NEURAL INFORMATION PROCESSING SYSTEMS

Doubly Hierarchical Geometric Representations for Strand-based Human Hair Generation

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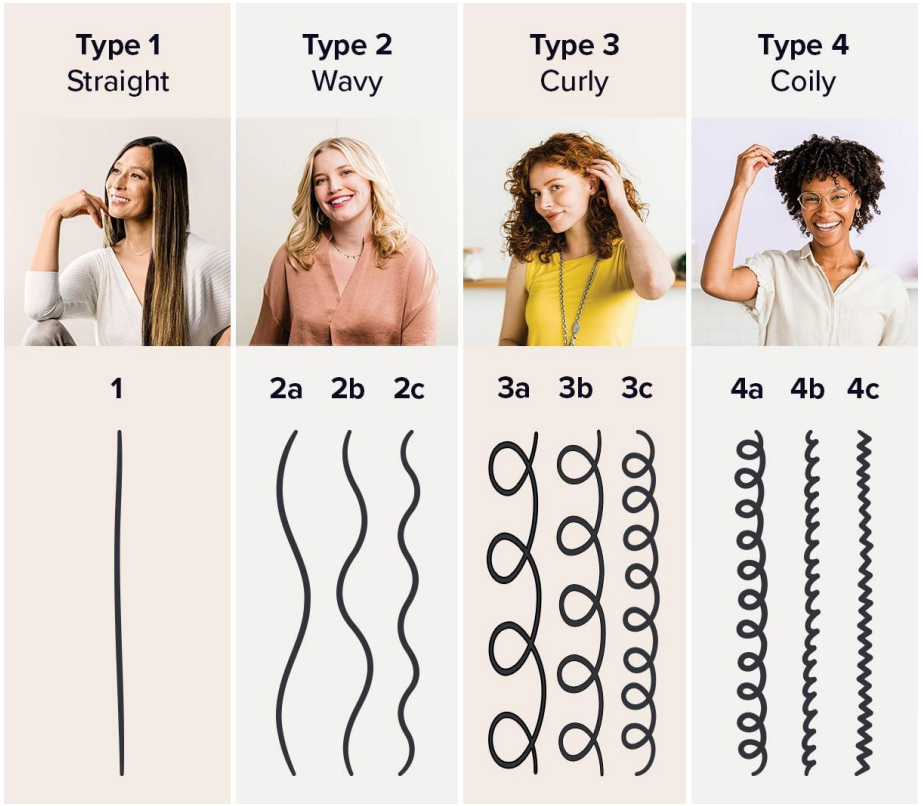
Meta

Strand-based hair geometry is complex and high-dimensional

- Each person has ~100K strands
  - Flexible density and amount
- Different hair types / curliness
  - Patterns in frequency space

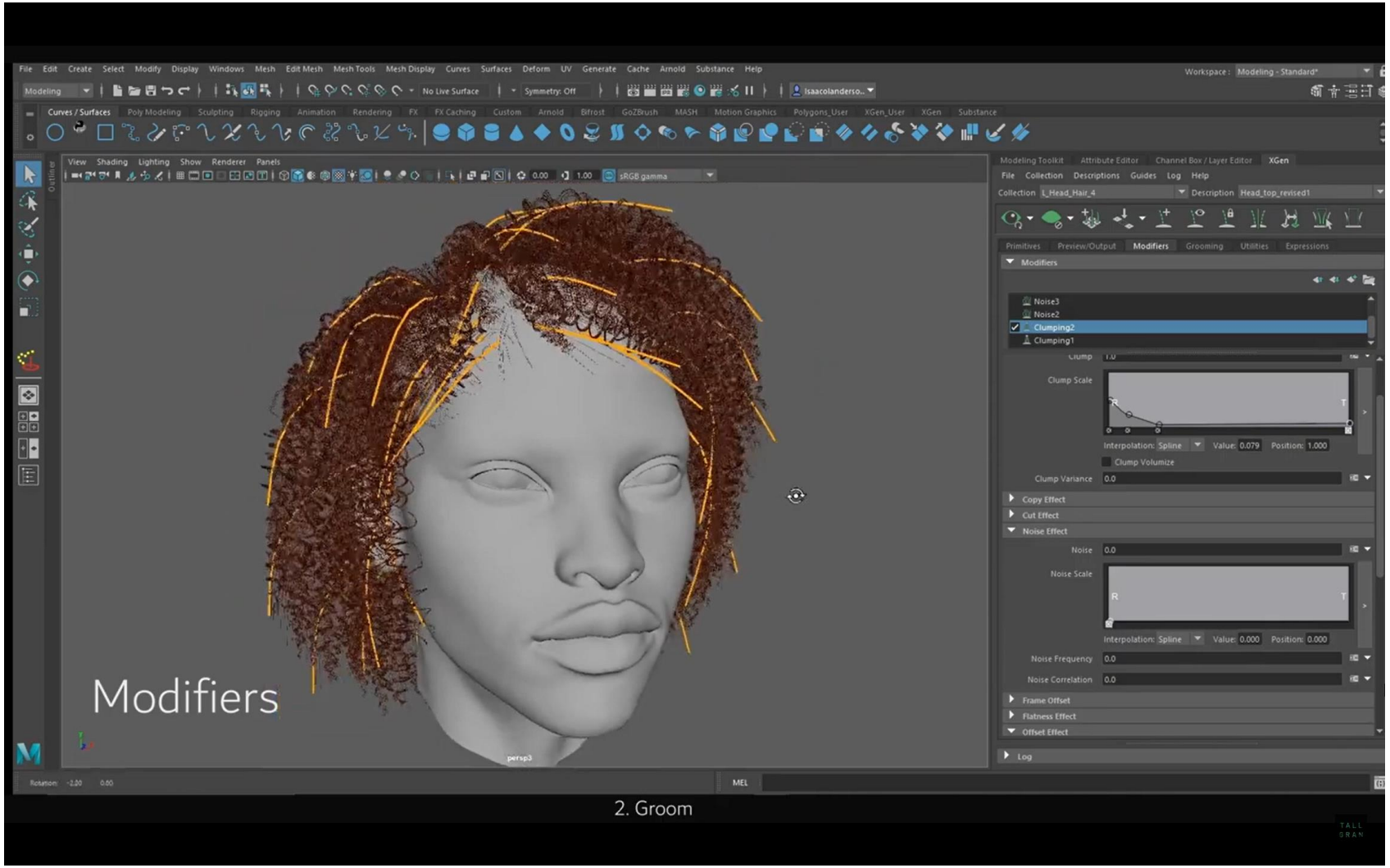


- A set of 1D curves in 3D space,
  with roots on the 2D head scalp manifold

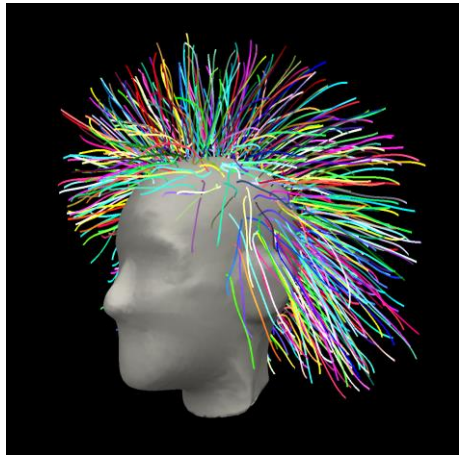
- Due to high dimensionality,
  a **hierarchical, coarse-to-fine** representation is needed for generative learning

Image credit: https://sharkclean.co.uk/different-hair-types-cms-page.hair-type

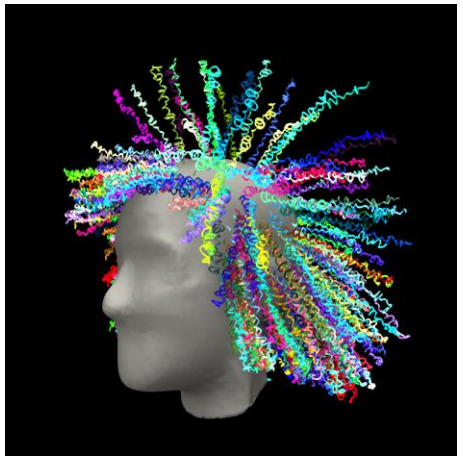
- Guide hair modelling in modern graphics tools (e.g. Maya Xgen, Houdini, ⋯)
  - The artist sculpts **sparse** and **smooth** curves as guide hair, to guide the coarse growing direction;
  - Dense hair with high-frequency details of curliness and noise generated from the algorithm.



Extract pseudo guide hair from data



Ideal guide hair



Guide hair extracted
by existing methods

with high-freq local curliness and noise details
undesired for coarse-scale features

Doubly hierarchical guide hair modelling

- Per-strand frequency decomposition
- Optimal sampling of important strands

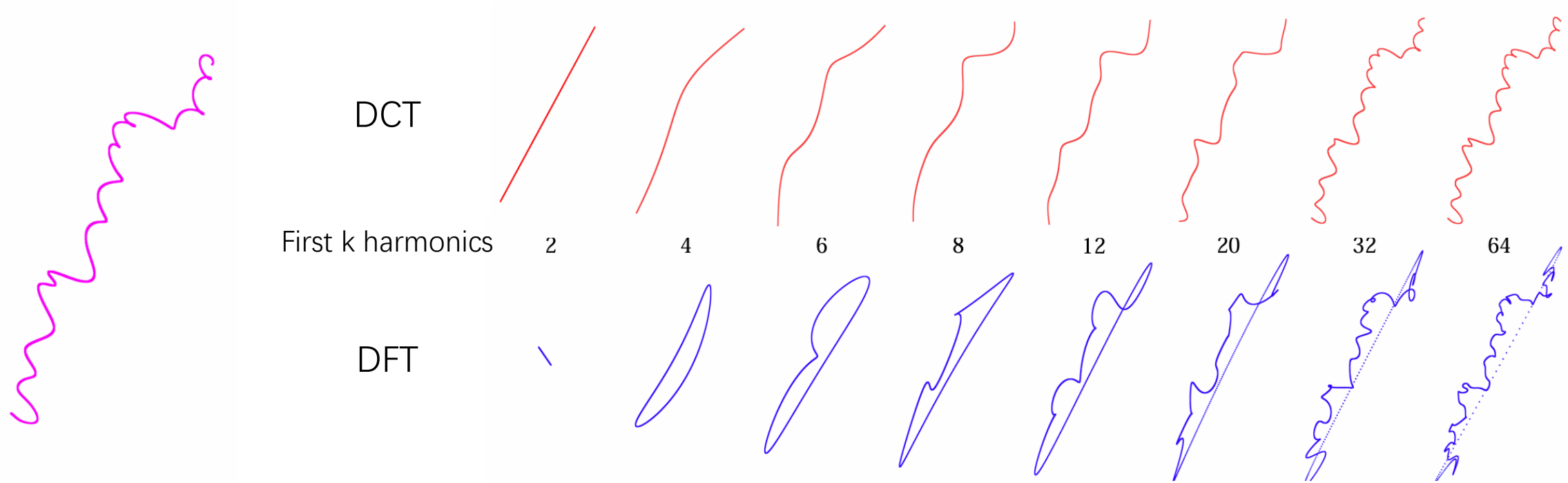
DCT
freq decomposition

K-medoids
Guide hair sampling

Doubly hierarchical guide hair modelling

- **Per-strand frequency decomposition**
- Optimal sampling of important strands

- Per-strand frequency decomposition for low-pass filtered curves
  - **DFT (Discrete Fourier transform)** bias to closed curves (Gibbs' oscillation)
  - **DCT (Discrete Cosine Transform)** better solution for open curves.



Original hair strand

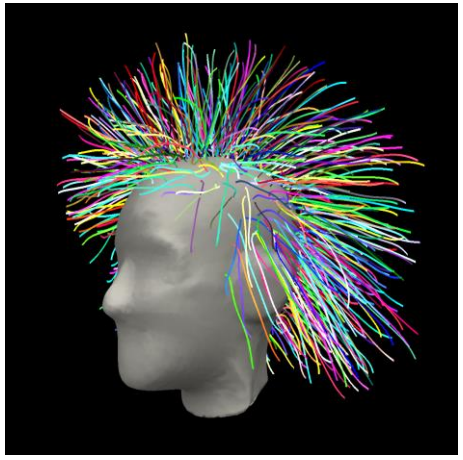
Low-pass filtered curves from frequency decomposition

Doubly hierarchical guide hair modelling

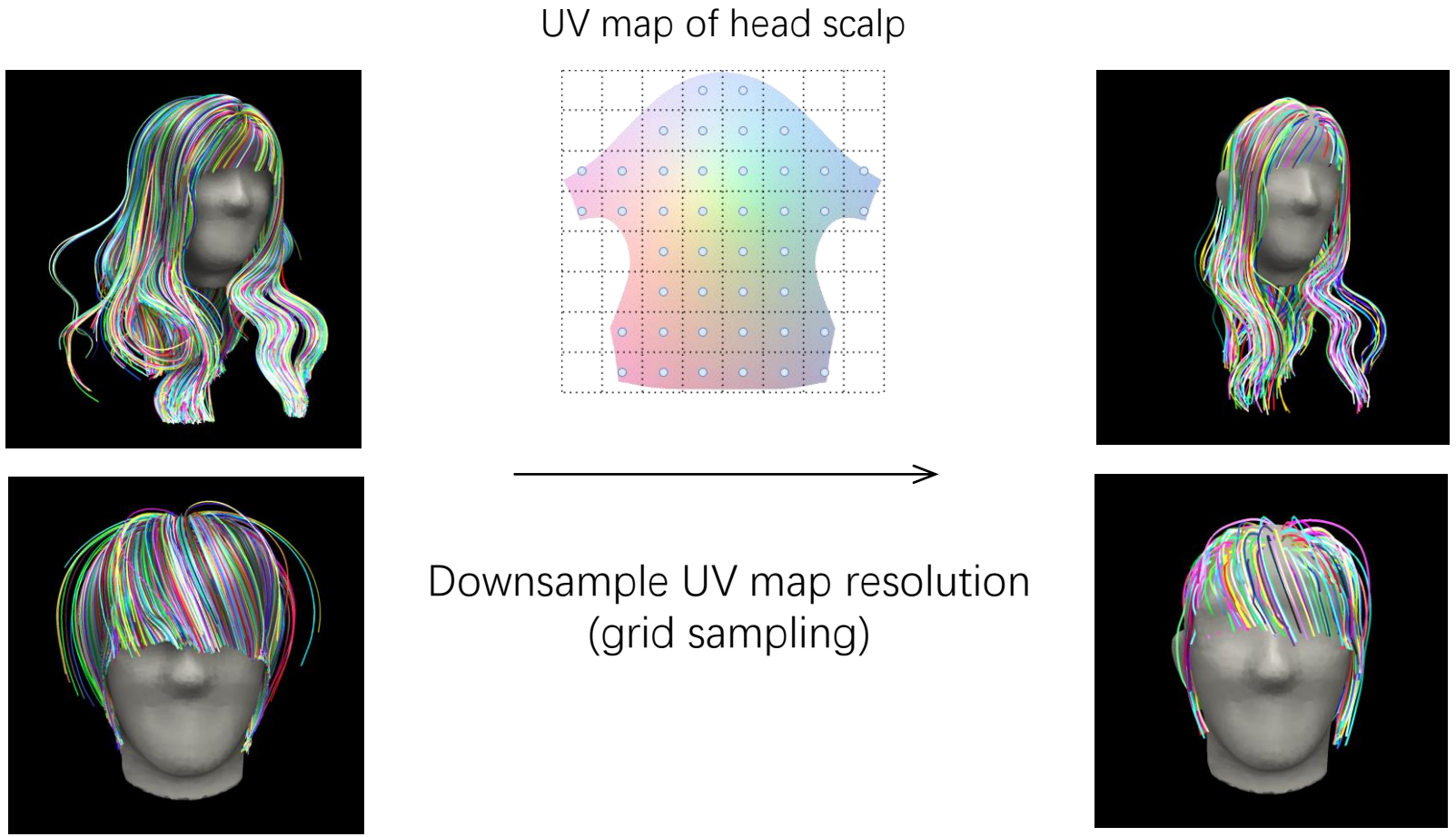
- Per-strand frequency decomposition
- **Optimal sampling of important strands**

DCT
freq decomposition

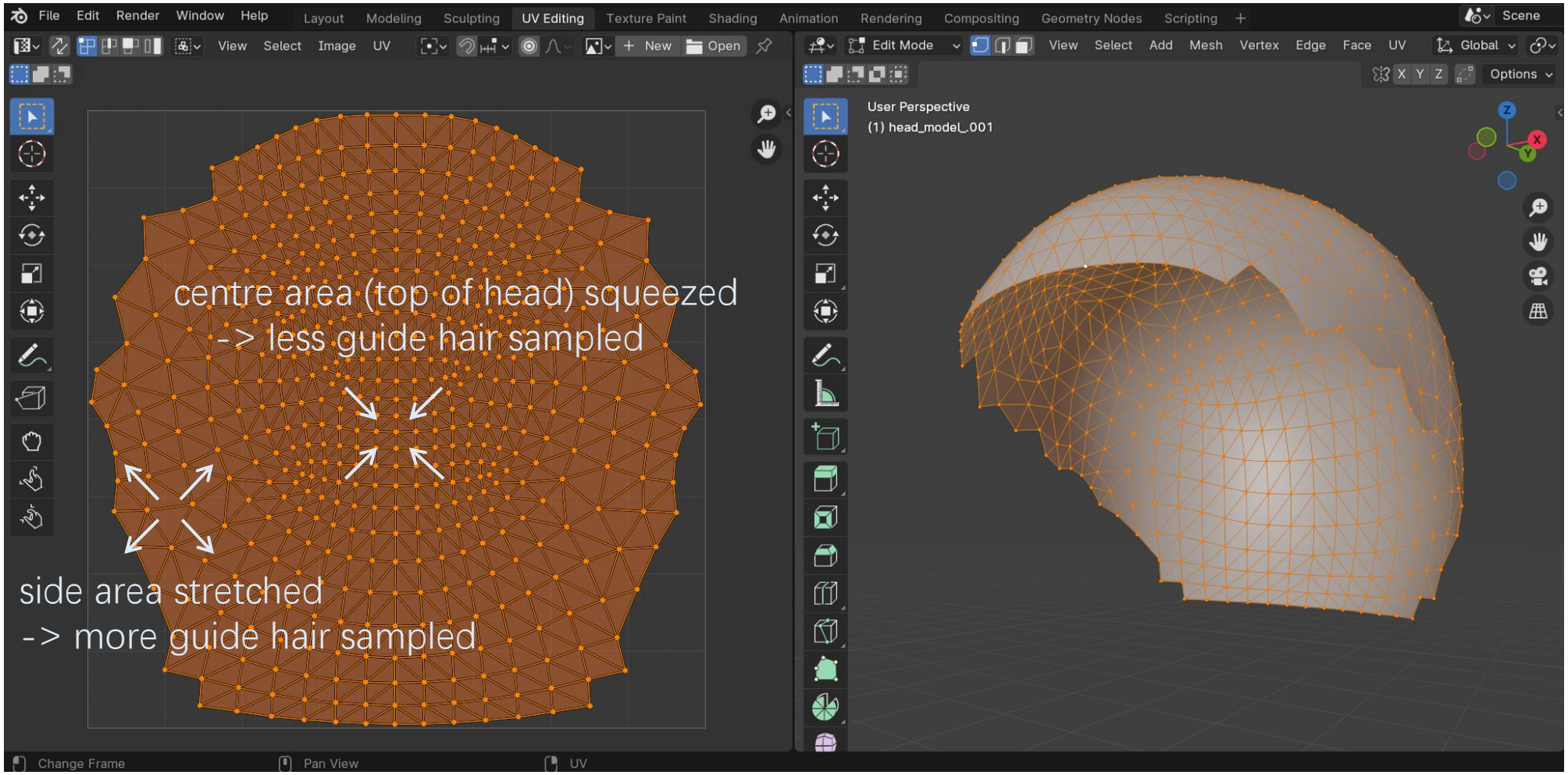
K-medoids
Guide hair sampling



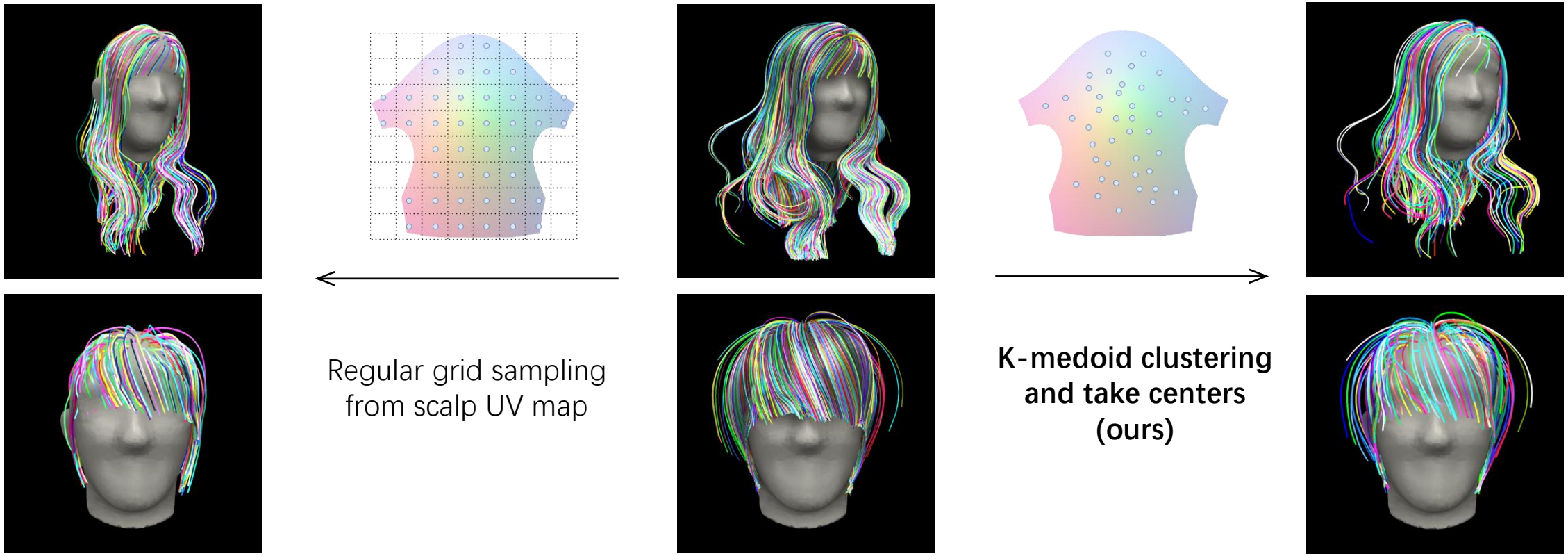
- Existing methods simply down-sample the scalp UV map for guide hair
- Problems with the regular grid sampling on the UV map (1)
  - Miss capture important details



- Problems with the regular grid sampling on the UV map (2)
  - UV mapping not area-preserving -> Less guide hair sampled from important area



- Optimal sampling of guide strands subset (ours)
  - Extract k-medoids clustering centres as guide strands
  - Optimal: the guide curve set is the closest to the original strand set (in terms of chamfer measurement).



Regular grid sampling from scalp UV map

K-medoid clustering and take centers (ours)

We show that our way of sampling guide hair is theoretically optimal

Theorem 1. *The medoid set* $\mathcal{U} = \{u_1, \ldots, u_k\}$ *from the* k*-medoids clustering of* $\mathcal{H}$ *is the optimal sampled hair curve set* $\mathcal{G}_k^*$*, if aggregated squared Euclidean distance* $d(l, l') = \frac{1}{n}\|l - l'\|_2^2 := \frac{1}{n}\sum_{t=0}^{n-1}\|l(t) - l'(t)\|_2^2$ *for two individual curves is used as the divergence function for* k*-medoids.*

Generation pipeline and network architecture

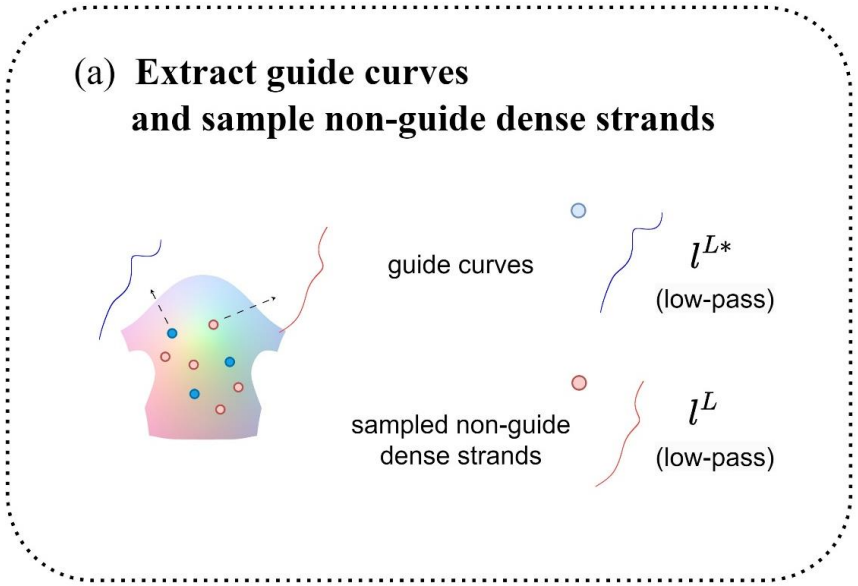
Guide hair

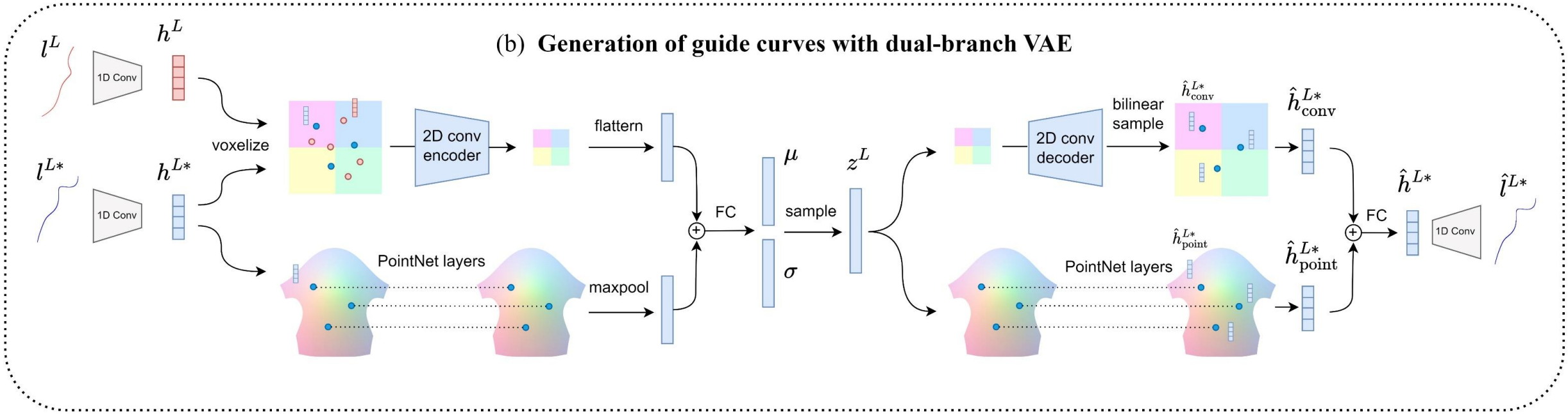
Dense hair

high-freq curliness and noise

Network architecture (1): Guide hair generation

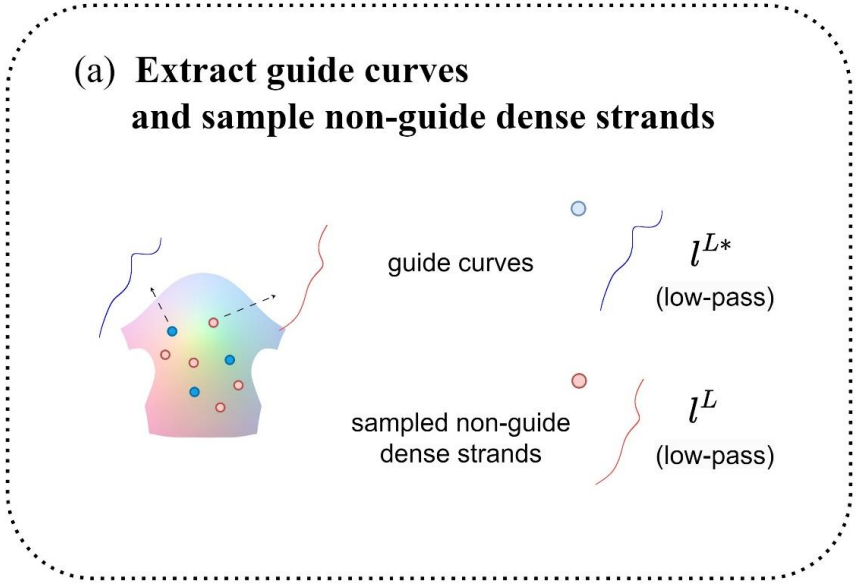
- Dual branch VAE,
  - Conv + PointNet branches, inspired by PVCNN
  - to handle flexible root positions.

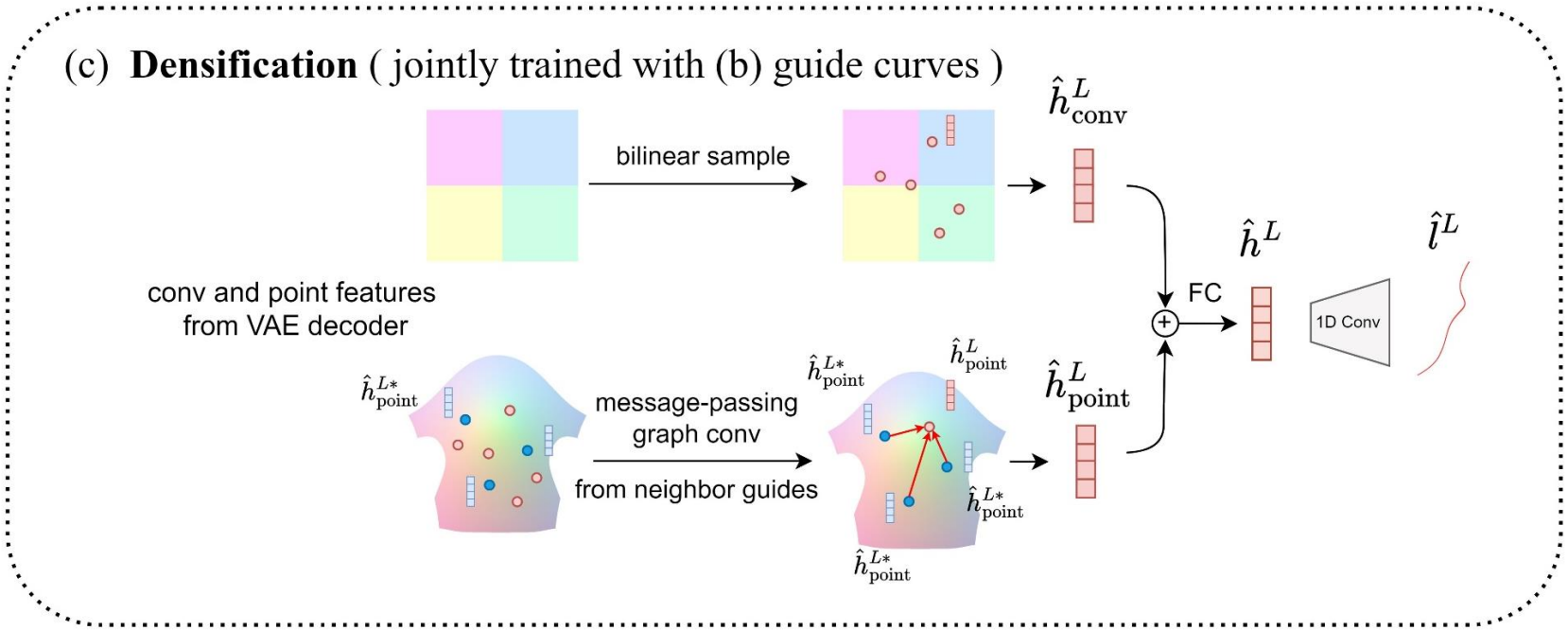




Network architecture (2): Upsample to dense hair

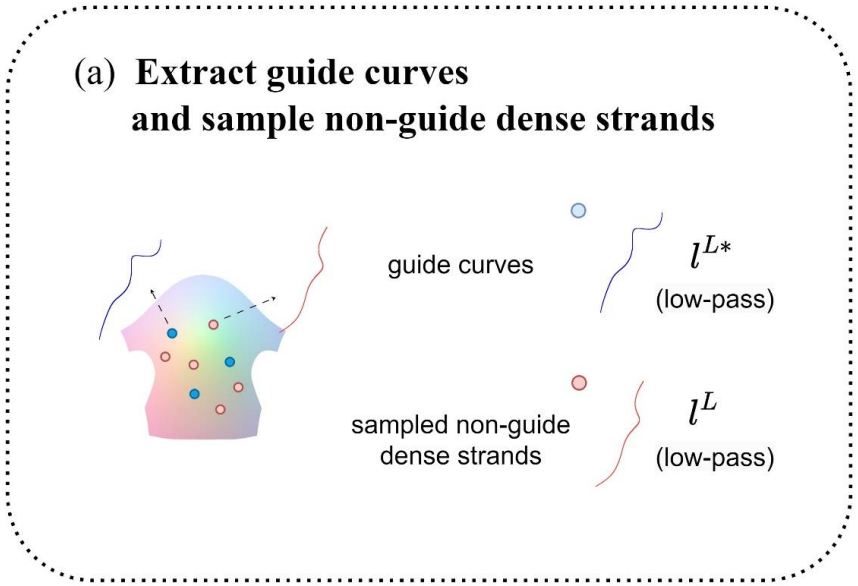
- Hybrid neural fields + graph message passing
- Can handle any amount and density
- Can be jointly trained with guide hair generation

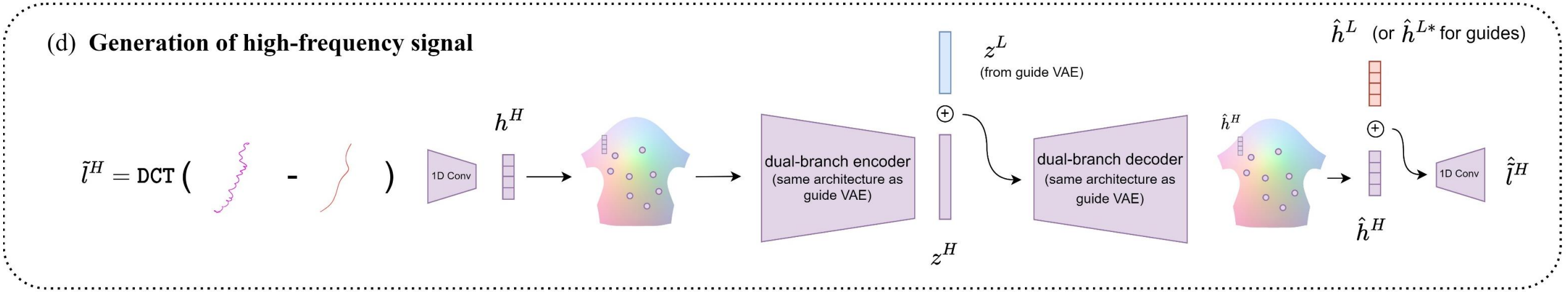


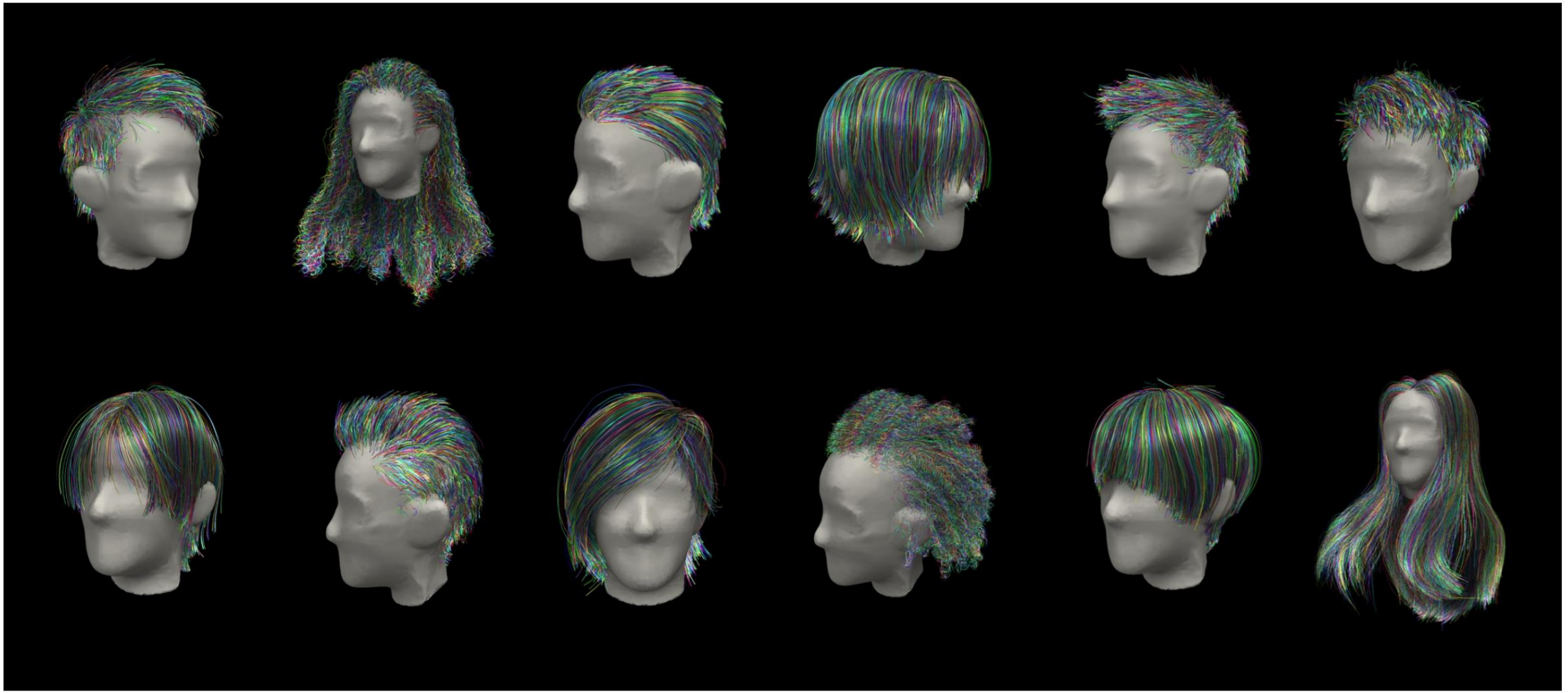


Network architecture (3): Add high-frequency details

- Another dual-branch network.
- Conditioned on low-freq. latent features







Recap: doubly hierarchical representations for generating strand-based hair geometry

- A novel hierarchical representation with mathematical insights
  - DCT to filter out high-frequency local noise and curliness
  - Optimal sampling of important strands from k-medoids clustering

- Generative network design for our representation
  - PVCNN-inspired architecture for guide hair generation with flexible roots
  - Upsample to dense strands: hybrid neural fields + graph message-passing
    - Handles any amount and any density
  - High-frequency details conditioned on latent features from low-freq model