Supplementary Materials for

Pianno: a probabilistic framework automating semantic annotation for spatial transcriptomics

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Supplementary Note

Transformation of spatial coordinates to image coordinates

There are usually two forms of spatial coordinates, one is an array-like row index, and the other is a pixel-level physical coordinate. For the former Mask is relatively simple and intuitive to construct. However, high-resolution spatial transcriptome techniques usually only have finer pixel-level physical coordinates, such as SlidseqV2, and therefore require the user to specify a scale factor (which defaults to 1 for array-like coordinates)The coordinate conversion is performed according to the following equation.

$$\begin{cases} i = \operatorname{int}\left(\frac{x_s - \min_{\forall s \in \mathbb{S}}\{x_s\}}{\operatorname{scalefactor}}\right) \\ j = \operatorname{int}\left(\frac{y_s - \min_{\forall s \in \mathbb{S}}\{y_s\}}{\operatorname{scalefactor}}\right) \end{cases}$$
(1)

where $int(\cdot)$ denotes the rounding function in Python, and the formula above is equivalent to binning for spots.

Supplementary Figures

Fig. S1 Comparison of spatial domains by clustering assignments via SpaGCN, SEDR, BayesSpace, DeepST, STAGATE, Pianno and manual annotation in all 12 samples of the human dlPFC dataset.

Fig. S2 Unsupervised clustering label mapping via Kuhn-Munkres Algorithm.

Fig. S3 Pianno's performance in structure and cell-type probability inference.

Fig. S4 Pianno annotation for MOB.

Fig. S5 Multimodal data exploratory analysis with Pianno.

Fig. S6 Sensitivity analysis.

| | | • 1 | 2 | 3 4 | 4 5 | • 6 | • 7 | | _ |
|--------------------|--------------------|--------------------|------------------------|--------------------|---------------------|--|---|---|------------------------------------|
| Leiden ARI=0.23 | SpaGCN ARI=0.42 | SEDR ARI=0.43 | BayesSpace ARI=0.47 | DeepST ARI=0.46 | STAGATE ARI=0.47 | cellassign ARI=0.051 ACC=0.4 F1=0.24 | Pianno(Initial) ARI=0.65 ACC=0.79 F1=0.76 | Pianno(Final) ARI=0.66 ACC=0.78 F1=0.73 | Manual annotation sample 151507 |
| | | | | | | | N. | | |
| ARI=0.22 | ARI=0.36 | ARI=0.34 | ARI=0.44 | ARI=0.4 | ARI=0.51 | ARI=0.012 ACC=0.11 F1=0.087 | ARI=0.56 ACC=0.75 F1=0.72 | ARI=0.61 ACC=0.78 F1=0.74 | sample 151508 |
| | | | | | | | | | |
| ARI=0.13 | ARI=0.46 | ARI=0.37 | ARI=0.4 | ARI=0.47 | ARI=0.48 | ARI=0.078 ACC=0.45 F1=0.27 | ARI=0.54 ACC=0.76 F1=0.76 | ARI=0.69 ACC=0.84 F1=0.82 | sample 151509 |
| | | | | | | ABI-0.044 | ARI=0.62 | ABI=0.72 | |
| ARI=0.19 | ARI=0.45 | ARI=0.39 | ARI=0.38 | ARI=0.48 | ARI=0.52 | ACC=0.28 F1=0.26 | ACC=0.81 F1=0.78 | ACC=0.85 F1=0.79 | sample 151510 |
| | | | | | | | | | |
| ARI=0.15 | ARI=0.27 | ARI=0.34 | ARI=0.38 | ARI=0.26 | ARI=0.33 | ARI=-0.056 ACC=0.2 F1=0.13 | ARI=0.44 ACC=0.67 F1=0.53 | ARI=0.51 ACC=0.72 F1=0.54 | sample 151669 |
| | | | | | | | | | 0 |
| ARI=0.14 | ARI=0.29 | ARI=0.27 | ARI=0.26 | ARI=0.26 | ARI=0.34 | ARI=0.07 ACC=0.034 F1=0.087 | AREU.43 ACC=0.64 F1=0.51 | AKI=0.44 ACC=0.63 F1=0.52 | sample 151670 |
| | | | 13 | | | | 23 | 2 | 6 |
| ARI=0.19 | ARI=0.43 | ARI=0.34 | ARI=0.47 | ARI=0.47 | ARI=0.46 | ARI=-0.0012 ACC=0.066 F1=0.021 | ARI=0.57 ACC=0.75 F1=0.54 | ARI=0.61 ACC=0.78 F1=0.58 | sample 151671 |
| | | | | | X | | 1 | * | |
| ARI=0.13 | ARI=0.36 | ARI=0.29 | ARI=0.48 | ARI=0.5 | ARI=0.5 | ARI=0.053 ACC=0.2 F1=0.12 | ARI=0.6 ACC=0.76 F1=0.54 | ARI=0.66 ACC=0.81 F1=0.57 | sample 151672 |
| i en | | Contraction of the | | ~ | | | | 2 | |
| ARI=0.25 | ARI=0.46 | ARI=0.5 | ARI=0.55 | ARI=0.48 | ARI=0.59 | ARI=0.17 ACC=0.3 F1=0.26 | ARI=0.61 ACC=0.77 F1=0.74 | ARI=0.64 ACC=0.8 F1=0.78 | sample 151673 |
| | 2 | 7) | 1 | | 2 | 1 | 2 | 7 | 7 |
| ARI=0.29 | ARI=0.39 | ARI=0.41 | ARI=0.3 | ARI=0.44 | ARI=0.61 | ARI=0.19 ACC=0.39 F1=0.32 | ARI=0.62 ACC=0.79 F1=0.75 | ARI=0.63 ACC=0.79 F1=0.75 | sample 151674 |
| | | | P | 1 | 2 | ARIED 025 | ARIE 0.51 | ARIED 54 | 1 |
| ARI=0.28 | ARI=0.35 | ARI=0.48 | ARI=0.53 | ARI=0.49 | ARIE0.56 | ACC=0.29 FT=0.22 | ACC-0 71 FT=0.68 | ACC-DITS FT=0.68 | sample 151675 |
| ARI=0.26 | ARI=0.31 | ARI=0.51 | ARI-0.37 | ARI=0.41 | ARI=0.59 | ARI+0.093 ACC=0.4 F1=0.22 | ARI+0.63 ACC=0.79 F1=0.74 | ARI-0.66 ACC-0.8 F1=0.73 | sample 151676 |

Fig. S1 Comparison of spatial domains by clustering assignments via SpaGCN, SEDR, BayesSpace, DeepST, STA-GATE, Pianno and manual annotation in all 12 samples of the human dlPFC dataset.

| | • L1 | • L2 L | .3 L4 | • (L5 L | .6 WM | unmatch | |
|-------------------------------|-------------------------------|--|-----------------------------------|-------------------------------|-------------------------------|----------------------------------|------------------------------------|
| Leiden ACC=0.45 F1=0.42 | SpaGCN ACC=0.59 F1=0.58 | SEDR ACC=0.61 F1=0.55 | BayesSpace ACC=0.61 F1=0.54 | DeepST ACC=0.63 F1=0.59 | STAGATE ACC=0.6 F1=0.51 | cellassign ACC=0.4 F1=0.24 | Manual annotation sample 151507 |
| | 330 | | | | | | |
| | | | | | | | |
| ACC=0.45 F1=0.42 | ACC=0.5 F1=0.48 | ACC=0.5 F1=0.44 | ACC=0.58 F1=0.57 | ACC=0.54 F1=0.5 | ACC=0.68 F1=0.67 | ACC=0.11 F1=0.087 | sample 151508 |
| | | and the second s | | 0.40 | | See. | |
| | A CONTRACTOR | | | A CORD | | | |
| ACC=0.39 F1=0.34 | ACC=0.61 F1=0.45 | ACC=0.58 F1=0.55 | ACC=0.62 F1=0.53 | ACC=0.66 F1=0.61 | ACC=0.66 F1=0.56 | ACC=0.45 F1=0.27 | sample 151509 |
| | 13 MA | and the second se | | | 1 | | |
| | 18.27 | | | | | | |
| ACC=0.48 F1=0.37 | ACC=0.56 F1=0.45 | ACC=0.58 F1=0.49 | ACC=0.56 F1=0.42 | ACC=0.63 F1=0.51 | ACC=0.68 F1=0.49 | ACC=0.28 F1=0.26 | sample 151510 |
| all set | ALL STREET | | | | | | |
| ACC=0.37 | ACC=0.44 | ACC=0.42 | ACC=0.61 | ACC=0.44 | ACC=0.54 | ACC=0.2 | |
| F1=0.29 | F1=0.36 | F1=0.4 | F1=0.6 | F1=0.4 | F1=0.44 | F1=0.13 | sample 151669 |
| | | | | | | | |
| ACC=0.38 | ACC=0.47 | ACC=0.47 | ACC=0.45 E1=0.38 | ACC=0.46 | ACC=0.57 | ACC=0.034 | samla 151670 |
| Color Service | | | | 1 | | | |
| | | | - Park | | | | |
| ACC=0.4 F1=0.33 | ACC=0.59 F1=0.54 | ACC=0.51 F1=0.46 | ACC=0.58 F1=0.47 | ACC=0.61 F1=0.58 | ACC=0.63 F1=0.54 | ACC=0.066 F1=0.021 | sample 151671 |
| and a | AN AL | 28 | | | | | |
| 1. A. A. | 1 | | | | | Contraction of the second | |
| ACC=0.36 F1=0.32 | ACC=0.55 F1=0.52 | ACC=0.46 F1=0.42 | ACC=0.64 F1=0.54 | ACC=0.63 F1=0.5 | ACC=0.65 F1=0.57 | ACC=0.2 F1=0.12 | sample 151672 |
| | A CONSTRUCTION | | | | | | |
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| ACC=0.44 F1=0.4 | ACC=0.58 F1=0.49 | ACC=0.64 F1=0.52 | ACC=0.69 F1=0.56 | ACC=0.68 F1=0.66 | ACC=0.75 F1=0.74 | ACC=0.3 F1=0.26 | sample 151673 |
| and the second | | | | A | | | |
| ACC-0.47 | ACC-0.49 | ACC-0.56 | ACC-0.46 | ACC-DEA | ACC-0.73 | ACC-0 39 | |
| F1=0.42 | F1=0.4 | F1=0.54 | F1=0.37 | F1=0.48 | F1=0.71 | F1=0.32 | sample 151674 |
| | | 9 | Lange - | | 2 | | |
| ACC=0.45 | ACC=0.48 | ACC=0.68 | ACC=0.62 | ACC=0.64 | ACC=0.73 | ACC=0.29 E1=0.22 | sample 151675 |
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| 14 A. | 19.5 | 31 | | | 1 | | 1) |
| ACC=0.42 F1=0.38 | ACC=0.46 F1=0.36 | ACC=0.67 F1=0.62 | ACC=0.52 F1=0.43 | ACC=0.56 F1=0.55 | ACC=0.71 F1=0.56 | ACC=0.4 F1=0.22 | sample 151676 |
| | | | | 1 | | and the second second | 6 |
| 10 M | | | | 777 | | | 71 |

Fig. S2 Unsupervised clustering label mapping via Kuhn-Munkres Algorithm. Source data are provided as a Source Data file.



Fig. S3 Pianno's performance in structure and cell-type probability inference. a, Posterior probability distribution in dlPFC sample 151673 inferred by Pianno. Top: posterior probability heatmap of different cortical structures. Bottom: violin plots of Pianno's inferred structure probability distributions in manually annotated cortical structures. b, The distribution probability of selected cell types inferred by Pianno, Cell2location, Tangram, and RCTD. Source data are provided as a Source Data file.



Fig. S4 Pianno annotation for MOB.



Fig. S5 Multimodal data exploratory analysis with Pianno. a, Proportion of unsupervised clusters within each structure. b, H&E stained image of human dlPFC sample 151671. The white lines delineated the boundaries between layers annotate by Pianno (right). Histological difference between L2 and L3 is highlighted and displayed (left). c, Visualization of L2 markers used during Pianno annotation of sample 151671. d, Visualization of known L2 markers not used during Pianno annotation of sample 151671. Those markers were found in the DEGs of L2 from sample 151671. e, Validation of laminar distribution of $NEFH^+$ in human dlPFC (left) and ACC (right). The lines delineated the boundaries between layers. The ISH images were downloaded from Allen Brain Atlas. f, Pearson correlation coefficients (R) between the NEFH expression pattern and the probability distribution of each L5 excitatory neuron subtypes in M1C L5.



Fig. S6 Sensitivity analysis. a, Accuracy of Pianno prediction on dlPFC samples (n=12), using marker genes randomly selected from the total marker gene list (n=10). The box bounds the interquartile range (IQR) divided by the median, with the whiskers extending to a maximum of $1.5 \times IQR$ from the box, and values beyond the whiskers are considered outliers, marked with hollow circles. b, For each dlPFC sample, the percentage of noise in the total marker list. c, Trend of accuracy of dlPFC samples (n=12) when the number of thresholds of the Multi-Otsu thresholding algorithm (N_class) increases from 1 to 5. d, Trend of the accuracy of Pianno annotation on dlPFC sample 151673 when the hyperparameters ω_1 and ω_2 in the High-Order MRF Prior Model increased from 0 to 1 with a step size of 0.01. Source data are provided as a Source Data file.