

Learning A Stroke-Based Representation for Fonts

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A. Hertzmann,² T. Funkhouser¹

1 - Princeton University

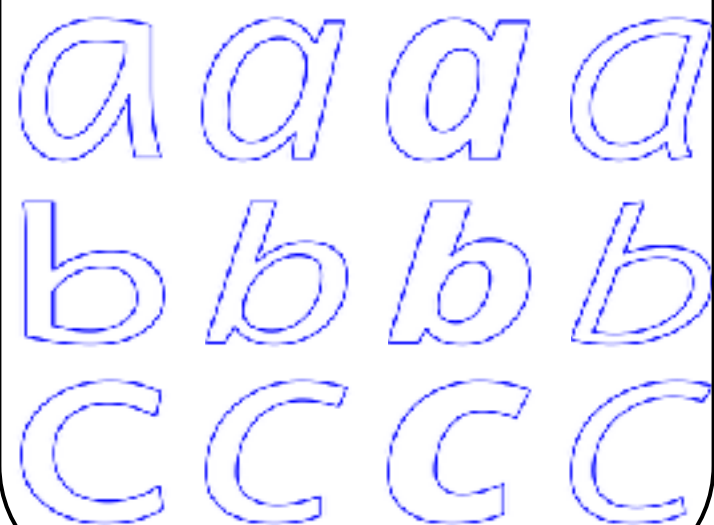
2 - Adobe Research





Goal: Stroke-Based Font Representation Suitable for Learning

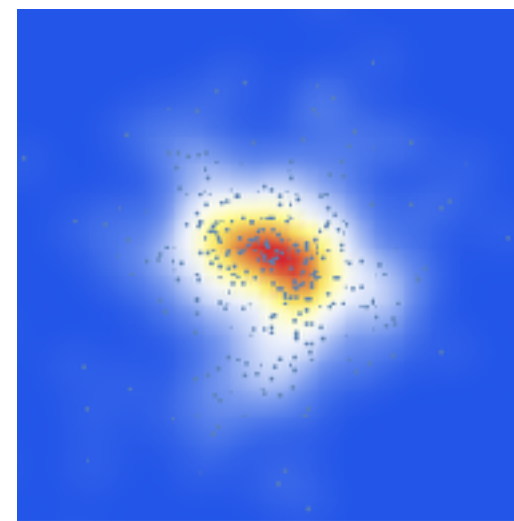
Examples:



Stroke-Based Parametrization

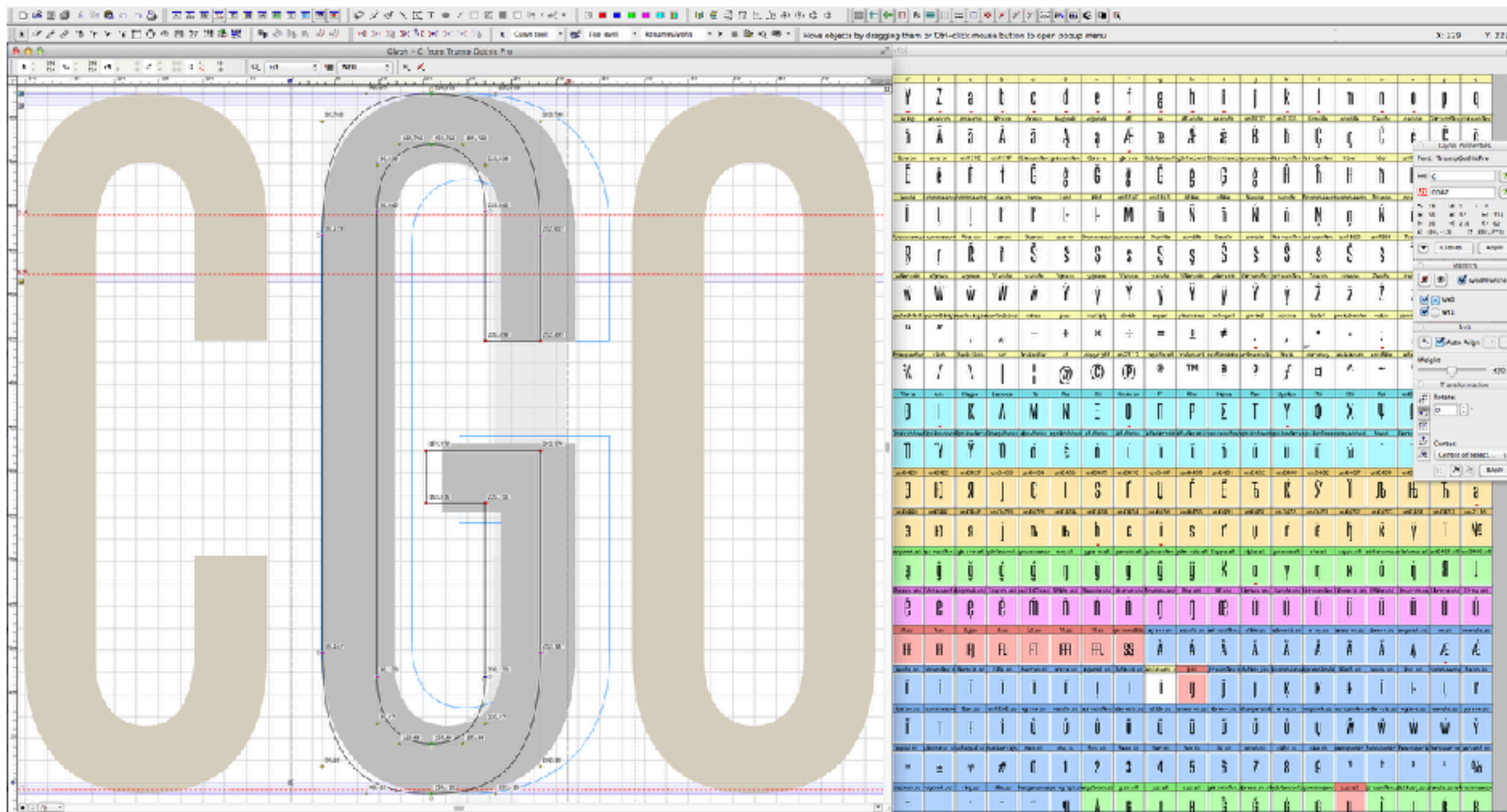


Manifold Learning:





Motivation



<https://www.fontlab.com>



Motivation



Motivation

h a n d g z o v e b c f i j k m p q r s t u w x y z
h a n d g z o v e b c f i j k m p q r s t u w x y z



Desired Font Representation Characteristics



Desired Font Representation Characteristics

- Detail-preserving





Desired Font Representation Characteristics

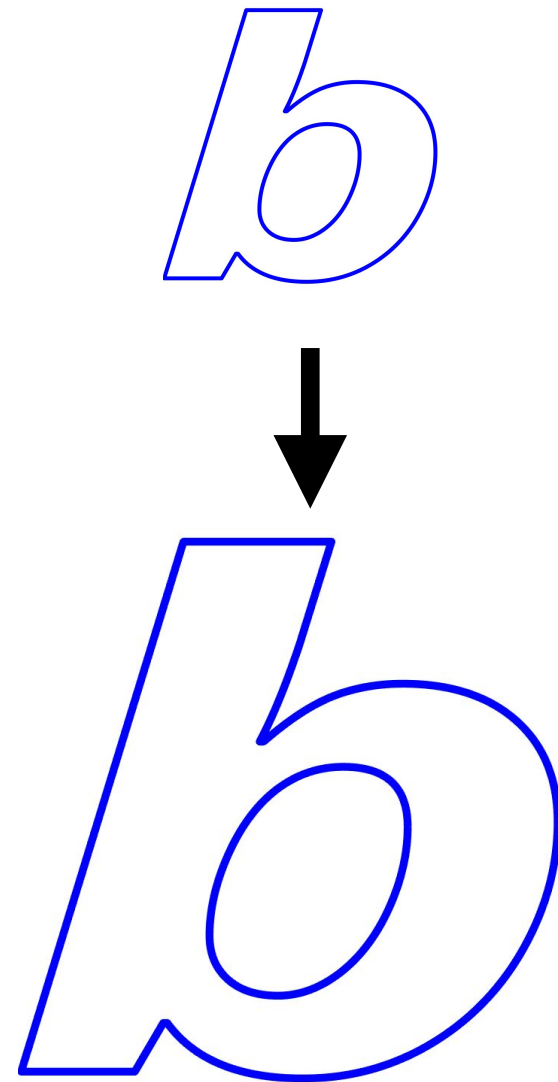
- Structure-aware





Desired Font Representation Characteristics

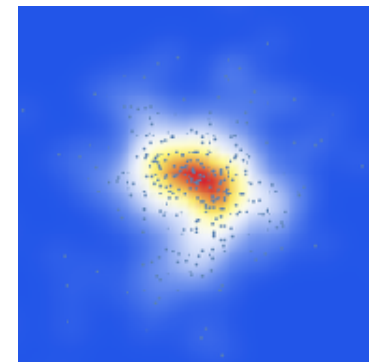
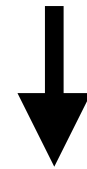
- Scales without artifacts





Desired Font Representation Characteristics

b



- Suitable for learning



Font Representations

- Raster - Based
- Contour - Based



Font Representations

Raster - Based

student

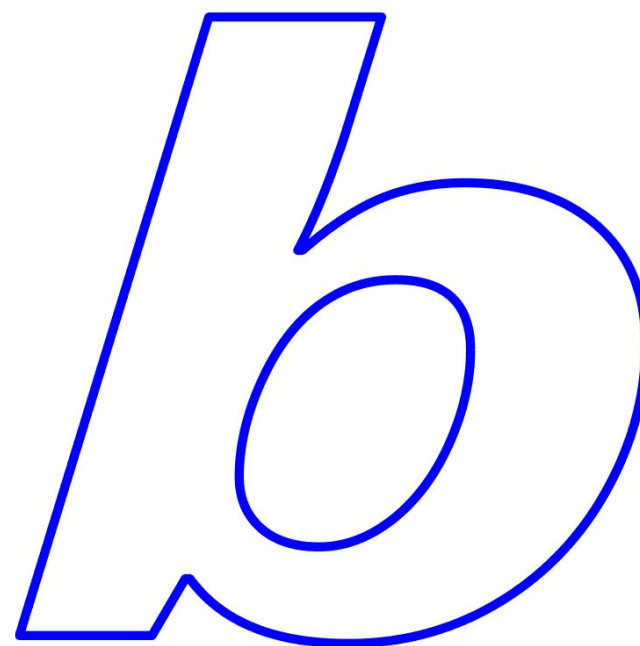
Limitations

- Scales with artifacts
- Not detail-preserving
- Not structure-aware



Font Representations

Contour-Based



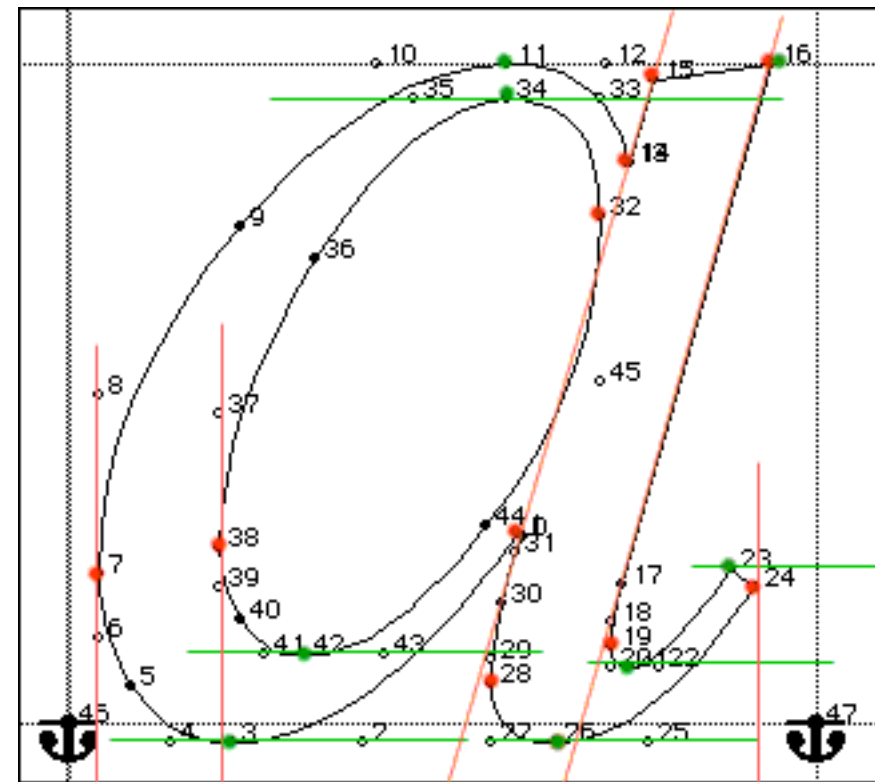


Font Representations

Bezier-Based

Limitations

- Not suitable for learning



[Microsoft Docs]

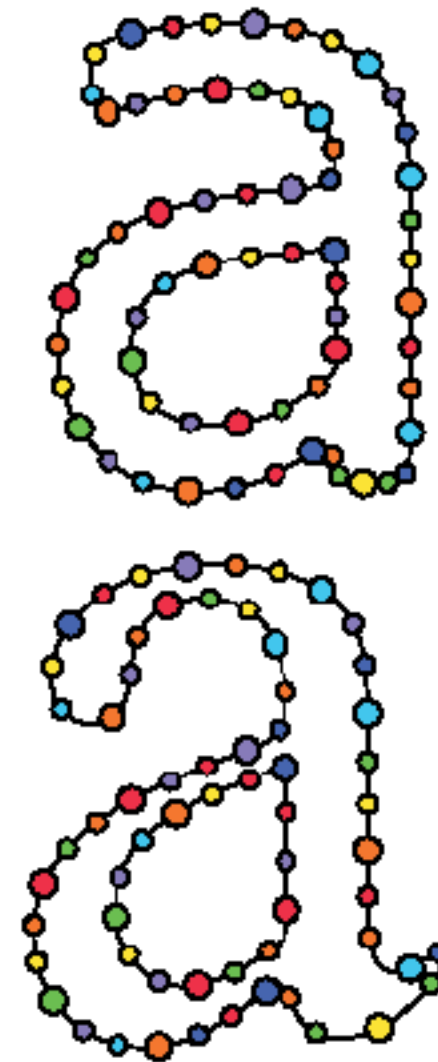


Font Representations

Consistent Outline-Based

Limitations

- Not structure-aware



[Campbell '14]

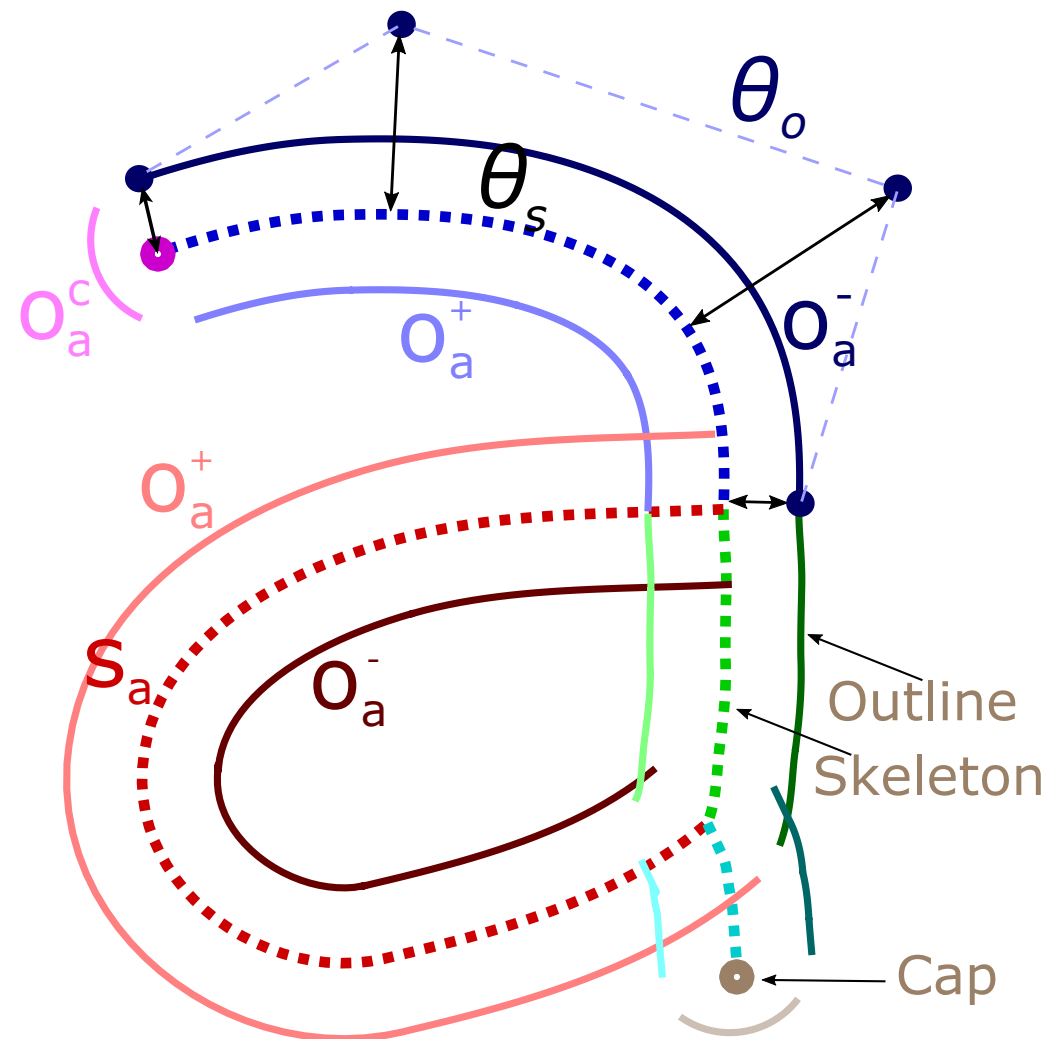


Font Representations

Proposed Representation

Characteristics

- Detail-preserving
- Structure-aware
- Scales without artifacts
- Suitable for learning



Part-Aware

Skeleton-Based Representation



Our Approach

Examples:

a a a a
b b b b
C C C C



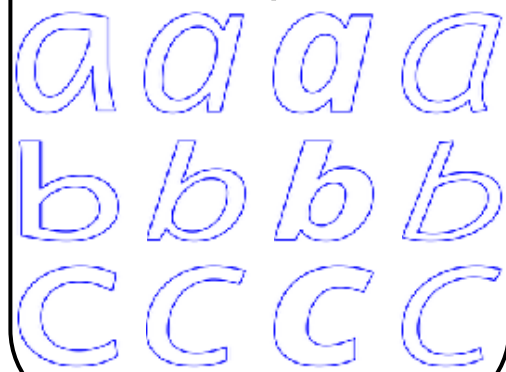
Consistency:



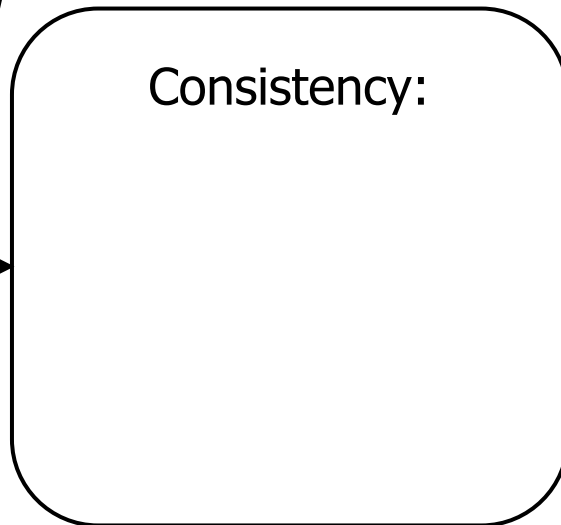
Our Approach

Template Fitting

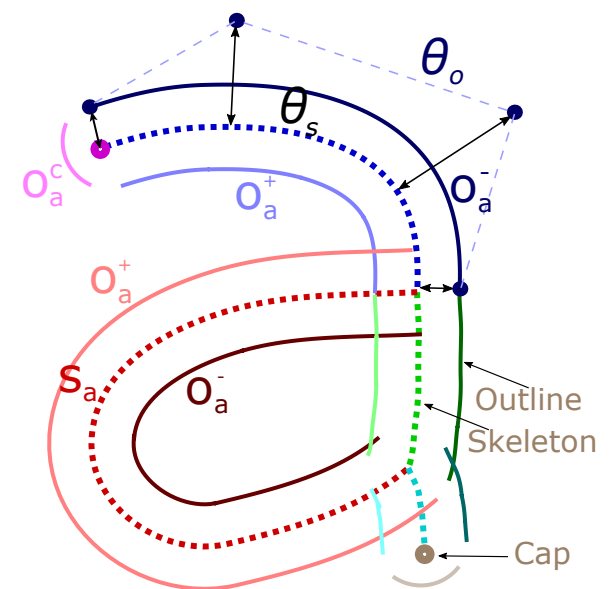
Examples:



Consistency:



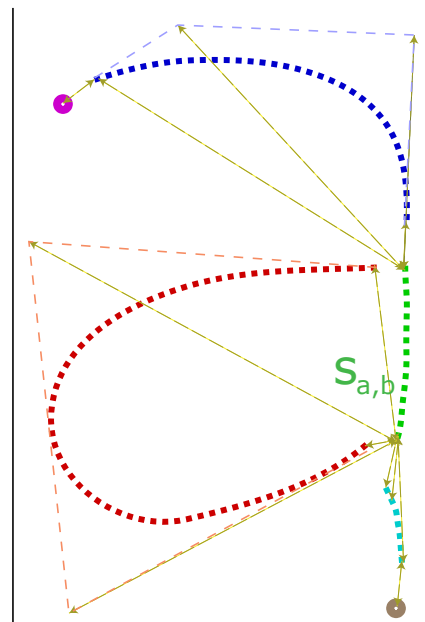
Template Definition



$$\theta_t \quad (1,1,1,0,1,0)$$

Connectivity Constraints

$$O_a^+ - O_a^+ - O_a^c - O_a^- \dots$$

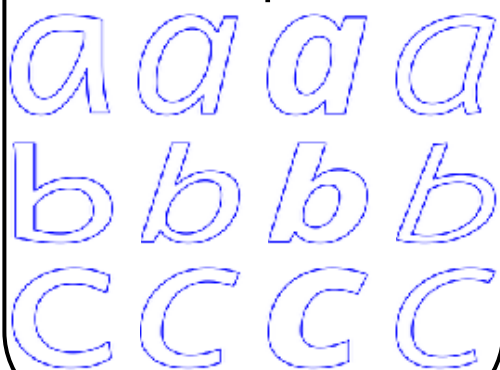




Our Approach

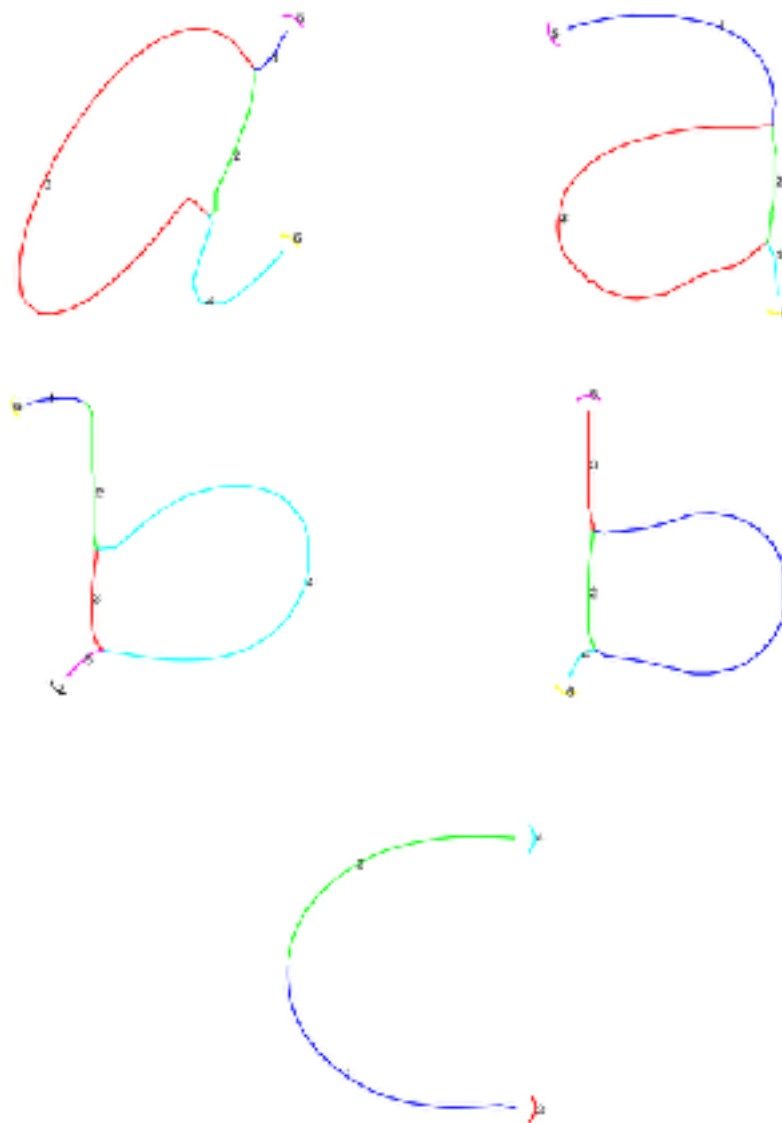
Template Fitting

Examples:



Consistency:

Template Definition





Our Approach

Template Fitting

Examples:

Consistency:

Skeleton Optimization

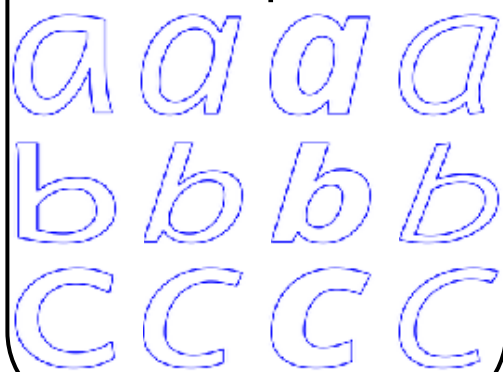
Initial Skeleton



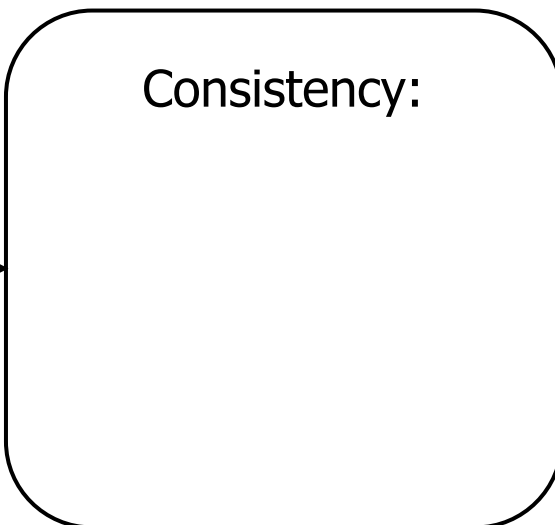
Our Approach

Template Fitting

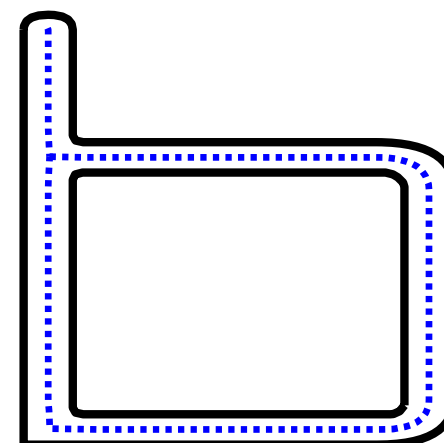
Examples:



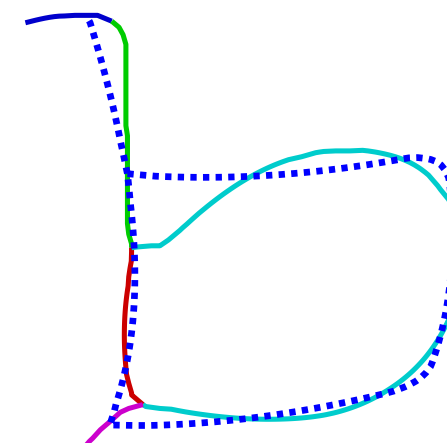
Consistency:



Skeleton Optimization



Initial Skeleton



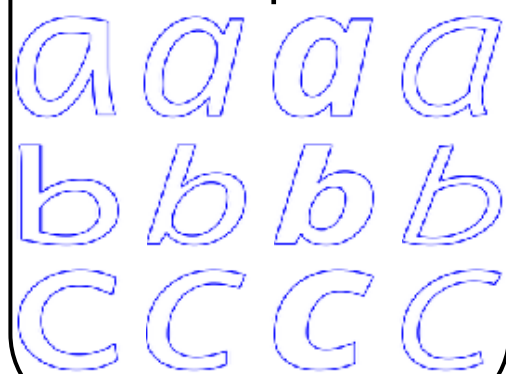
Registration



Our Approach

Template Fitting

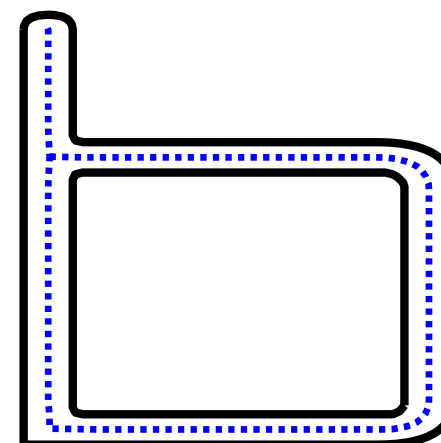
Examples:



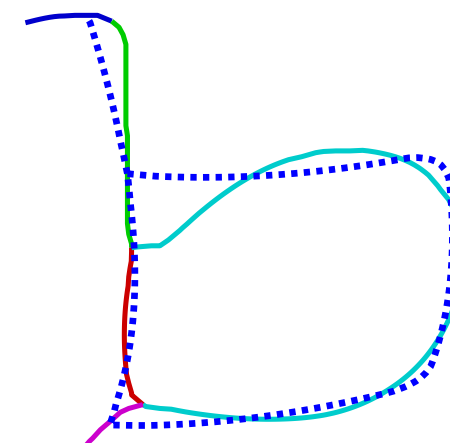
Consistency:



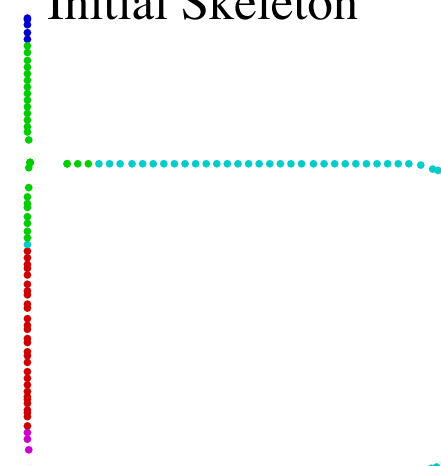
Skeleton Optimization



Initial Skeleton



Registration

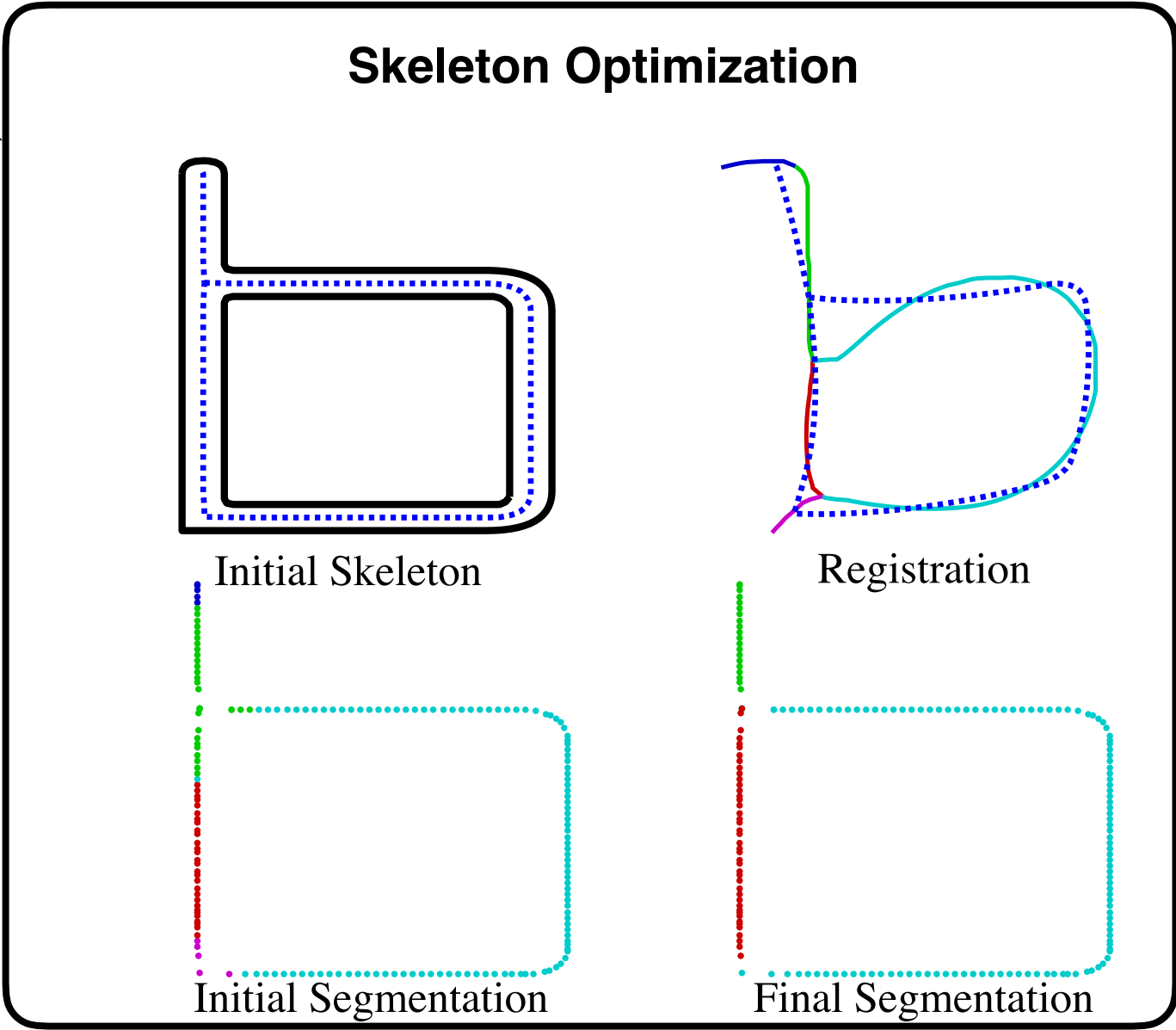
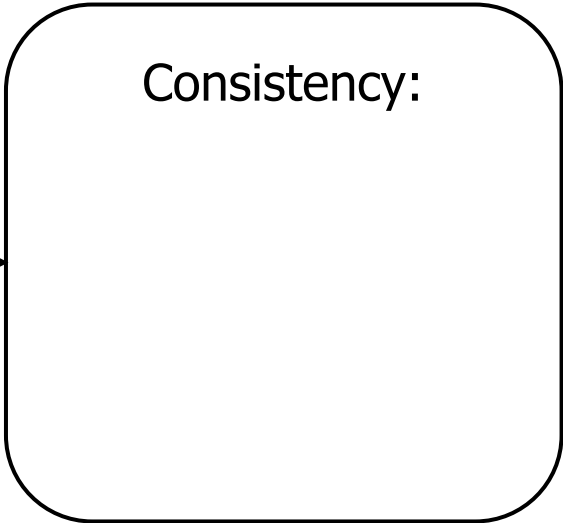
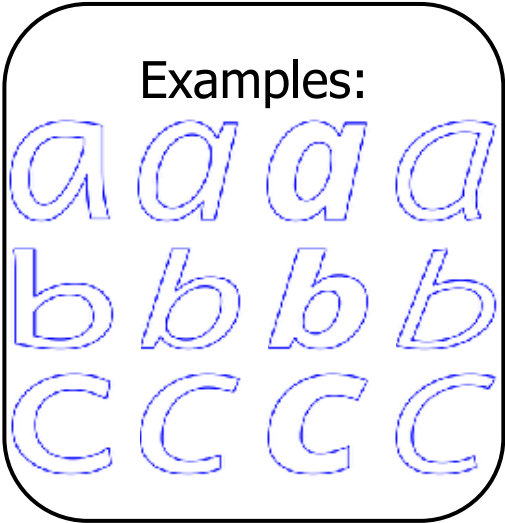


Initial Segmentation



Our Approach

Template Fitting

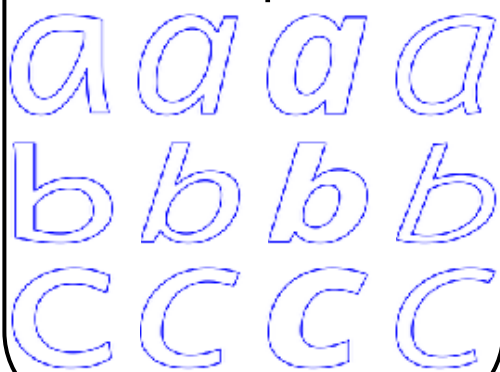




Our Approach

Template Fitting

Examples:



Consistency:

Outline Optimization

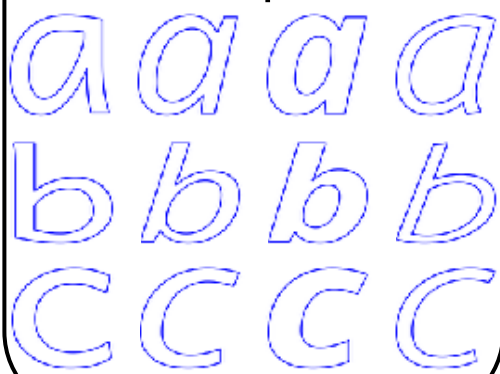
$$E = E_{\text{corr}} + E_{\text{ft}}$$



Our Approach

Template Fitting

Examples:



Consistency:

Outline Optimization

$$E = E_{\text{corr}} + E_{\text{ft}}$$

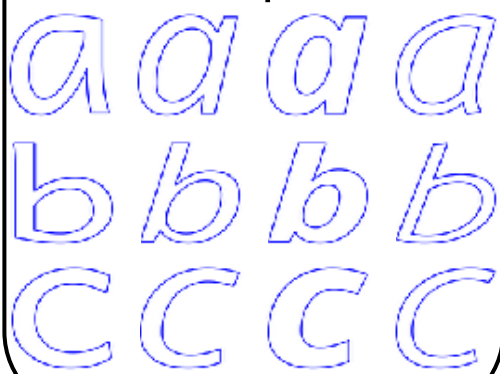
$$E_{\text{corr}}(G_{c,f}, \Theta) = \sum_{x \in P(G_{c,f})} h_{\sigma_{\text{corr}}} (D(x, O_c(\Theta))) \\ + \sum_{y \in P(O_c(\Theta))} h_{\sigma_{\text{corr}}} (D(y, G_{c,f}))$$



Our Approach

Template Fitting

Examples:



Consistency:

Outline Optimization

$$E = E_{\text{corr}} + E_{\text{ft}}$$

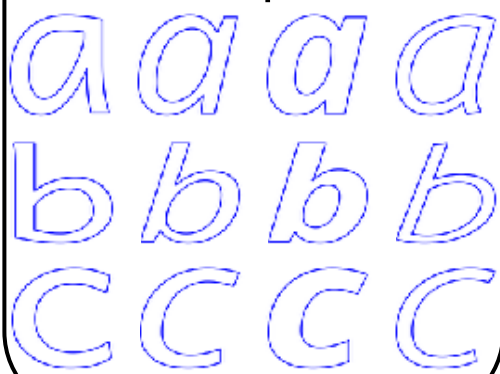
$$E_{\text{corr}}(\underset{\text{GT outline}}{G_{c,f}}, \underset{\text{template parameters}}{\Theta}) = \sum_{x \in P(\underset{\text{GT outline}}{G_{c,f}})} \underset{\text{Gaussian kernel}}{h_{\sigma_{\text{corr}}}} (\underset{\text{generated outline}}{D(x, O_c(\Theta))})$$
$$+ \sum_{y \in P(O_c(\Theta))} h_{\sigma_{\text{corr}}} (D(y, \underset{\text{dense curve sampling}}{G_{c,f}}))$$
$$x = [\underset{\text{coordinates}}{q_X}, \underset{\text{coordinates}}{q_Y}, \underset{\text{normal weight}}{w_n} \underset{\text{normal}}{n_X(q)}, \underset{\text{normal weight}}{w_n} \underset{\text{normal}}{n_Y(q)}]$$



Our Approach

Template Fitting

Examples:



Consistency:

Outline Optimization

$$E = E_{\text{corr}} + E_{\text{ft}}$$

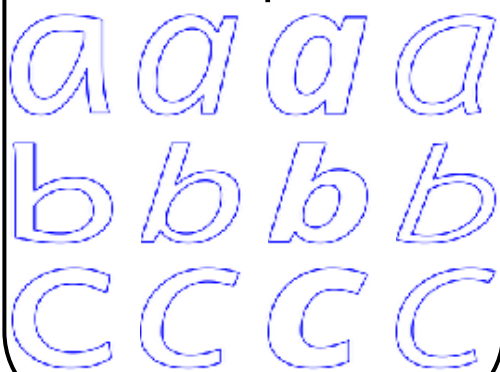
$$E_{\text{ft}}(G_{c,f}, \Theta) = \sum_{x \in F(O_c(\Theta))} D_{\text{curve}}(x, F_{\tau_{\text{ft}}}(G_{c,f}))$$



Our Approach

Template Fitting

Examples:



Consistency:

Outline Optimization

$$E = E_{\text{corr}} + E_{\text{ft}}$$

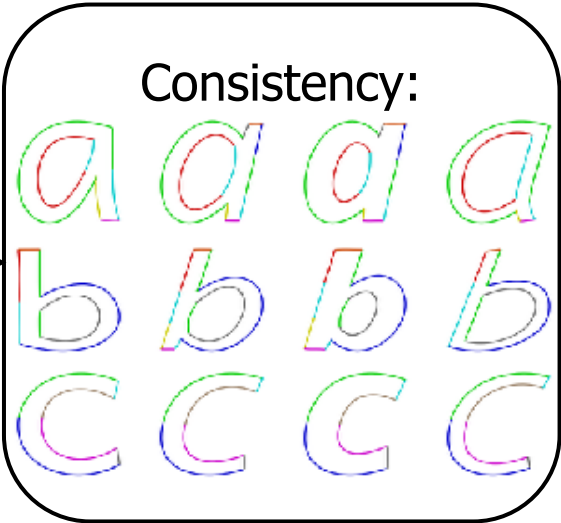
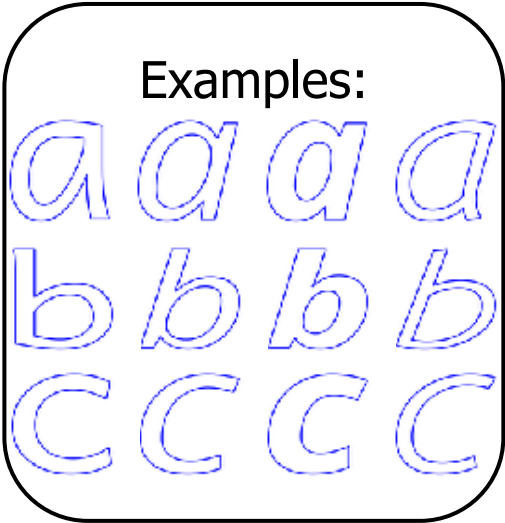
$$E_{\text{ft}}(\underset{\text{GT outline}}{G_{c,f}}, \underset{\text{template parameters}}{\Theta}) = \sum_{\underset{\text{set of feature points}}{x \in F(O_c(\Theta))}} \underset{\text{arc-length intrinsic distance}}{D_{\text{curve}}(x, F_{\tau_{\text{ft}}}(G_{c,f}))}$$

subset of junction points near feature point

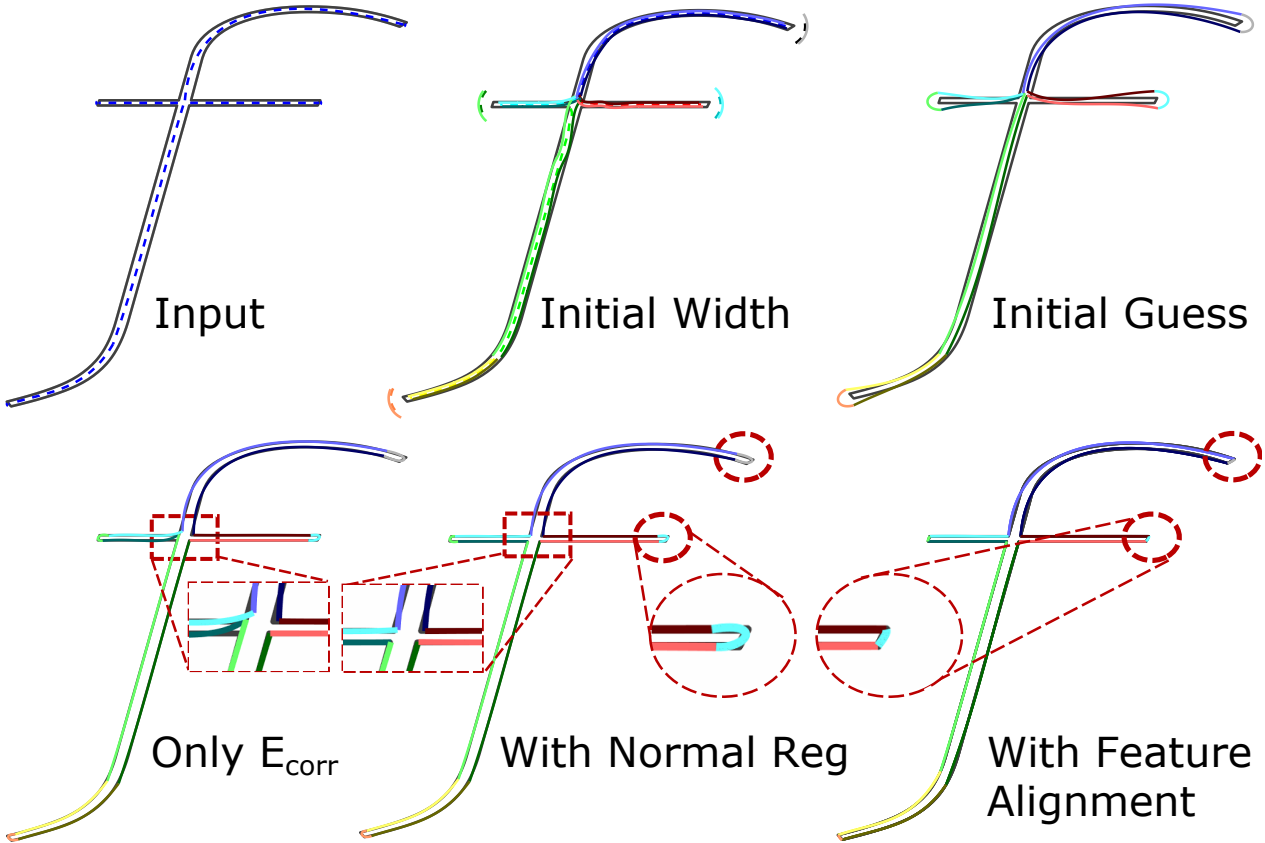


Our Approach

Template Fitting

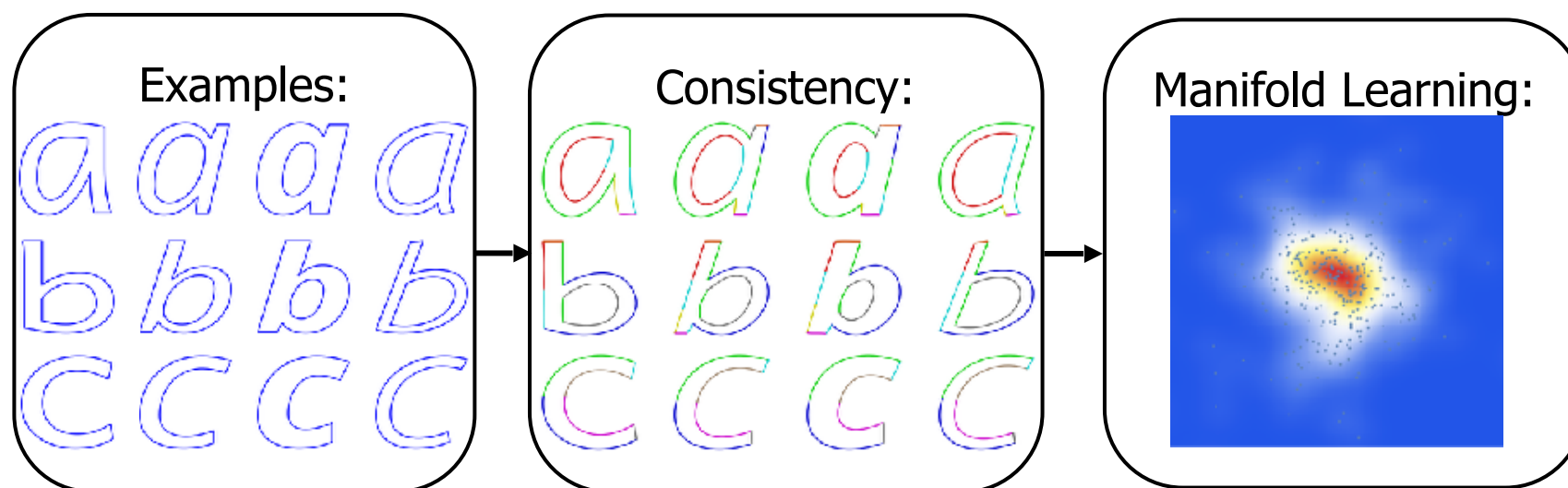


Outline Optimization



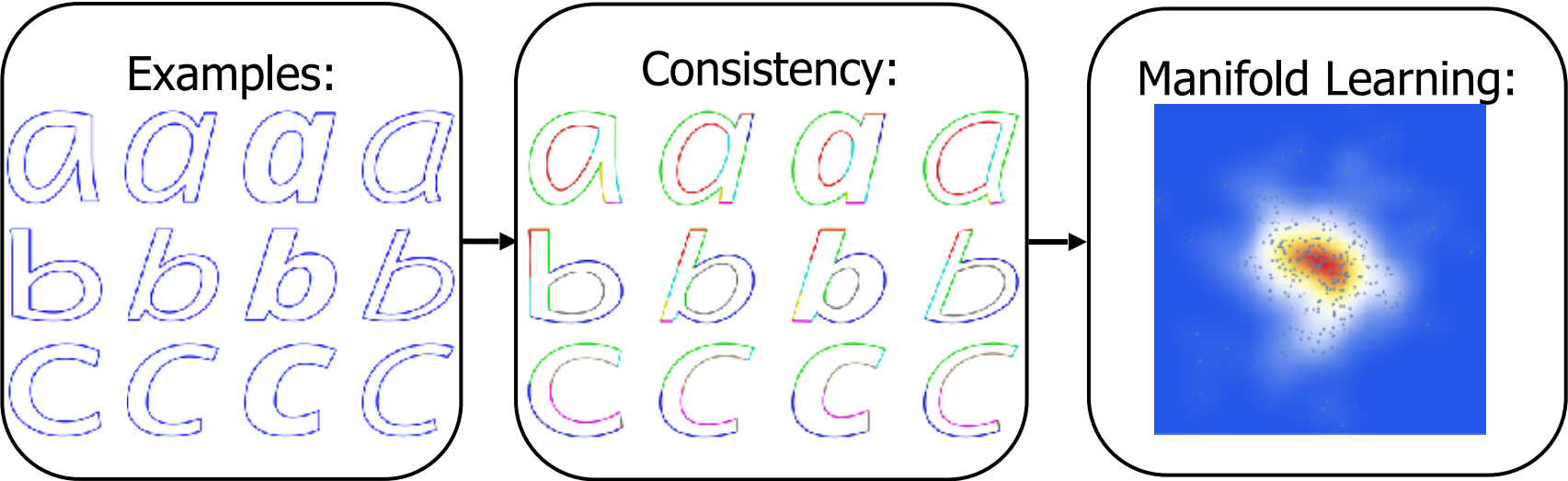


Our Approach


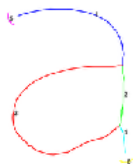




Our Approach

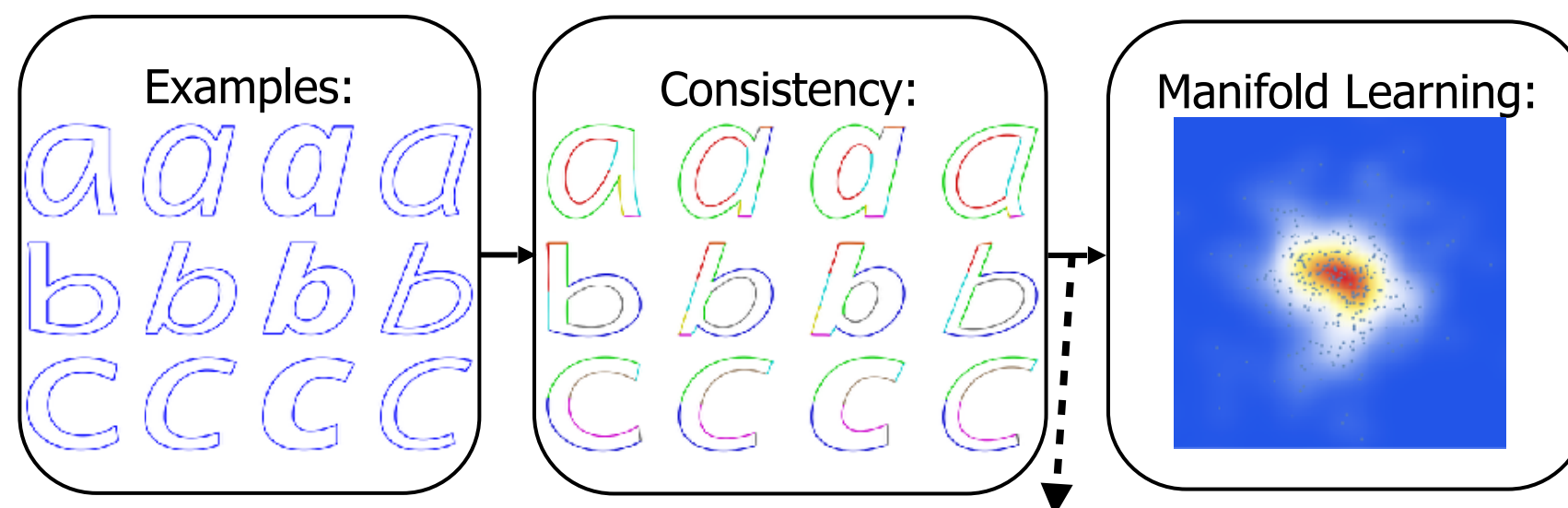


$$f = [f_{a_1} \overset{\text{NaN}}{\cancel{f_{a_2}}} \dots]$$



Our Approach



EM-PCA

[Row98]

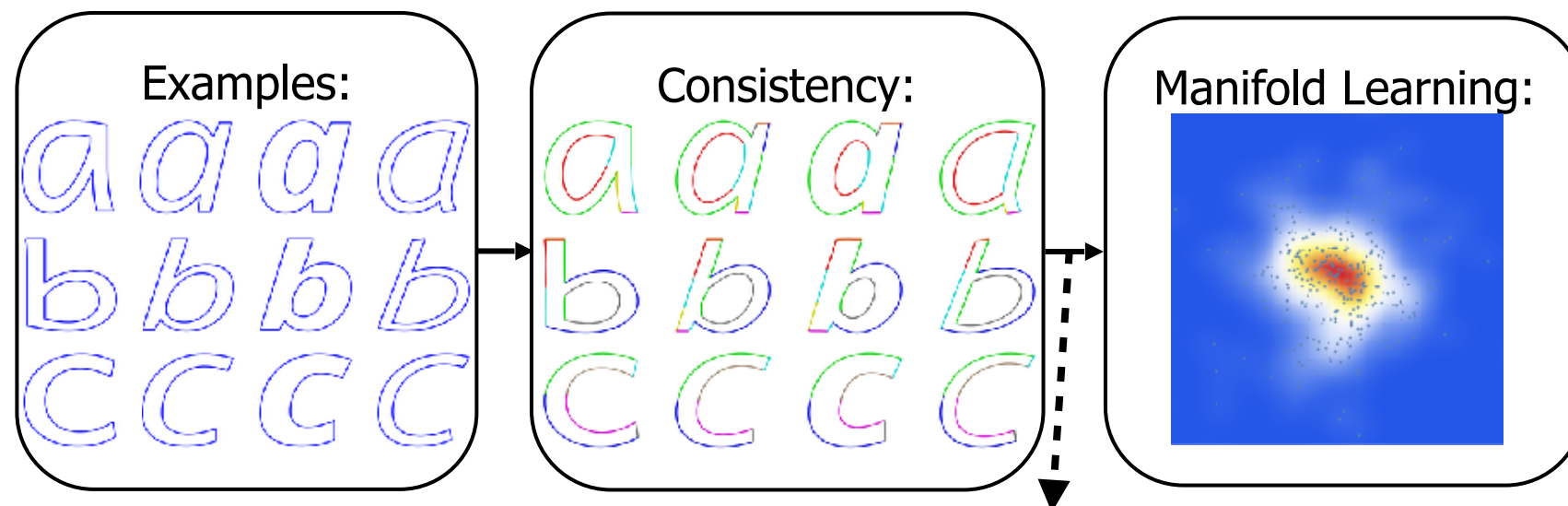
Input Latent
Vectors coordinates

$$Y = CX + V$$

Transformation Noise
Matrix



Our Approach



EM-PCA

[Row98]

Input Vectors Latent coordinates

$$Y = CX + V$$

Transformation Matrix Noise

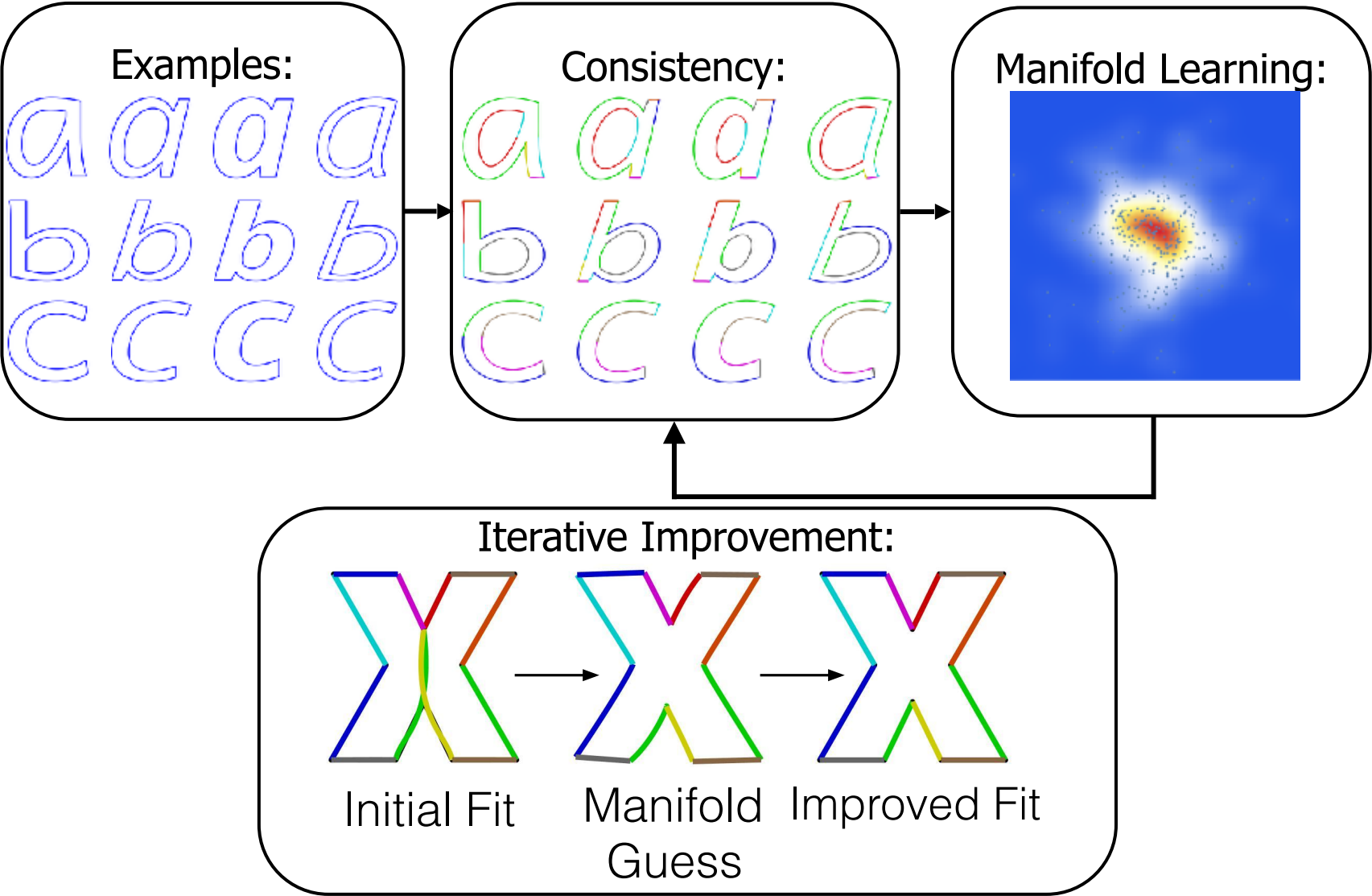
Learning Steps:

E-step: $X = (C^T C)^{-1} C^T Y$

M-step: $C^{new} = Y X^T (X X^T)^{-1}$



Our Approach

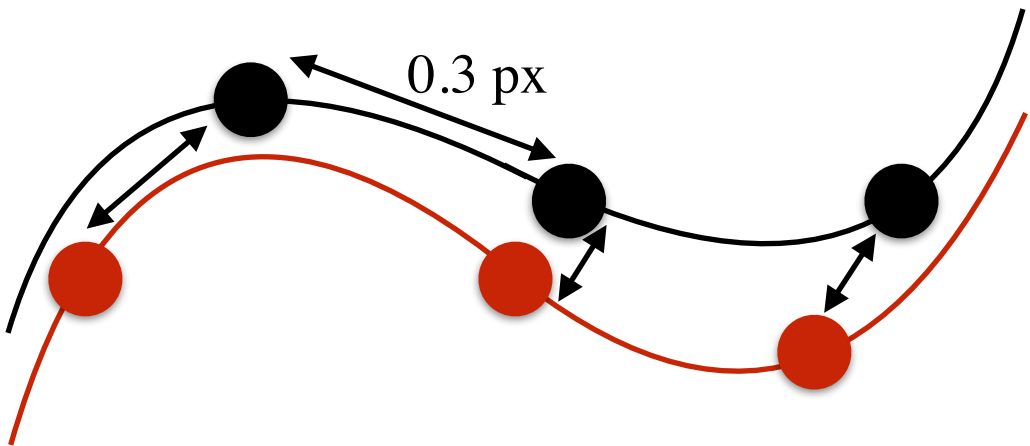
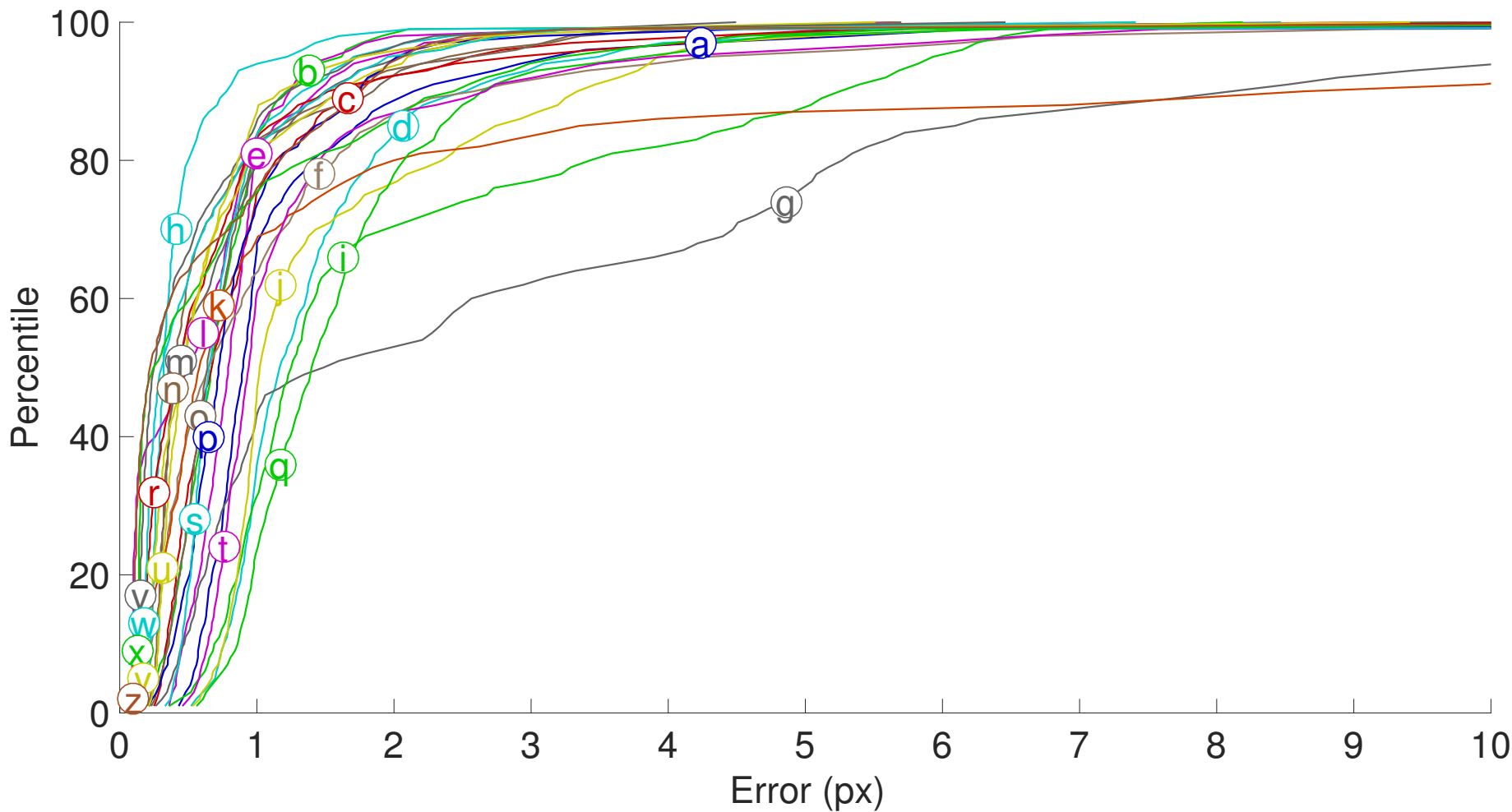




Fitting Results

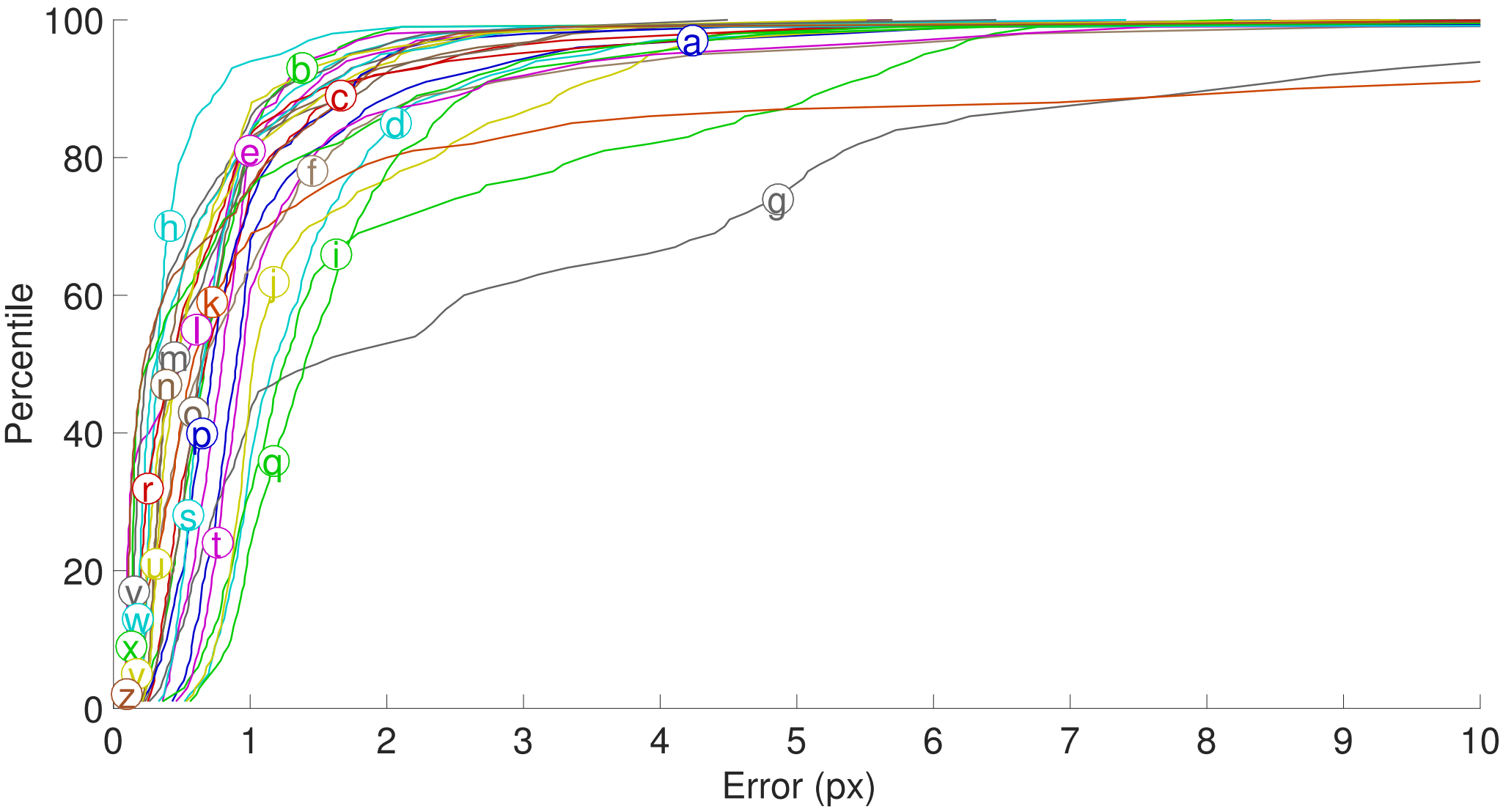


Fitting Results





Fitting Results



Error: 0.52



Error: 0.99



Error: 1.96



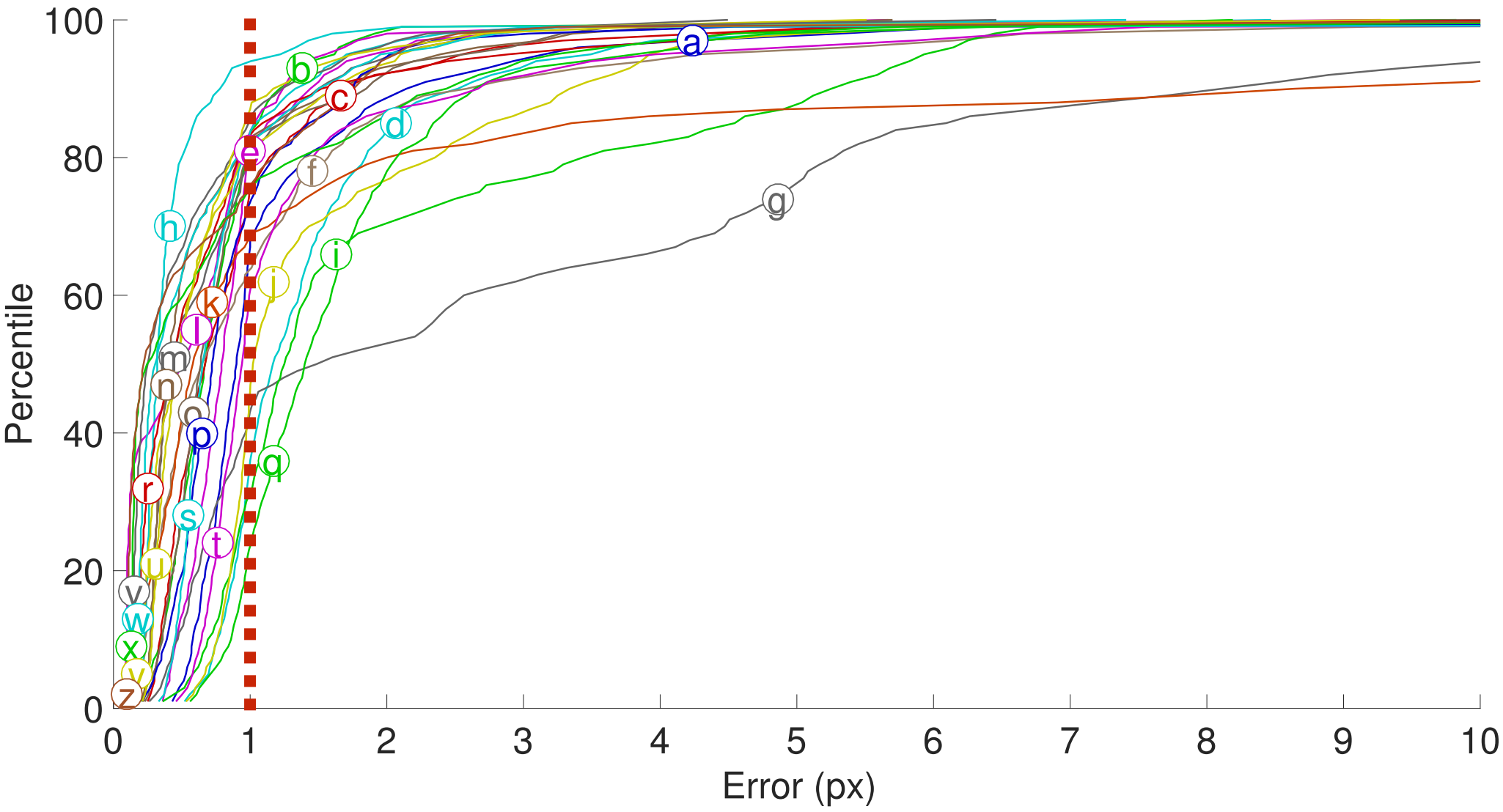
Error: 3.49



Error: 8.54



Fitting Results



Error: 0.52



Error: 0.99



Error: 1.96



Error: 3.49



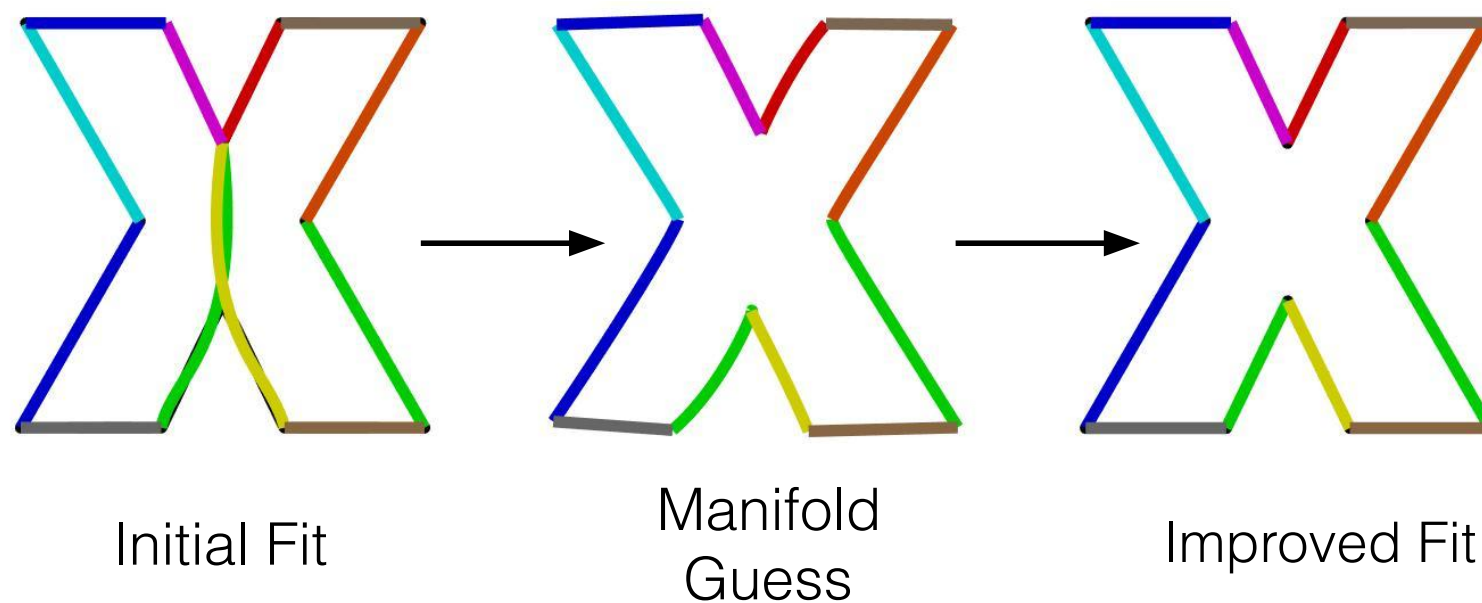
Error: 8.54



Iterative Improvement Evaluation

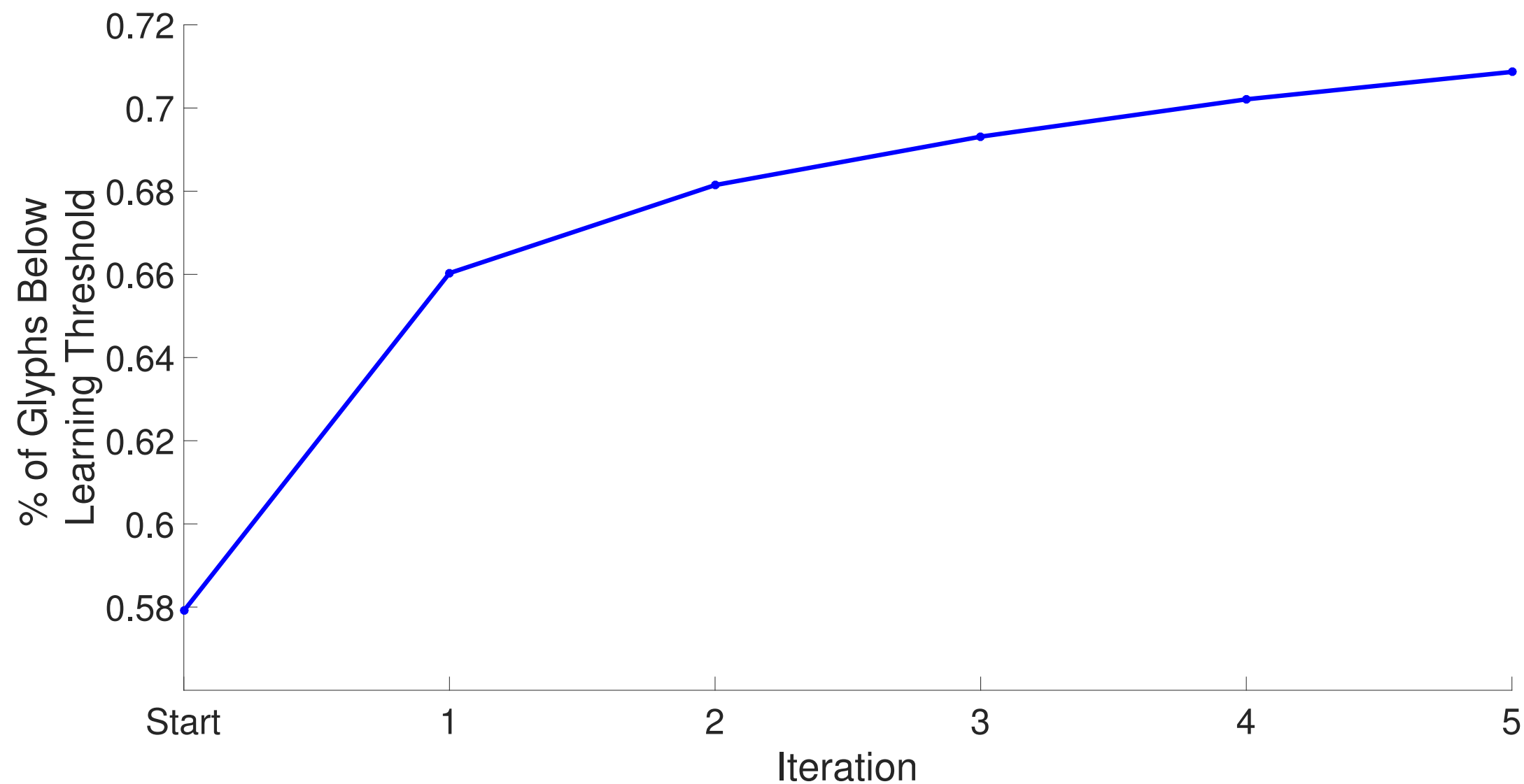


Iterative Improvement Evaluation



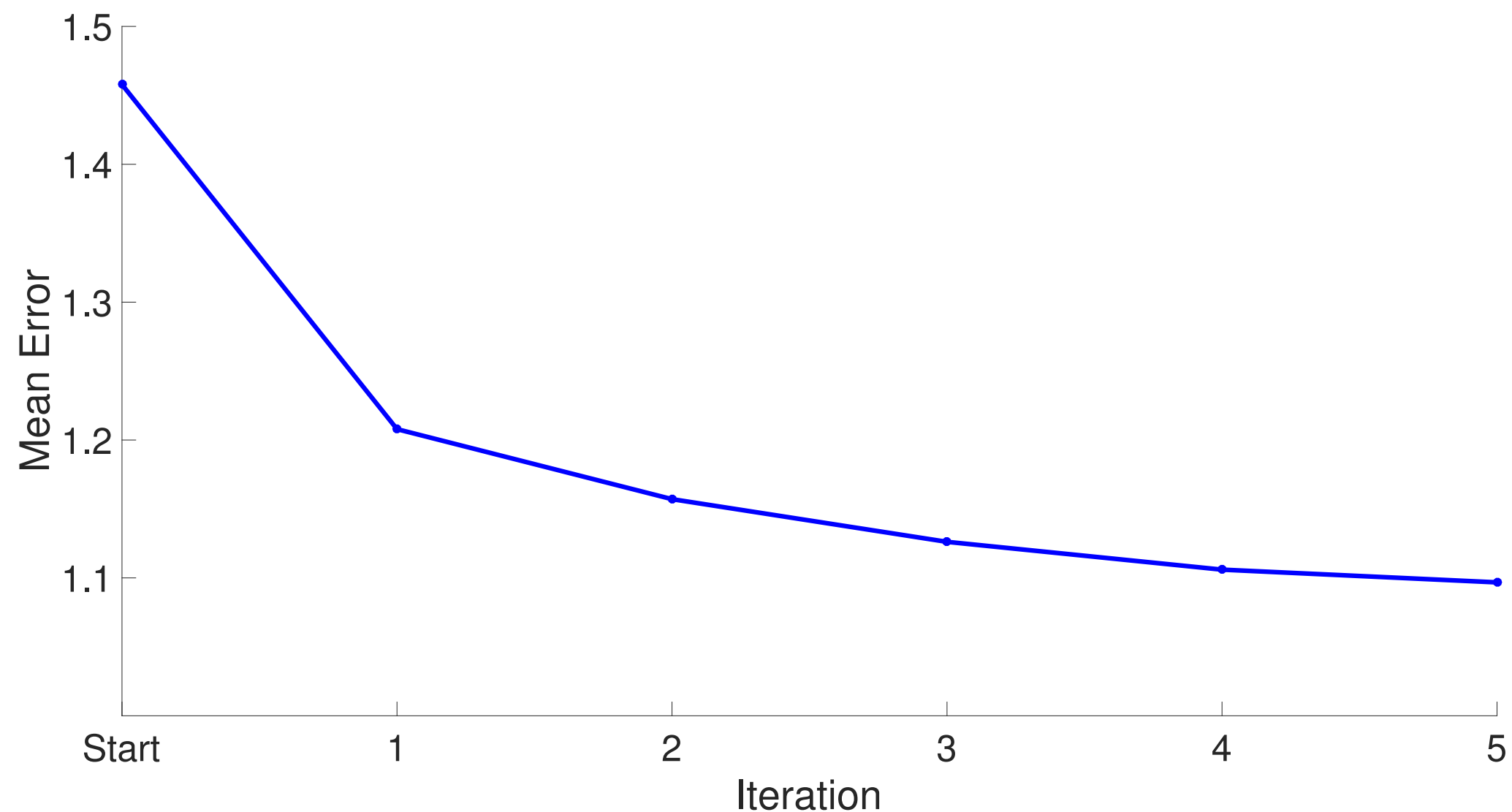


Iterative Improvement Evaluation





Iterative Improvement Evaluation





Comparison to Non-Part-Aware Approach



Comparison to Non-Part-Aware Approach

hhhhhhhhhh

Part-Based Representation



Comparison to Non-Part-Aware Approach

hhhhhhhhhh

Part-Based Representation

hhhhhhhhhh

Single Contour Representation[CK14]

hhhhhh

Part-Based Representation

hhhhhh

Single Contour Representation[CK14]



Comparison to Non-Part-Aware Approach

hhhhhhhhhh

Part-Based Representation

hhhhhhhhhh

Raster-Based

hhhhhh

Part-Based Representation

hhhhhh

Raster-Based



Comparison to Non-Part-Aware Approach

hhhhhhhhhh

Part-Based Representation

hhhhhhhhhh

Single Contour Representation[CK14]

hhhhhhhhhh

Raster-Based

hhhhhh

Part-Based Representation

hhhhhh

Single Contour Representation[CK14]

hhhhhh

Raster-Based



Generative Model Comparison



Generative Model Comparison

hhhhhhhhhhhhhhhh

EM-PCA

hhhhhhhhhhhhhhhh

Denoising VAE

hhhhhhhhhhhhhhhh

Vanilla VAE

hhhhhh

EM-PCA

hhhhhh

Denoising VAE

hhhhhh

Vanilla VAE



Generative Model Comparison

hhhhhhhhhh

EM-PCA

hhhhhhhhhh

Denoising VAE

hhhhhh

EM-PCA

hhhhhh

Denoising VAE



Applications

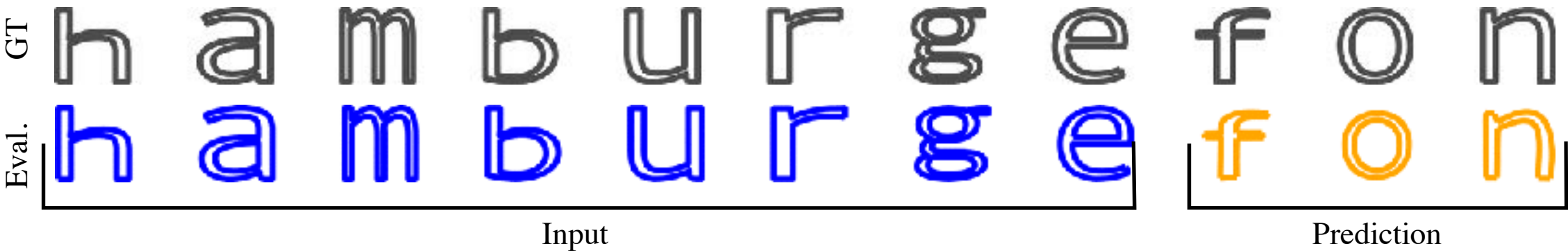


Style Completion



Style Completion: Light Fonts

MerriweatherSans-Light



Exo-Light





Style Completion: Regular/Bold Fonts

Nobile-BoldItalic

GT	<i>h</i>	<i>a</i>	<i>m</i>	<i>b</i>	<i>u</i>	<i>r</i>	<i>g</i>	<i>e</i>	<i>f</i>	<i>o</i>	<i>n</i>
Eval.	<i>h</i>	<i>a</i>	<i>m</i>	<i>b</i>	<i>u</i>	<i>r</i>	<i>g</i>	<i>e</i>	<i>f</i>	<i>o</i>	<i>n</i>
	Input								Prediction		

DoppioOne-Regular

GT	h	a	m	b	u	r	g	e	f	o	n
Eval.	h	a	m	b	u	r	g	e	f	o	n
	Input								Prediction		



Style Completion: Italic Fonts

Nobile-BoldItalic

GT	<i>h</i>	<i>a</i>	<i>m</i>	<i>b</i>	<i>u</i>	<i>r</i>	<i>g</i>	<i>e</i>	<i>f</i>	<i>o</i>	<i>n</i>
Eval.	<i>h</i>	<i>a</i>	<i>m</i>	<i>b</i>	<i>u</i>	<i>r</i>	<i>g</i>	<i>e</i>	<i>f</i>	<i>o</i>	<i>n</i>

Input

Prediction

MinionPro-It

GT	<i>h</i>	<i>a</i>	<i>m</i>	<i>b</i>	<i>u</i>	<i>r</i>	<i>g</i>	<i>e</i>	<i>f</i>	<i>o</i>	<i>n</i>
Eval.	<i>h</i>	<i>a</i>	<i>m</i>	<i>b</i>	<i>u</i>	<i>r</i>	<i>g</i>	<i>e</i>	<i>f</i>	<i>o</i>	<i>n</i>

Input

Prediction



Style Completion: Serif Fonts

Amethysta-Regular

GT	h	a	m	b	u	r	g	e	f	o	n
Eval.	h	a	m	b	u	r	g	e	f	o	n
	Input								Prediction		

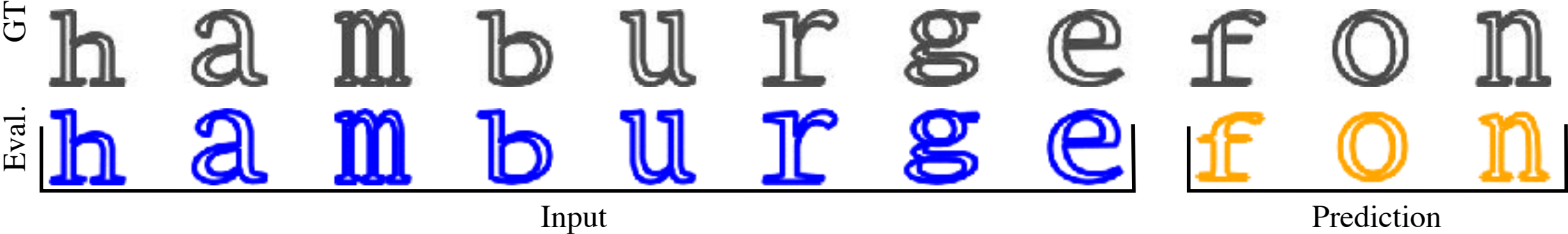
Oldenburg-Regular

GT	h	a	m	b	u	r	g	e	f	o	n
Eval.	h	a	m	b	u	r	g	e	f	o	n
	Input								Prediction		

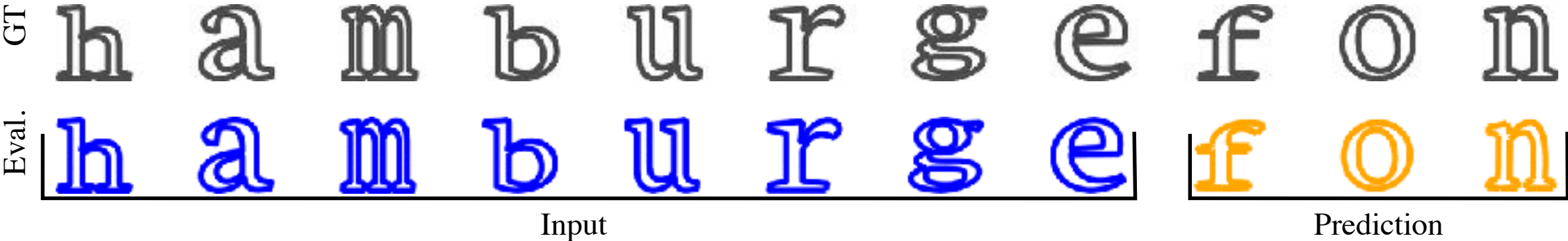


Style Completion: Serif Fonts

Neuton Light



Neuton Regular





Style Completion



Style Completion

h a n d g z o v e b c f i j k m p q r s t u w x y z



Style Completion

h a n d g z o v e b c f i j k m p q r s t u w x y z
h a n d g z o v e b c f i j k m p q r s t u w x y z



Style Completion

h a n d g z o v e b c f i j k m p q r s t u w x y z
h a n d g z o v e b c f i j k m p q r s t u w x y z
h a n d g z o v e b c f i j k m p q r s t u w x y z



Style Completion

h a n d g z o v e b c f i j k m p q r s t u w x y z
h a n d g z o v e b c f i j k m p q r s t u w x y z
h a n d g z o v e b c f i j k m p q r s t u w x y z
h a n d g z o v e b c f i j k m p q r s t u w x y z



Style Completion

h a n d g z o v e b c f i j k m p q r s t u w x y z
h a n d g z o v e b c f i j k m p q r s t u w x y z
h a n d g z o v e b c f i j k m p q r s t u w x y z
h a n d g z o v e b c f i j k m p q r s t u w x y z
h a n d g z o v e b c f i j k m p q r s t u w x y z





handgzovebcfzjkmpqrstuwx y z



A 3D visualization of a 26x8 grid of characters. The characters are arranged in 8 rows and 26 columns. The color of the characters transitions from blue on the left to orange on the right, with a gradient across the entire grid. The characters are rendered in a 3D font style, giving the grid a sense of depth.



[illegible]

[illegible]

[illegible]

[illegible]

[illegible]



[illegible]



A grid of 16 rows of the sentence "handgloveabcdefjklmpqrstuvwxy z". Each row contains the same sequence of letters, but one letter is highlighted in orange in each row, while the others are blue. The highlighted letters progress from right to left across the rows.

Row	Highlighted Letter
1	z
2	y
3	x
4	w
5	v
6	u
7	t
8	s
9	r
10	q
11	p
12	m
13	k
14	j
15	i
16	f

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]



handglovebcfijklmnpqrstuvwxyza

[illegible]

[illegible]



Font Retrieval



Font Retrieval

Query Font: Ubuntu-Light

h a m b U r g e f o n

Nearest Neighbor: Ubuntu

h a m b U r g e f o n

Farthest Font: Dosis-ExtraLight

h a m b U r g e f o n



Topology-Aware Retrieval

Query Font: Ubuntu-Light

h a m b U r g e f o n

Nearest Neighbor: Ubuntu

h a m b U r g e f o n

Farthest Font: Dosis-ExtraLight

h a m b U r g e f o n

Nearest Serifed Font: AnticSlab-Regular

h a m b u r g e f o n



Topology-Aware Retrieval

Query Font: Ubuntu-Light

h a m b U r g e f o n

Nearest Neighbor: Ubuntu

h a m b U r g e f o n

Farthest Font: Dosis-ExtraLight

h a m b U r g e f o n

Nearest Serifed Font: AnticSlab-Regular

h a m b u r g e f o n

Nearest Font With Topology 1 of a: Inder-Regular

h a m b U r g e f o n

Nearest Font With Topology 2 of a: Ubuntu

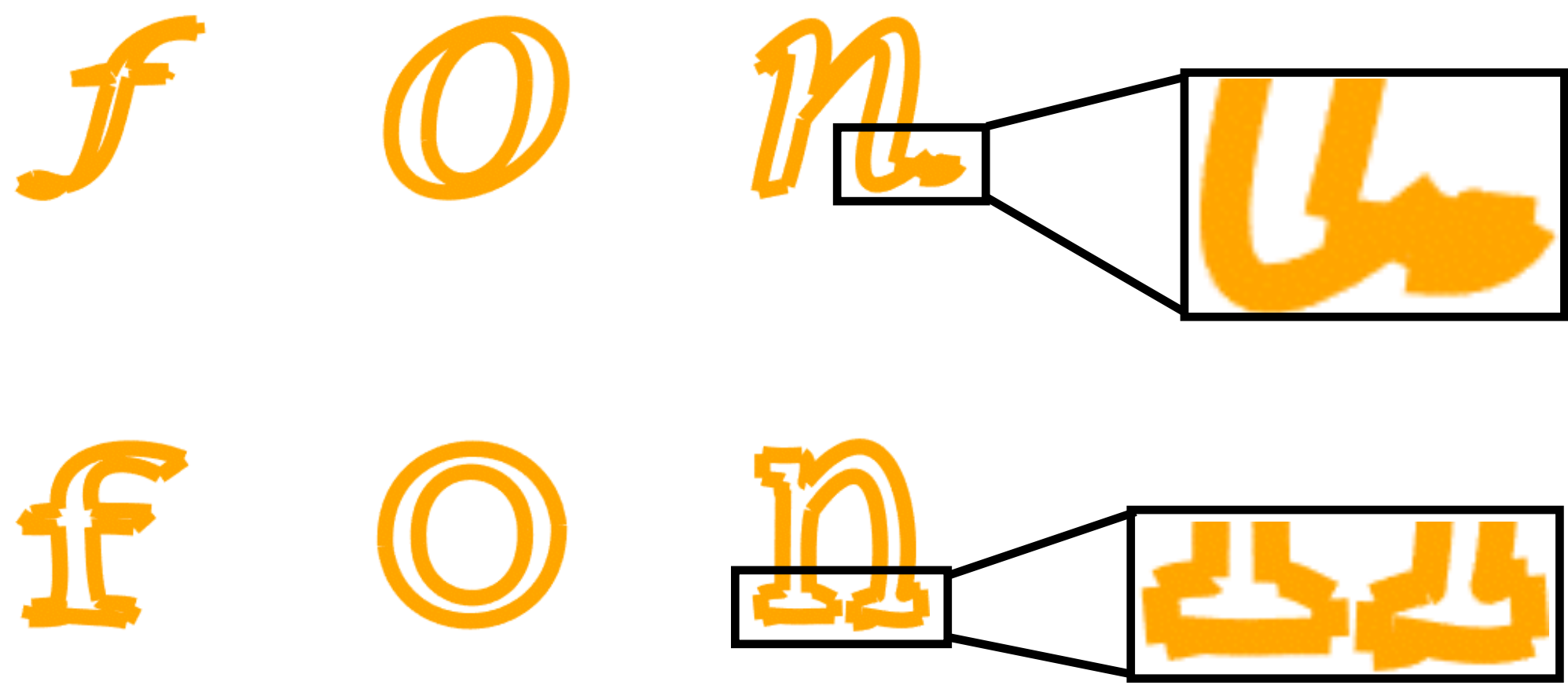
h a m b U r g e f o n



Limitations



Limitations





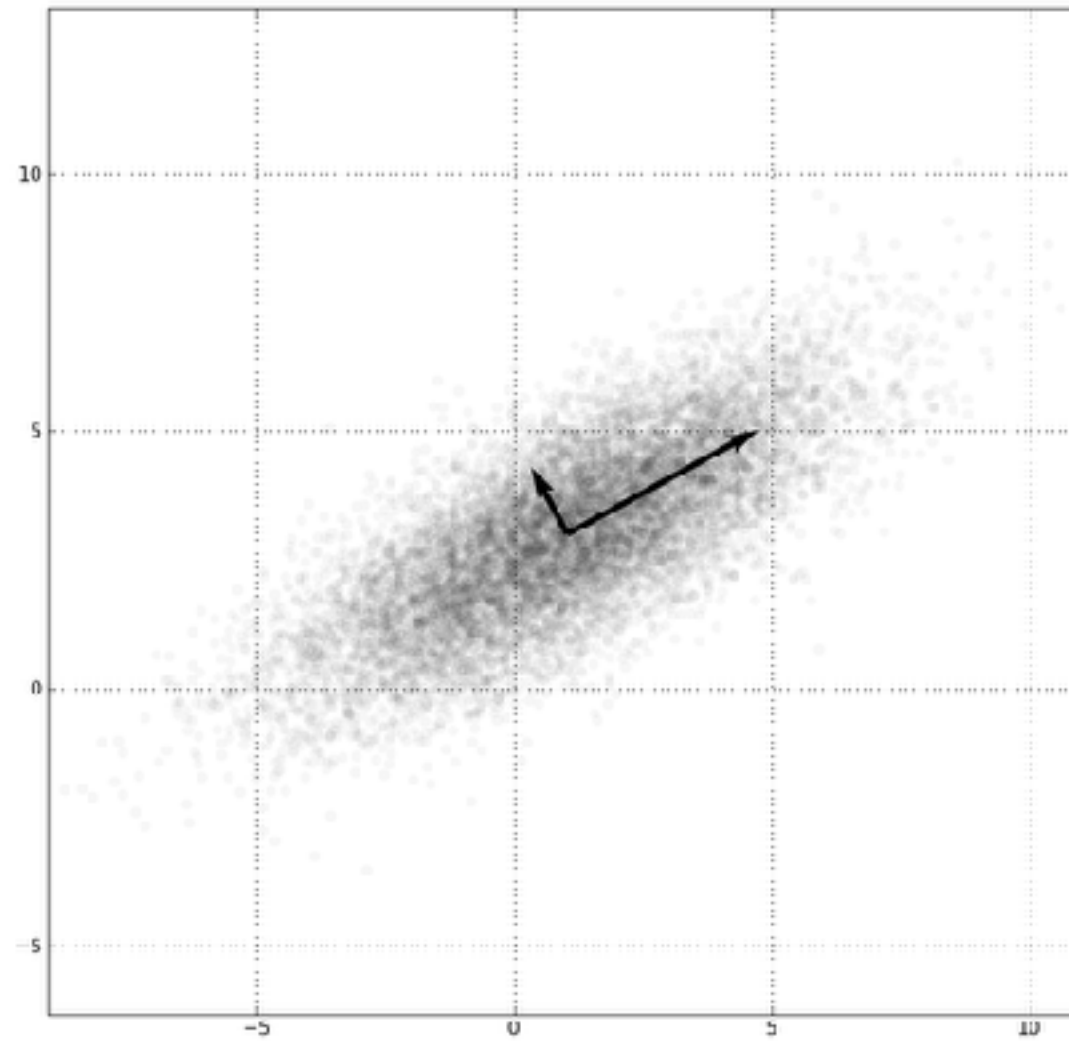
Limitations



[<https://design.google>]



Limitations



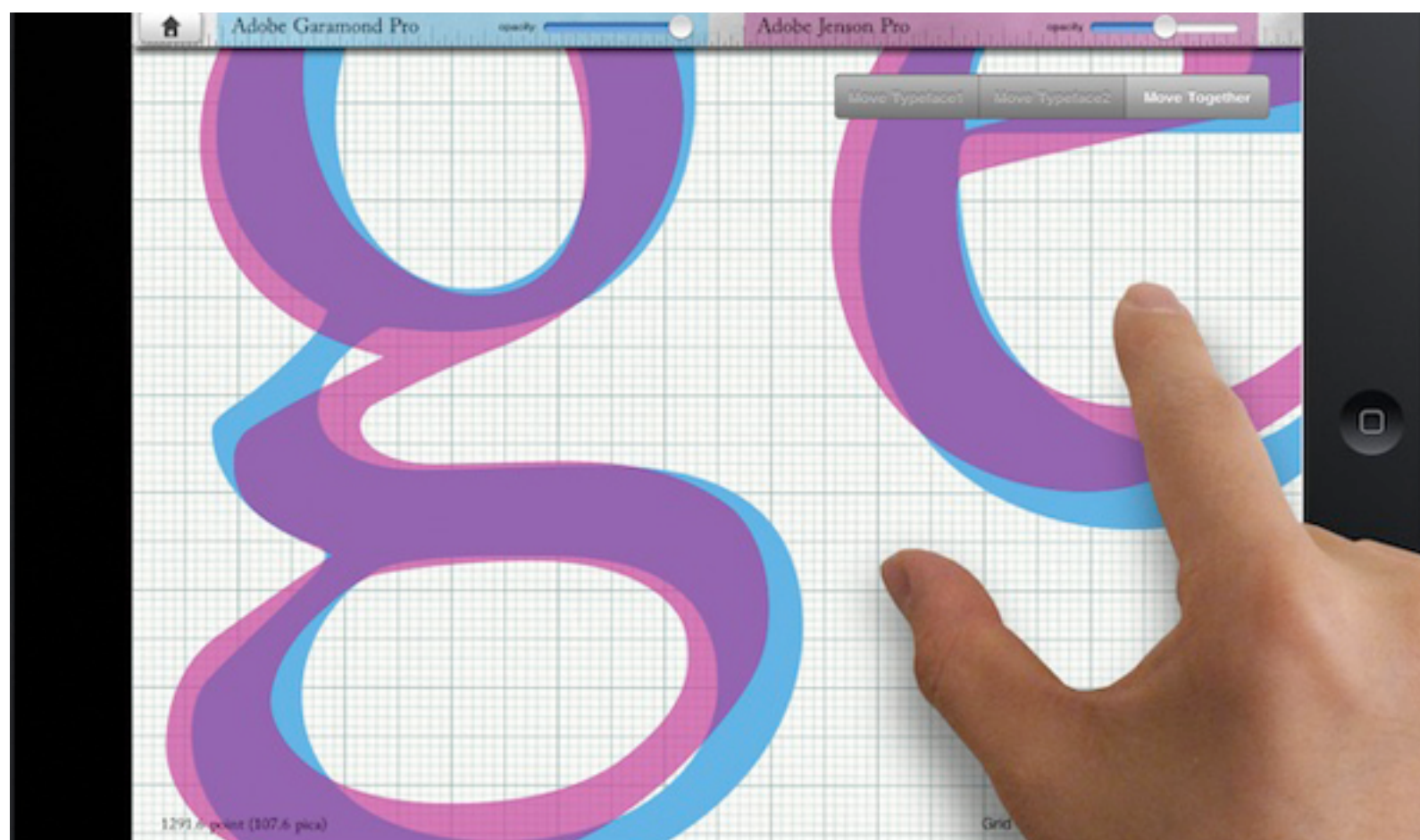
[<https://inventingsituations.net>]



Future Work



Future Work



[<https://www.theatlantic.com>]



Future Work

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Future Work



[Nejati '16]



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