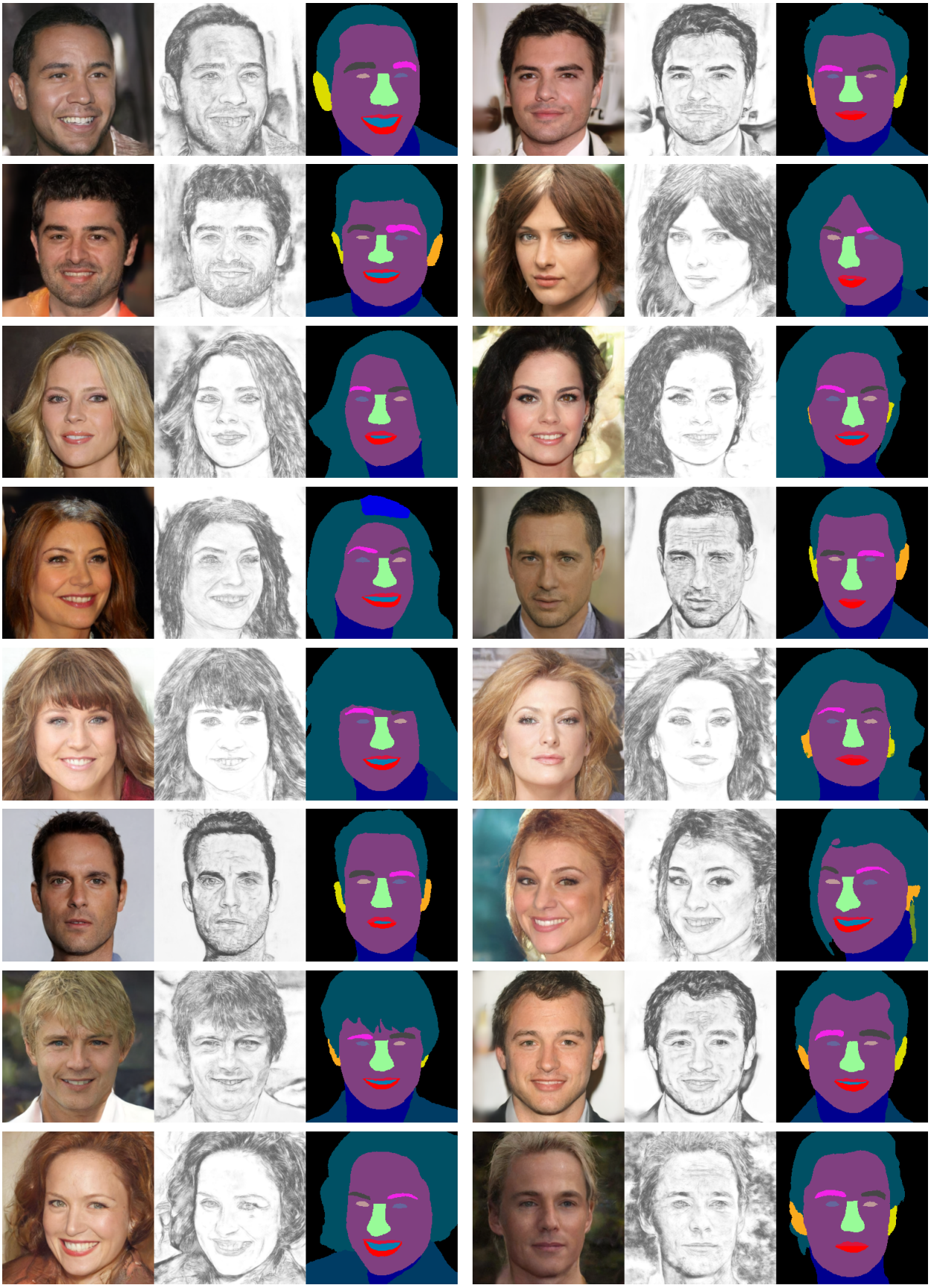

Figure 19: Examples of unconditional generation ()→(Face,Sketch,Mask) for MDD N=100%.

Figure 20: Examples of diversity face generation (sketch,mask)→face for MDD N=100%.

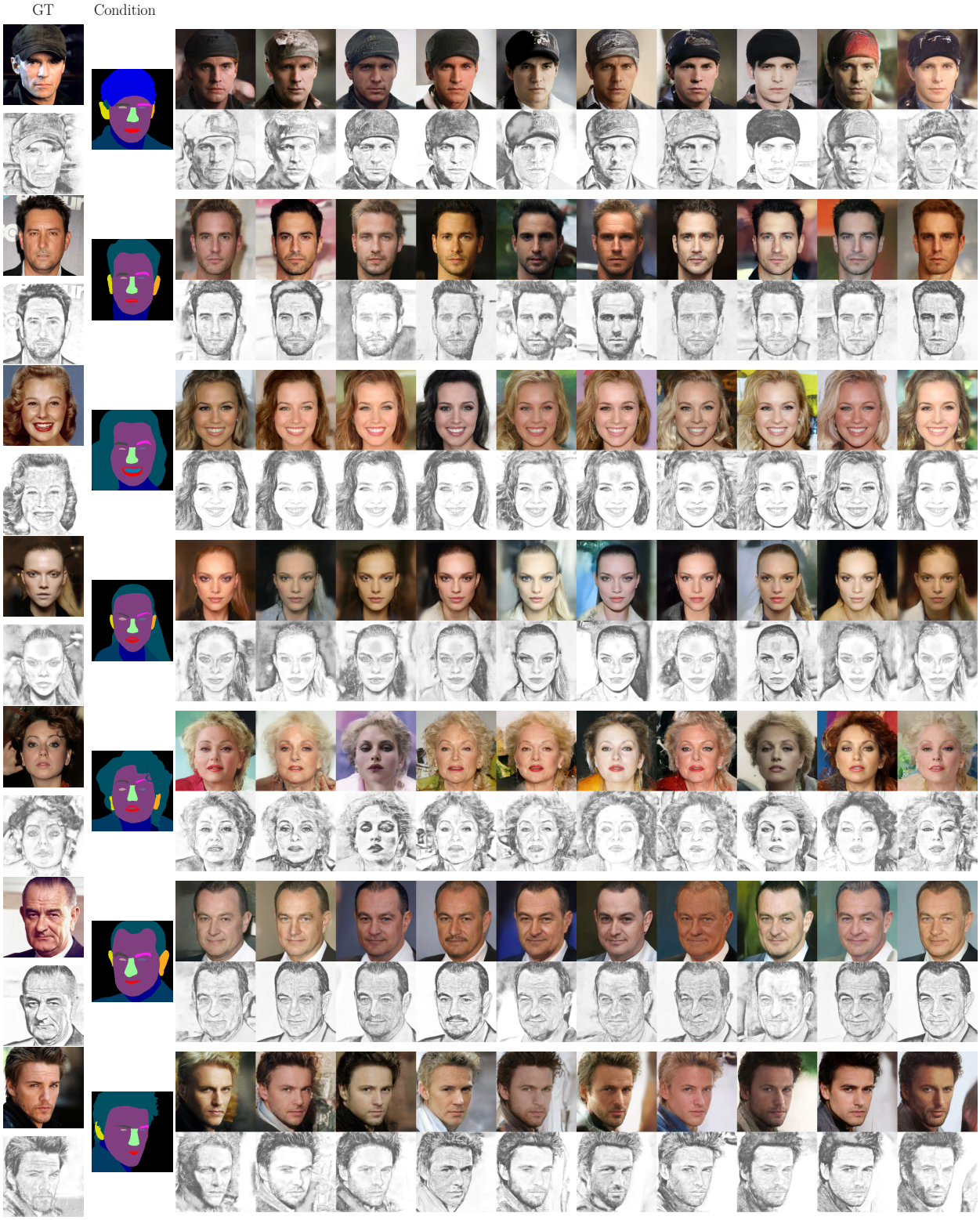

Figure 21: Examples of diversity face and sketch generation Mask→(Face, Sketch) for MDD N=100%.