

FUSE: A Flow-based Mapping Between Shapes

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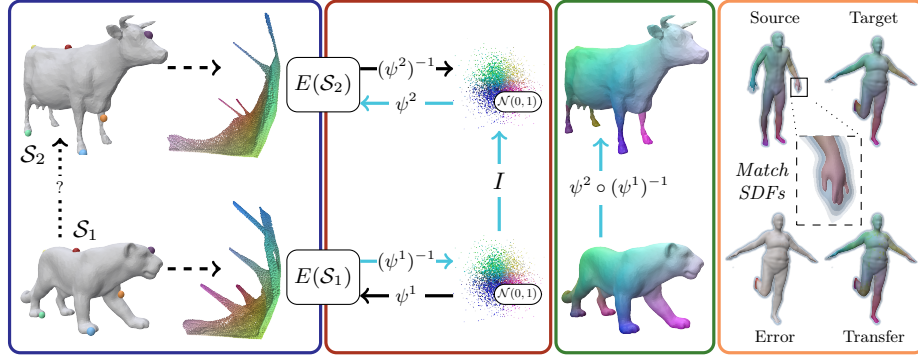


Fig. 1: Our representation establishes a map between shapes S_1, S_2 by optimizing invertible flows (red box) between embedding distributions (blue box) and the unit Gaussian $\mathcal{N}(0, 1)$. The composition of said flows (green box) is a pointwise map between the surfaces, enabling shape matching and supporting various 3D representations, including neural signed distance fields (orange box).

Abstract. We introduce a novel neural representation for maps between 3D shapes based on flow-matching models, which is computationally efficient and supports cross-representation shape matching without large-scale training or data-driven procedures. 3D shapes are represented as the probability distribution induced by a continuous and invertible flow mapping from a fixed anchor distribution. Given a source and a target shape, the composition of the inverse flow (source to anchor) with the forward flow (anchor to target), we map points between the two surfaces. By encoding the shapes with a pointwise task-tailored embedding, this construction provides an invertible and modality-agnostic representation of maps between shapes across point clouds, meshes, signed distance fields (SDFs), and volumetric data. The resulting representation consistently achieves high coverage and accuracy across diverse benchmarks and challenging settings in shape matching. Beyond shape matching, our

framework shows promising results in other tasks, including UV mapping and registration of raw point cloud scans of human bodies.

Keywords: Shape Matching · Flow Matching · Neural Representations

1 Introduction

Shape matching has long been recognized as a “key problem” in geometry processing: indeed, accurate correspondences between two shapes enable simple solutions for several downstream tasks (*e.g.*, pose transfer [52] or interpolation [16]). Most of the research in this field, following the common practices from 3D graphics industry, was built on the triangle mesh representation, which approximates a continuous 2-dimensional manifold embedded in $\mathbb{R}^3$ piecewise linearly with a collection of triangles connected by their common edges and vertices. However, recent progress in the fields of computer vision and deep learning has popularized novel ways of encoding 3D geometry, such as neural representations [41, 47]. These solutions offer several advantages compared to triangle meshes, but lack their large suite of tools and algorithms for analysis and manipulation [64].

In this work, we address this challenge by introducing a novel representation for maps between a source and a target shape that can be applied over various geometric encodings. We namely refer to this representation as FUSE. Constructing a map with this representation requires only two components: i) the ability to sample points from the involved surfaces, and ii) a pointwise feature embedding designed for the target task. Once feature embeddings are computed for the sampled points on both source and target shapes, FUSE estimates an invertible flow from each embedding distribution to a shared anchor distribution, following Flow Matching framework [25]. FUSE then expresses the map between the two shapes as the composition of the inverse flow of the source (source $\rightarrow$ anchor) and the forward flow of the target (anchor $\rightarrow$ target). We note that, given the flows of any two shapes, the map is obtained with no additional optimization, with only landmarks as information shared by the two shapes.

In the context of shape matching, our representation introduces a probabilistic perspective on embedding alignment, where semantically similar features are encouraged to align through a shared probability distribution. Combined with the guarantee of mapping points directly into the target embedding space, our framework produces high-coverage and accurate correspondences that are relevant for different applications. We evaluate the proposed approach through a comprehensive experimental study, comparing it against several shape matching baselines, ranging from well-established axiomatic methods to recent data-driven approaches; FUSE shows high, if not the highest, accuracy on various benchmarks. Our contributions can be summarized as follows:

- We introduce FUSE, the first flow-matching based representation for 3D shape maps that naturally enables correspondence between shapes expressed in different modalities (*e.g.*, meshes, point clouds, and SDFs);

- We quantitatively show that FUSE achieves competitive or superior matching accuracy over state-of-the-art methods, particularly in the context of landmark-based shape matching;
- We showcase the versatility of FUSE, employing it as a backbone for other downstream applications, ranging from shape parametrization to point cloud deformation.

2 Related Work

2.1 Neural Shape Representations

Recent research in geometric deep learning and geometry processing popularized the practice of encoding 3D shapes in the weights of neural networks, which is referred to as neural shape representation. The early contributions in this field are due to [40] and [47], followed by the introduction of NeRF [41], which led to a vast effort to adapt neural shape representations to other tasks besides reconstruction. Examples of these adaptations are to shape deformation [1, 3, 43, 64], text-guided shape editing [28, 61] and generation [27, 49]. Recent contributions also introduced neural representations for 3D simulations [46] and computation of geometric operators over spherical neural surfaces [62].

The work of [21] is closely related to ours, as they propose a method to represent functions continuously over surfaces in intrinsic space. Lastly, FUSE’s architecture is inspired by Geometry Distributions [65], which proposes to represent geometry as a continuous map from a 3D Gaussian distribution to the surface with a denoising diffusion model [53]. However, by targeting the specific goal of representing maps between shapes, we build upon flow matching [25], and model flows directly over an intrinsic feature space, rather than standard Euclidean or extrinsic coordinates. These two choices together enable FUSE to represent mappings, as we prove by targeting the shape correspondence task.

2.2 Shape Matching

Shape correspondence is a fundamental task in geometry processing, with a wide range of approaches proposed over the years, which can largely be distinguished by how they represent the map between shapes and features [2, 7, 38, 54, 56]. Among these, the functional map framework [44] and its follow-up works [10, 13, 30, 37, 39] have emerged as a dominant paradigm, where correspondences are represented as linear operators between functional spaces. These methods offer attractive properties such as smoothness and invariance to deformations, but the reliance on spectral bases limits their generalization to non-mesh representations [37] and in obtaining bijective maps [4, 36, 60].

Another class of approaches leverages optimal transport (OT) [12, 29, 51], in which correspondences are represented by transport plans that minimize the cost of transporting a distribution of features from one shape to another. In the presence of sampling imbalances or ambiguous features, OT plans often exhibit mass-splitting behavior, where individual points distribute probability mass

across multiple targets. This diffusion can degrade correspondence sharpness and stability when recovering discrete maps. Alternatively, registration-based approaches directly optimize non-linear deformation fields in 3D [16, 24, 50, 57]. The fields are often parameterized via deformation networks or complex architectures, achieving accurate alignments at the cost of solving computationally heavy optimization problems and depending on rigid initialization or learned priors.

Hybrid approaches combine the strengths of the above formulations [9, 10, 18, 19, 22, 45, 59], gaining in efficiency and robustness, but still relying on learned priors and struggling to generalize to other representations. Another common approach is template-based matching, representing correspondences as a composition of maps with respect to a common template, selected a priori [17, 34, 35] or directly at test time [32]. On a different perspective, FUSE offers a novel representation for maps. Based on flow matching [25], our method models a correspondence as a composition of continuous invertible flows between intrinsic feature spaces and a shared anchor distribution, inherently enforcing bijectivity and high-coverage in obtained maps, without learned priors or per-pair optimization in a pipeline naturally agnostic of the geometric representation.

3 Background

Shapes and Matching. A 3D shape $\mathcal{S}$ is modeled as a compact two-dimensional manifold embedded in $\mathbb{R}^3$. From a computational standpoint, single shapes may be represented in several ways: polygonal meshes, point clouds, signed distance functions and volumetric meshes are notable examples. In this work, we identify a shape $\mathcal{S}$ as a continuous manifold from which we can sample unordered sets of points $\{x_i\}_{i=0}^n$, encoded by their 3D coordinates (i.e. $x_i \in \mathbb{R}^3$) independently from the adopted representations.

Given 3D shapes $\mathcal{S}_1 = \{x_i\}_{i=1}^{n_1}$ and $\mathcal{S}_2 = \{y_j\}_{j=1}^{n_2}$ with a common semantic, a point-to-point correspondence T_{12} maps each point x_i to its corresponding point y_j . Shape matching is the task of estimating such correspondence. In the non-rigid scenario, estimating correspondences directly from 3D coordinates is challenging; thus, most methods describe the shapes via pointwise *features*, characterizing their semantics and geometry [14, 54, 56]. For each point $x_i \in \mathcal{S}_1$, we compute a vector of features $f_i \in \mathbb{R}^d$ that we can then store as a row in the *embedding matrix* $E_1 \in \mathbb{R}^{n_1 \times d}$ (same goes for $\mathcal{S}_2$). Ideally, one can solve for the correspondence directly by leveraging the similarity between these encodings [2]. In practice, more complex pipelines are required to align the features and retrieve the correspondence from their relations [44].

Flow Matching. Flow Matching (FM) [25, 26] is a framework for learning continuous in time probability paths $(p_t)_{t \in [0,1]}$ that transport a known source distribution p_0 (e.g., a Gaussian) to an unknown target p_1 (e.g., data samples). This is achieved by learning a *velocity field* $u_t^\theta(x)$ describing the instantaneous dynamics of the path, parameterized by a neural network θ . For each $x \in \mathbb{R}^d$, the velocity

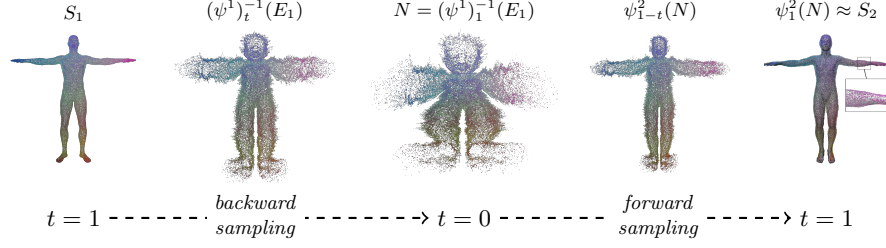


Fig. 2: Visual example of the proposed pipeline. For visualization purpose, we select a pair for which we can solve for the correspondence using the 3D coordinates as features embedding. Estimated correspondence is encoded by the color (matched points have the same color).

field induces a flow $\psi_t(x)$ as the solution of the ODE $\frac{d}{dt}\psi_t(x) = u_t(\psi_t(x))$ with initial condition $\psi_0(x) = x$. Crucially, the flow ψ_t is invertible and diffeomorphic: starting from any point sampled from p_1 , i.e., $x \sim p_1$, integrating the ODE backward yields a point $\psi_0^{-1}(x) \sim p_0$. The bidirectionality enables transport between distributions in both directions. Since u_t is generally intractable, [25, 26] proposed Conditional Flow Matching (CFM), replacing u_t with a tractable conditional velocity field $u_t(x_t | x_1)$, while preserving the same gradients:

$$\mathcal{L}_{\text{CFM}}(\theta) = \mathbb{E}_{t, x_1, x_t \sim p_t(\cdot | x_1)} [\|v_t^\theta(x_t) - u_t(x_t | x_1)\|^2]. \quad (1)$$

where $\mathbb{E}_{t, x_1, x_0}$ represents the average over randomly sampled timesteps in $[0, 1]$ and over source and target samples $x_0 \sim p_0, x_1 \sim p_1$. A simple choice for the field is linear interpolation, $x_t = (1-t)x_0 + tx_1$ with $u_t = x_1 - x_0$. CFM training is thus simulation-free, although generating samples still requires integrating the learned ODE. In the remainder of the paper, we will refer to CFM simply as Flow Matching (FM).

4 FUSE

Given the overview presented in the previous section, we can now provide all the details of our novel representation FUSE which we outlined in Fig. 1. The complete source code is available at <https://github.com/Lorenzo01earo/FUSE-Flow-based-Mapping-Between-Shapes>.

4.1 Flow Optimization

Given a pair of shapes $\mathcal{S}_1 = \{x_i\}_{i=1}^{n_1}$, $\mathcal{S}_2 = \{y_j\}_{j=1}^{n_2}$ and an embedding matrix $E_\ell \in \mathbb{R}^{n_\ell \times d}$ (with $\ell = 1$ or 2), we denote the resulting embedding distributions as $p^\ell = E_\ell$ (see blue box of Fig. 1). For each shape, we train an independent flow model that learns a continuous, invertible mapping $\psi^\ell: [0, 1] \times \mathbb{R}^d \rightarrow \mathbb{R}^d$. This flow transports samples from a fixed, shared Gaussian $p_0 = \mathcal{N}(0, 1)^d$ (the

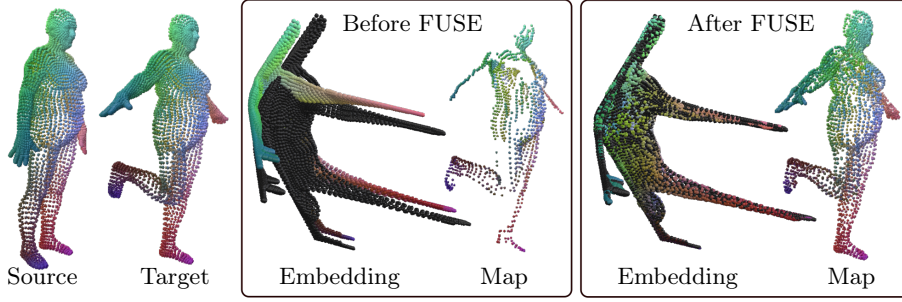


Fig. 3: Effect of FUSE visualized on the first three coordinates of embedding and on the relative obtained map.

anchor distribution) to the shape’s embedding distribution p^ℓ , i.e. $\psi_1^\ell(x) \sim p^\ell$ given $x \sim p_0$. Each flow is parametrized by a neural network and trained via Conditional Flow Matching [25,26] as we described earlier (see red box of Fig. 1). Each flow is trained independently on its shape, requiring only the ability to sample embeddings from the surface.

4.2 Fusing Representations

FUSE determines maps between shapes by composing their flows. Given the two trained flows ψ^1 and ψ^2 , we define the map from $\mathcal{S}_1$ to $\mathcal{S}_2$ as:

$$\Phi^{12} = \psi^2 \circ (\psi^1)^{-1} \quad (2)$$

This composition leverages the Gaussian distribution as a common anchor: we transport the embedding points from $\mathcal{S}_1$ back to the Gaussian via $(\psi^1)^{-1}$, then forward to $\mathcal{S}_2$ via ψ^2 as depicted in Fig. 2. This process offers several advantages:

1. Injection of invariance of the adopted embeddings in the output map;
2. For any pair of shapes represented by the respective flows from a common distribution, no extra training is required to obtain a map between them;
3. Representation invariance: creating a bridge with FUSE only requires sampling from the surface, which is straightforward on most 3D representations.

We can leverage this representation of maps between shapes to perform various tasks on the discrete geometry. For instance, to retrieve the correspondence between points of two discretized shapes, we can perform a nearest neighbor search in the embedding space.

$$T_{12} = \text{NearestSearch}(\Phi^{12}(E(\mathcal{S}_1)), E(\mathcal{S}_2)) \quad (3)$$

The validity of this construction rests on the nature of the FM solutions and the shared anchor distribution. While FM training relies on independent random couplings between Gaussian and data samples, this randomness affects

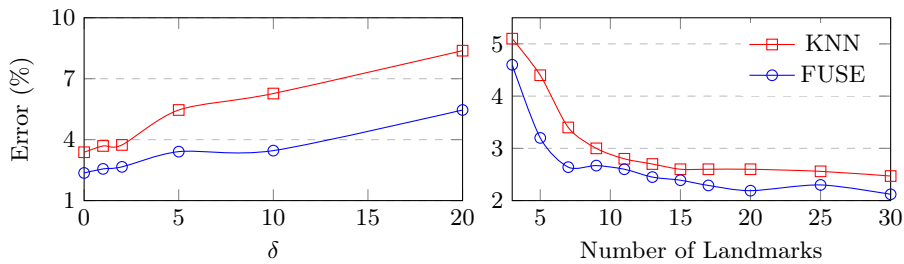


Fig. 4: Stability analysis of FUSE. On the left: robustness under landmark perturbation (δ). On the right: performances varying the number of landmarks.

only the conditional velocity fields, not the learned flow. Theorem 2 in [25] shows that marginalizing the conditional fields $u_t(x | x_1)$ over $x_1 \sim p_1$ recovers the *unique* marginal field u_t generating the probability path between p_1 and p_0 ; since this field is determined by (p_1, p_0) alone, so is the induced flow ψ_t . Consequently, if $E(S_1) = E(S_2) = p_1$, the flows ψ^1 and ψ^2 coincide regardless of the couplings used during training, and when $E(S_1)$ and $E(S_2)$ are similar, their composition $\psi^2 \circ (\psi^1)^{-1}$ aligns $E(S_1)$ to $E(S_2)$ and produces accurate correspondences (Fig. 3). For this reason, points with similar embeddings from different shapes are mapped to nearby regions within the anchor (green box in Fig. 1), provided that both shapes share the same semantic structure.

The same reasoning also highlights when FUSE can be effective. When S_1 and S_2 differ by a transformation to which E is not invariant, the distributions $E(S_1)$ and $E(S_2)$ become dissimilar and not alignable by the flow composition. Instead, when the two embedding distributions share the same semantic structure, by forcing the image of $E(S_1)$ to align with $E(S_2)$ before applying KNN (Fig. 3), FUSE reduces the sensitivity to embedding variations. This is why, as the isometry decreases (Tab. 4) or the landmark placement becomes noisy (Fig. 4), the advantage of FUSE over other methods tends to increase.

4.3 Embedding Selection

The choice of embedding E is critical. First, the generalization of FUSE to any 3D representation depends on E being computable and invariant over 3D representations. Secondly, the embedding determines the properties of the FUSE map (*e.g.*, shape matching needs some E that captures metric and semantic information about the shapes). Every shape matching pipeline relies on assumptions that inject prior knowledge into the process. These assumptions are necessary to resolve fundamental ambiguities, most notably

Table 1: Correspondence error under different prior assumptions. The results are obtained without any test-time refinement. *ULRSSM results are obtained using public checkpoints. Details on metric and datasets in 5.

Method	Prior	Error	
		FAUST	SMAL
Diff3	Vision model	0.089	0.189
ULRSSM*	Training-data	0.043	0.063
FUSE	Landmarks	0.028	0.059

intrinsic symmetries, which cannot be disambiguated from purely geometric information alone. Past methods encode this prior in different ways: [10] learns a feature extractor in an unsupervised manner, where the (data) prior is induced by training over a collection of shapes; [14] leverages a pretrained large-scale vision model to extract semantic information from rendered views of meshes; [2] relies on informative spectral signatures. Each of these strategies introduces representation-specific dependencies that limit their applicability: spectral bases, rendering pipelines, or available training data.

In contrast, 3D coordinates (*i.e.*, “identity” embeddings) are universally available but lack intrinsic geometric or semantic meaning, making them unsuitable for shape correspondence. One effective alternative is the Geodesic Feature Embedding (**GFE**), which represents surface points as vectors of geodesic distances to a small set of landmarks L , yielding a compact embedding in $\mathbb{R}_+^{|L|}$ that encodes the intrinsic geometry. Landmarks provide a minimal yet powerful form of prior: they provably resolve intrinsic symmetries by anchoring the semantic orientation of the shape, and are consistently employed in axiomatic shape matching methods derived from the Functional Maps [44] framework. In our case, landmarks are manually selected on one shape (5 or 6 depending on the semantics of the dataset) and transferred to the rest of the dataset via ground truth correspondences; ?? in the supplementary material shows the selected landmarks for each dataset. As shown in Tab. 1, despite this simple prior, FUSE with landmark-based GFE achieves the lowest correspondence error on both FAUST and SMAL against state-of-the-art prior-based methods [10, 14].

Importantly, different algorithms have been developed to compute or efficiently approximate geodesic distances on triangle meshes, signed distance fields, and point clouds, such as Dijkstra’s shortest path algorithm, the heat method [11], and fast marching [42]. While computing geodesic distances generally involves estimating the underlying surface, established methods exist (e.g. [11]) that do so implicitly with stable results. As a consequence, FUSE does not require explicit surface estimation over point clouds and can employ them directly as an input representation.

However, geodesic embeddings are not naturally aligned across shapes from a distributional perspective as a non-rigid deformation can significantly alter the geodesic distances between points. With FUSE, the flow composition acts as a probabilistic alignment mechanism: by mapping geodesic features through the Gaussian prior, we obtain distributional alignment across shapes, as shown in Fig. 3 Fig. 3.

Generality and robustness. While GFE is our primary choice, FUSE can be applied to any pointwise embedding. To understand when it is effective, we vary both the embedding type (Tab. 2) and the landmark configuration (Fig. 4). In our experiments, FUSE does not appear to suffer from the increasing dimensionality: adding landmarks from 3 to 30 yields progressively better results that consistently outperform KNN (Fig. 4, right); we observe the same behaviour when perturbing landmark positions by a random fraction of the shape diameter (Fig. 4, left). Instead, Tab. 2 reveals that a critical factor is *smoothness*: GFE

Table 2: Euclidean error on FAUST and SMAL datasets with different embeddings. WKS* and WKS-L* are smoothed versions, to show the improvement of FUSE over KNN in the presence of low-energy embeddings.

Method	FAUST							SMAL				
	x, y, z	GFE	WKS	WKS*	WKS-L	WKS-L*	ULRSSM	x, y, z	GFE	WKS	WKS-L	ULRSSM
Dim	3	5	20	20	20	20	256	3	5	20	20	256
KNN	0.1572	0.0454	0.1007	0.1125	0.0428	0.0522	0.0723	0.2903	0.0879	0.2736	0.0697	0.1061
FUSE	0.1488	0.0289	0.1015	0.0901	0.0556	0.0416	0.0829	0.3226	0.0595	0.3039	0.0668	0.1117
Dirichlet	0.0002	0.0001	0.0056	0.0008	0.0022	0.0004	0.1847	0.0001	0.0001	0.0257	0.0131	0.637

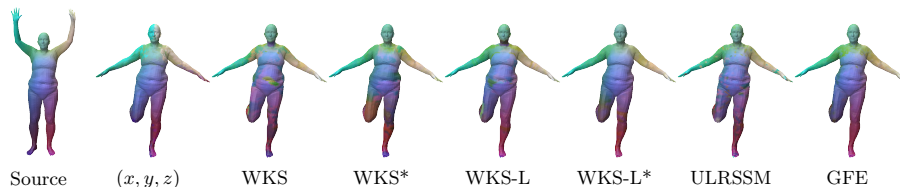


Fig. 5: Correspondences obtained by FUSE with different embeddings. We note that (x, y, z) does not encode the semantic correspondence and cannot capture the non-rigid deformation. WKS does not solve the intrinsic symmetries of the shape. With learned embeddings (ULRSSM), our methods introduce high-frequency artifacts.

has very low Dirichlet energy and benefit greatly from the flow mapping, while WKS [2] and learned embeddings [10] have substantially higher Dirichlet energy, resulting in poor performance. We refer to this as *curse of frequency*: high-frequency embeddings induce complex distributions that are harder for the flow to align, a challenge mirroring known difficulties in Functional Maps optimization [39, 44]. GFE exhibits lower spectral complexity, making them particularly well-suited for FUSE. We note that smoothing the embeddings via projection on a small set of Laplace-Beltrami eigenbasis [23, 55, 58], (WKS* and WKS-L* in Tab. 2) consistently improves FUSE’s accuracy over raw features, even in non-landmark-based scenarios. This suggests that integrating smoothly learned features with flow-based models is a viable direction and fosters future work.

We note that the invertibility of the flows does not by itself induce a bijection between the shapes: the final KNN step (Sec. 4.2) assigns each source point its nearest target independently, so the matching is not strictly bijective, as is standard in point-based correspondence. Since both the GFE and the flow are defined continuously over the surface, the construction naturally extends toward a continuous, fully bijective map, which we leave to future work.

4.4 Flow matching over Diffusion

Building on the recent work of [65], which represents 3D shapes as probability distributions generated via a Denoising Diffusion Implicit Model (DDIM) [53], we adopt the same probabilistic representation while constructing maps between

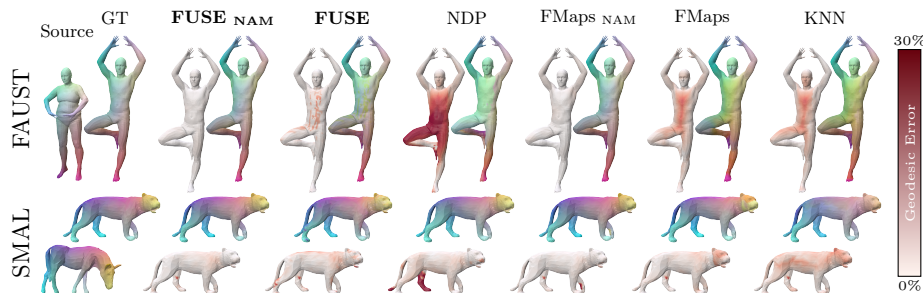


Fig. 6: Qualitative evaluation: We report a pair of shapes with visualization of the p2p as transferred colormap and in terms of the geodesic error visualized via a hot-colormap. We note the lower but less smooth error of Ours compared to FMaps.

shapes using flow matching rather than DDIM. Although FM and DDIM can be similar, the former offers distinct advantages for our purposes. FM establishes an explicit relationship between the Gaussian distribution and the data distribution. This ensures that the inverse flow maps any shape back to the exact Gaussian distribution in a deterministic manner. This property guarantees that all shapes lie in an ideally shared latent space. In contrast, methods such as DDIM only asymptotically approach the Gaussian through large noise schedules, resulting in deviations from the anchor space.

We quantify this effect in Tab. 3, evaluating shape pairs with GFE using two criteria: (1) the accuracy of nearest-neighbor correspondences both in the anchor space and in the embedding space, and (2) the JS and KL divergence between embedding distributions. We compute these metrics before and after inverting the flows using DDIM (FUSE_{DDIM}) and FM (FUSE). The results show that FUSE achieves substantially lower divergence and higher correspondence accuracy, confirming that accurate anchoring to the Gaussian directly correlates with improved matching performance. DDIM’s inversion leads to larger deviations from the anchor and thus inferior map quality. In the supplementary materials, we provide a mathematical derivation of this crucial difference, along with additional examples.

Table 3: FUSE_{DDIM} vs FUSE in terms of shape matching error (first four rows) and probability divergence (last two rows) on the FAUST dataset. Lower is better for all the metrics.

Metric	Raw	FUSE _{DDIM}	FUSE
Euclidean Error (anchor)	0.045	0.099	0.042
Geodesic Error (anchor)	0.043	0.095	0.039
Euclidean Error	-	0.037	0.028
Geodesic Error	-	0.035	0.027
Mean KL Divergence	0.2528	0.3519	0.0375
Mean JS Divergence	0.1928	0.2128	0.0829

5 Results

We evaluate our representation, considering shape matching as the main task, but also presenting possible extensions of FUSE targeting other applications.

5.1 Non-Rigid Shape Matching

We first analyze the performance of FUSE against more standardized benchmarks, considering pairs of meshes and point clouds. We then explore novel and more challenging scenarios by matching SDFs and inter-representation pairs. We restrict our analysis to landmarks-based methods, as discussed in Sec. 4.3.

Baselines. We evaluate FUSE against baselines from different paradigms. Methods using our same geodesic feature encoding include nearest neighbor search in the embedding space (KNN) and in the anchor distribution space (FUSE_{ANCHOR}), OT (Optimal Transport with Sinkhorn relaxation [12]), Functional Maps (FMaps) with geodesic descriptors [44], and refined variants FMaps_{ZO} (ZoomOut [39]) and FMaps_{NAM} (Neural Adjoint Maps [59]). Further, we also consider the original Functional Maps formulation with WKS [2], the neural extrinsic Neural Deformation Pyramid (NDP) approach [24], the vision-foundation Diff3F [14], and the data-driven ULRSSM [10]. Finally, we use FUSE to initialize ZoomOut and NAM (FUSE_{ZO} and FUSE_{NAM}).

Datasets. We evaluate our method on well-established datasets for non-rigid shape matching: **FAUST** [6] (near-isometric human meshes), **SMAL** [10, 66] (non-isometric quadruped meshes), **SHREC20** [15] (strongly non-isometric animal meshes), and **KINECT** [5, 59] (human point clouds). We manually pick 5 landmarks for humans and 6 for animals, ?? in the supplementary shows the selected landmarks for each dataset.

Metrics. We evaluate the quality of correspondence using four metrics: two measures of accuracy, Euclidean (Eucl.) and geodesic (Geod.) distances [20], as well as Dirichlet energy [33] and coverage of the computed maps. Lower values are better for the first three metrics, while a higher value is better for Coverage. Quantitative results are reported in Tab. 4, qualitative in Fig. 6, and plots with the full distribution of the metrics in ?? of the supplementary material.

Mesh correspondences. While FMaps-based methods tend to produce smoother maps with smaller Dirichlet energy, our method standouts in terms of both Euclidean and geodesics accuracy. Due to the nature of the flows, invertible by design, FUSE achieves better coverage of the target surface overall. The introduction of refinement strategies (*i.e.*, ZO and NAM) adds pairwise optimization,

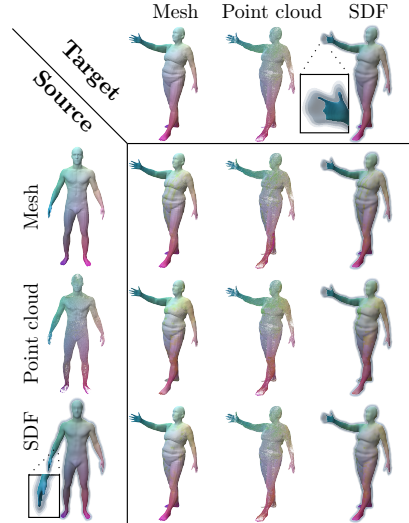


Fig. 7: Coordinate transfer among different 3D representations enabled by FUSE.

Table 4: Averaged results from all the considered datasets for our method and the other baseline solutions. For each column, the best result is highlighted in bold.

Method	FAUST (quasi-iso)				SMAL (non-iso)				SHREC20 (strong non-iso)				Kinect (point cloud)			
	Eucl. ↓	Geod. ↓	Dirich. ↓	Cov. ↑	Eucl. ↓	Geod. ↓	Dirich. ↓	Cov. ↑	Eucl. ↓	Geod. ↓	Dirich. ↓	Cov. ↑	Eucl. ↓	Geod. ↓	Dirich. ↓	Cov. ↑
KNN	0.0454	0.0434	0.0022	0.2452	0.0879	0.0836	0.0016	0.1364	0.1083	0.1036	0.0063	0.1446	0.1119	0.1095	0.0025	0.0995
OT [12]	0.0926	0.0856	0.0016	0.0890	0.0779	0.0741	0.0012	0.1129	0.1252	0.1168	0.0060	0.1001	0.1327	0.1273	0.0047	0.0748
FMap [44]	0.0401	0.0400	0.0016	0.3236	0.0756	0.0744	0.0018	0.2162	0.1381	0.1411	0.0077	0.2037	0.0810	0.0779	0.0031	0.1683
FMapwks [2]	0.0331	0.0334	0.0017	0.3759	0.0647	0.0623	0.0023	0.2585	0.1197	0.1131	0.0203	0.2380	0.0723	0.0718	0.0045	0.2211
FMapzo [39]	0.0207	0.0195	0.0009	0.6969	0.0625	0.0611	0.0065	0.4706	0.1454	0.1480	0.0152	0.3495	0.0706	0.0710	0.0062	0.4043
FMapNAM [59]	0.0245	0.0240	0.0009	0.6323	0.0617	0.0589	0.0015	0.4694	0.1041	0.0962	0.0082	0.2860	0.0689	0.1118	0.0026	0.3494
NDP [24]	0.0702	0.0886	0.0020	0.4893	0.0555	0.0675	0.0010	0.4818	0.0698	0.0649	0.0013	0.5016	0.0457	0.0438	0.0012	0.4190
Diff3f [14]	0.0697	0.1109	0.0497	0.3075	0.1594	0.2278	0.0560	0.2146	0.0876	0.1036	0.0443	0.1579	0.1394	0.1732	0.0755	0.1448
Diff3f FMap [14]	0.0553	0.0886	0.0036	0.4427	0.1283	0.1943	0.0114	0.2789	0.1173	0.1357	0.0133	0.2376	0.1880	0.2087	0.0362	0.0565
ULRSSM [10]	0.0092	0.0109	0.0011	0.7302	0.0370	0.0374	0.0030	0.4936	0.3286	0.3496	0.2299	0.1337	N/A	N/A	N/A	N/A
FUSEANCHOR	0.0425	0.0390	0.0241	0.3483	0.0579	0.0542	0.0185	0.3708	0.0912	0.0806	0.0538	0.3619	0.0983	0.0925	0.0328	0.2459
FUSEDDIM	0.0402	0.0407	0.0023	0.2973	0.0921	0.0879	0.0016	0.1500	0.0856	0.0797	0.0030	0.2214	0.1106	0.1101	0.0025	0.1326
FUSE	0.0289	0.0274	0.0066	0.5320	0.0595	0.0576	0.0075	0.5156	0.0975	0.0896	0.0339	0.5278	0.0969	0.0914	0.0137	0.4931
FUSE zo	0.0200	0.0189	0.0009	0.7127	0.0437	0.0413	0.0023	0.5361	0.1275	0.1312	0.0093	0.3763	0.0690	0.0662	0.0046	0.4173
FUSE NAM	0.0179	0.0168	0.0009	0.7027	0.0422	0.0388	0.0010	0.5520	0.0658	0.0603	0.0027	0.5342	0.0770	0.0702	0.0023	0.3904

further improves the base results of the FUSE pipeline and while considerably increasing the smoothness of the maps. Notably, initializing these refinements methods with FUSE yields better results than using the standard FMaps initialization, particularly evident in the case SHREC20 with strongly non-isometric pairs. Geodesic distances are particularly sensitive to deviations from isometry, and even though corresponding points can be associated with structurally similar distance distributions, actual values may wildly vary. We also observe that, in the more challenging scenario of non-isometric pairs, FUSEANCHOR achieves marginally better accuracy than our approach, at the cost of a considerably higher Dirichlet energy and lower coverage. This suggests that the lack of smoothness in the maps produced by FUSE depends on the flow inversion from the surface to the anchor distribution, which is a non-smooth operation. ULRSSM [10] achieves the best results on FAUST and SMAL, but underperforms substantially on SHREC20. As a data-driven method, it requires extensive training on a large dataset, it is restricted to meshes, whereas our flows can be efficiently trained from different representations and easily composed.

Point cloud correspondences. Point cloud matching presents a unique challenge: FUSE requires reliable geodesic distances and sufficient surface coverage, both of which are difficult to guarantee on unstructured data, since the surface information outside of the vertices is unknown. This degrades FUSE’s performance relative to extrinsic methods like NDP [24], which bypasses geodesics entirely at the cost of failing under strong non-rigid deformations (e.g., FAUST). However, FUSE still outperforms non-refined geodesic methods (KNN, OT, FMaps), proving that the flow mechanism itself adds value.

5.2 Alternative Representations

Since FUSE only requires the ability to sample points from a surface and to compute single-to-all geodesic distances, it enables shape matching in a broader class of representations, such as Signed Distance Functions (SDFs), as well as inter-representation matching (see Fig. 7).

Inter-representation matching. We conduct experiments on shape pairs from different FAUST-like collections: from the original FAUST meshes, we extract the vertices to use as point clouds, and we compute SDFs as discussed in the previous paragraph. For each shape, geodesics are computed sticking to the constraints of the representation (*i.e.*, heat geodesics [11] on point clouds, Dijkstra on mesh or voxel grid). As mentioned in Sec. 5.1, FUSE inevitably struggles on matching tasks involving only point clouds, but achieves results comparable to mesh-to-mesh matching when at least one shape is represented as mesh or SDF. We provide an example of matching for all possible combinations of meshes, point clouds and SDFs in Fig. 7. A deeper analysis is presented in the supplementary material.

Table 5: Quantitative evaluation of the SDF-based FAUST dataset without considering the topological error.

Method	Eucl. ↓	Geod. ↓	Dirich. ↓	Cov. ↑
KNN	0.0562	0.0569	0.0023	0.1744
NDP	0.0525	0.0643	0.0016	0.5139
OT	0.0921	0.0881	0.0018	0.0936
FUSE ANCHOR	0.0472	0.0469	0.0175	0.2784
FUSE	0.0375	0.0385	0.0069	0.4653

SDFs shape matching. To our knowledge, no dataset exists to evaluate quantitatively matching between SDFs, so we introduce a new benchmark derived from FAUST. For each shape, we train a neural implicit model following [3], and for evaluation, we project the original mesh vertices onto the corresponding SDF surface, ensuring accuracy is always measured on the original mesh geom-

etry. We note that this implicit reconstruction may alter the topology of some shapes. To apply FUSE, we uniformly sample $\sim 10^5$ points from the zero level set and voxelize each SDF surface to compute geodesic distances via Dijkstra. As in Sec. 5.1, these geodesic embeddings are then used to train the flow models. Tab. 5 reports the results for all shapes whose SDFs preserve valid topology.

FUSE provides a matching estimation without pair-specific supervision, additional training, or fine-tuning and with results comparable or better than other methods. While ZO and NAM refinement methods can be applied between meshes and point clouds to greatly improve the matching quality, these methods cannot be used on SDFs where FUSE added value is most significant, as it provides the most accurate maps compared to other baselines.

5.3 Applications

FUSE allows to model 3D surfaces as probability distributions via surface sampling and to compute maps without explicit optimization, effectively making it a “bridge” between distinct representations. We exploit this peculiar property to use FUSE as a backbone for various tasks other than pure shape matching.

Human scans fitting and skinning. Given the scan of a human body, represented as a 3D point cloud $\mathcal{S}$, we use FUSE to match it to a triangle mesh representing the neutral pose $\mathcal{T}$ of a templated body model, obtained with SMPL-X [48]. By exploiting the correspondence, we can easily fit the body model’s parameters to approximate $\mathcal{S}$ via minimization of the MSE between corresponding points. This procedure, whose results we show in the left column of Fig. 8, yields style

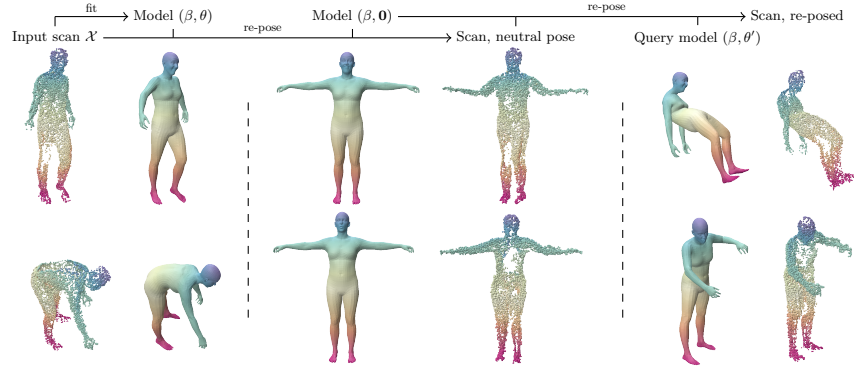


Fig. 8: Results for human-scan fitting and skinning. Input scans identities are preserved in the edited poses (see preserved scan defects on right leg, back and chest). We first optimize β and θ using FUSE correspondences, then re-pose the scan by applying point-wise offsets from the neutral pose.

and pose vectors (β, θ) . If we compute the vertex offsets from the the SMPL-X output for the optimized θ to the neutral pose $\mathcal{T}$, we can apply them “as-is” to the corresponding points in $\mathcal{S}$ to obtain the point cloud in neutral pose. Finally, given a novel pose vector θ' , we can iterate this process to obtain the scan in the required pose. Two example applications of our pipeline are depicted in Fig. 8.

Mesh parametrization. Given a genus-zero surface $\mathcal{S}$ and a reference sphere Φ , we train flows from a Gaussian to each shape using 3D coordinates as embeddings. Composing these flows yields a bijection between $\mathcal{S}$ and Φ , allowing us to transfer the sphere’s UV parametrization to the shape. As FUSE maps may lack smoothness (see Sec. 5.1), transferred UVs are used to supervise an MLP that predicts continuous UV coordinates, enforcing a smooth prior. Since the MLP operates in the embedding space, the procedure applies to any representation supported by FUSE. In this setting, 3D coordinates are sufficient, as no semantic consistency is required. In Fig. 9 we show an example.

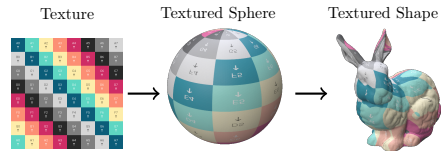


Fig. 9: Illustration of our parametrization via texture mapping.

Volume matching. Our representation-agnostic formulation naturally extends to volumetric shapes, three-dimensional manifolds with well-defined geodesic distances, enabling targeting of volume-matching tasks. We apply FUSE to tetrahedral meshes, comparing it to Volumetric FMaps [31]. Results from Tab. 6 and Fig. 10 mirror our analysis on the surface scenario: comparable or improved accu-

racy, particularly in case of strong non-isometry, where the functional approach struggles. Details on the metrics are in the supplementary materials.

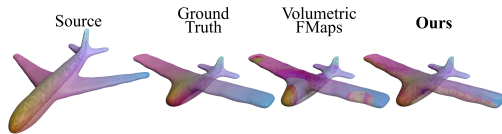


Fig. 10: Qualitative comparison of Ours vs Volumetric Functional Maps on a pair of non isometric tetrahedral meshes.

Table 6: Volumetric correspondence by accuracy and isometricity.

Mesh	Isometry ↓	Accuracy ↓	
		VolFmaps	Ours
Octopus	0.0449	0.0151	0.0215
Cat	0.0561	0.0237	0.0422
Dino_skel	0.0851	0.0652	0.0426
Airplane	0.2207	0.1273	0.0942
Average	0.1017	0.0578	0.0501

6 Conclusions and Limitations

We presented FUSE, a representation for maps between shapes based on Flow Matching. By composing per-shape invertible flows through a shared anchor distribution, FUSE produces accurate, high-coverage correspondences that are agnostic to the underlying geometric representation, supporting meshes, point clouds, SDFs, and volumetric data. Its probabilistic formulation offers an alternative to classical correspondence-based pipelines and provides a concrete starting point for works integrating learned features with flow-based alignment.

FUSE has three main limitations. First, symmetry disambiguation depends entirely on the embedding: geodesic landmarks handle this well, but embeddings lacking symmetry-breaking information (e.g., WKS) lead to degraded results. Second, the reliance on consistent geodesic distances limits its effectiveness on point clouds and makes it unsuitable for partial matching in its current form. Third, the final KNN retrieval step (Sec. 4.2) makes the matching not strictly bijective, as is standard in point-based methods, though the continuity of both the GFE and the flow already supports a continuous solution. Extending FUSE to partial settings [8, 63], enforcing full bijectivity, and integrating learned smooth features are natural directions for future work.

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