

# Learning A Stroke-Based Representation for Fonts

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A. Hertzmann<sup>2</sup>, T. Funkhouser<sup>1</sup>

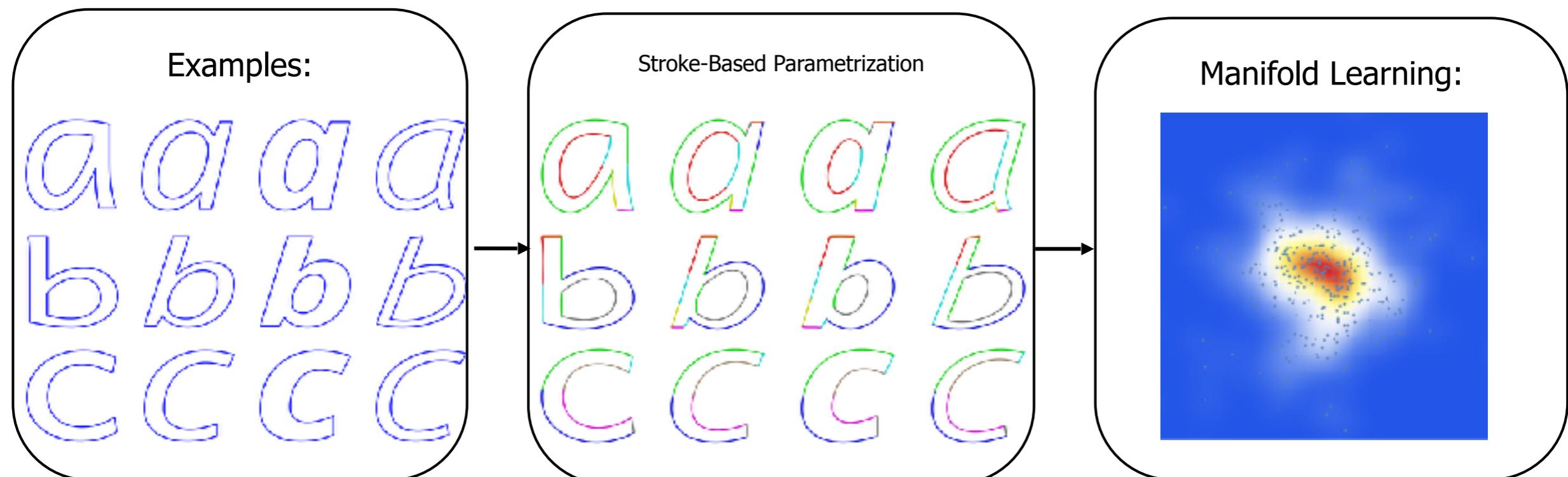
1 - Princeton University

2 - Adobe Research



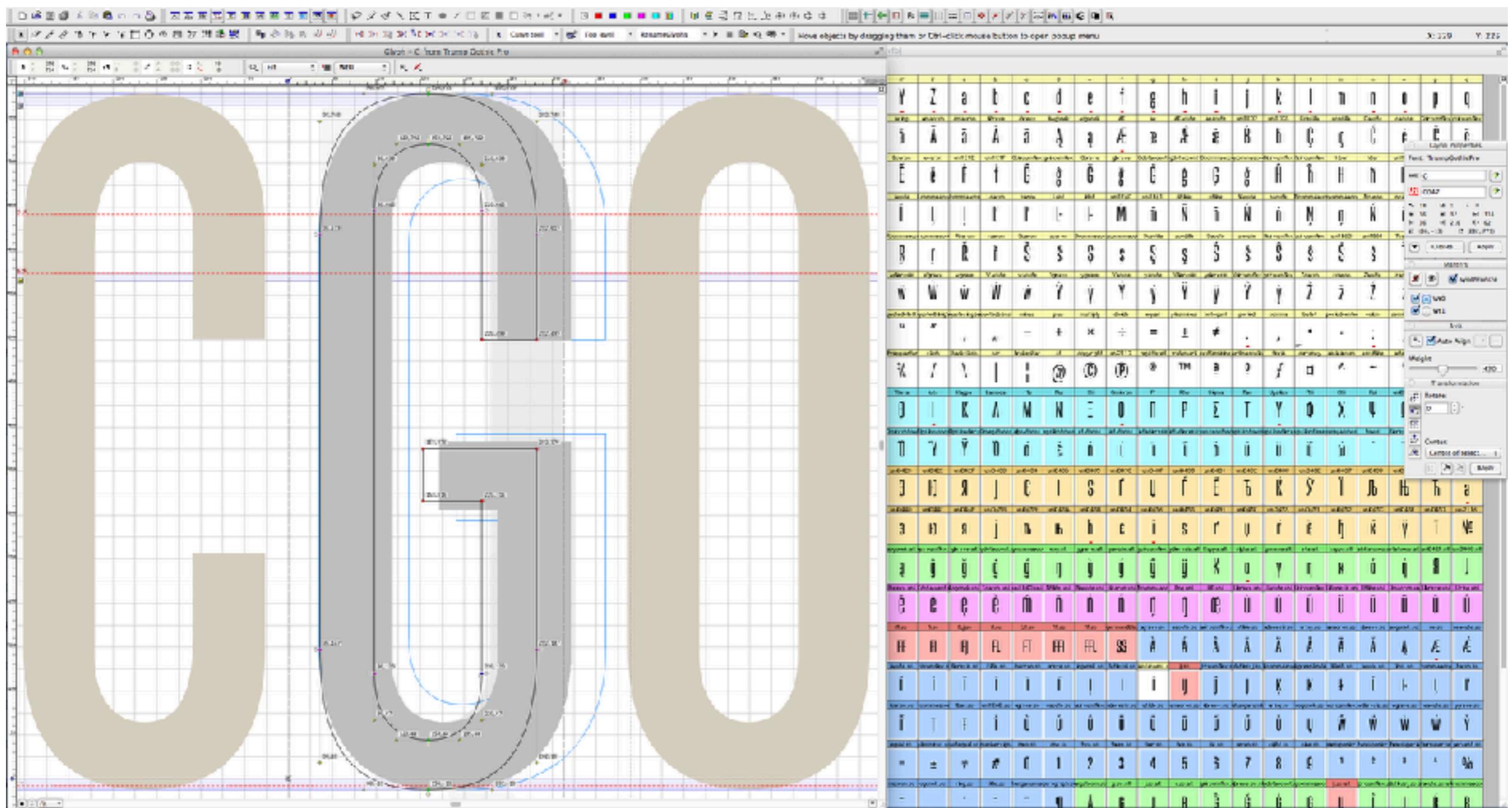


# Goal: Stroke-Based Font Representation Suitable for Learning





# 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

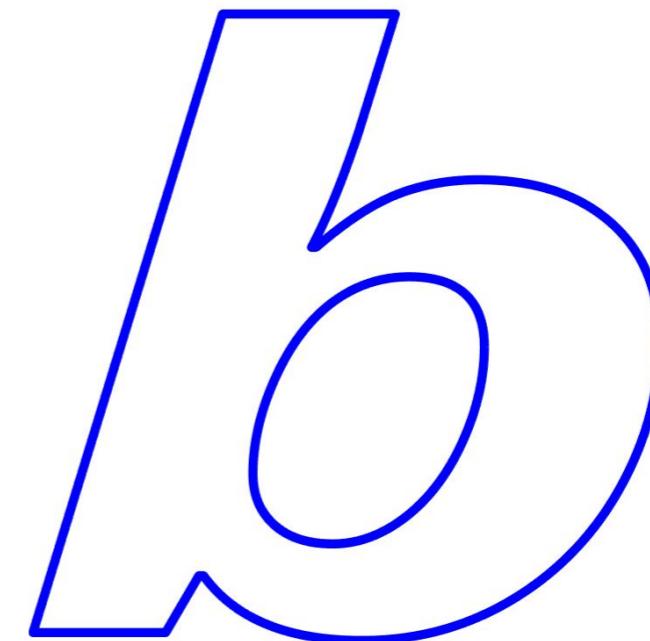


# Desired Font Representation Characteristics



# Desired Font Representation Characteristics

- Detail-preserving



A blue outline of the letter 'A' with a thick stroke, demonstrating a detail-preserving font representation.



# Desired Font Representation Characteristics

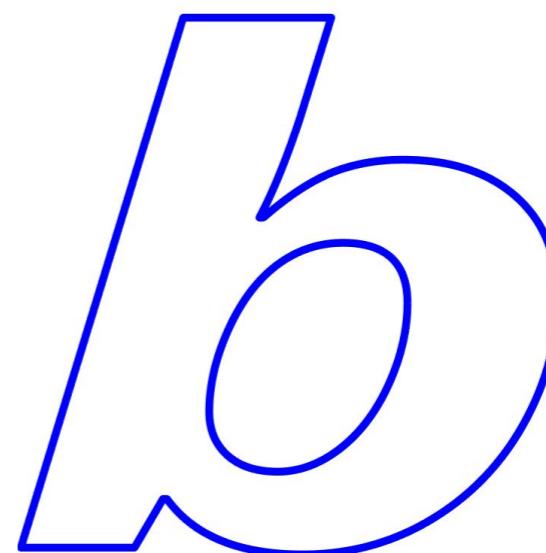
- Structure-aware





# Desired Font Representation Characteristics

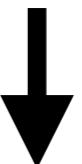
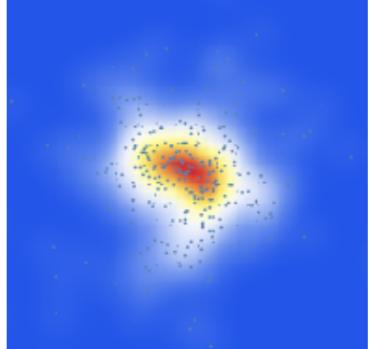
- Scales without artifacts

A small blue outline of the lowercase letter 'b'.A large blue outline of the lowercase letter 'b', which appears distorted or 'scaled without artifacts', illustrating a visual representation of font characteristics.



# Desired Font Representation Characteristics

- Suitable for learning

A blue outline of the lowercase letter 'b'.  
A black downward-pointing arrow.  
A square heatmap visualization showing a central cluster of red and yellow dots against a blue background, representing a learned font embedding space.



# Font Representations

- Raster - Based
- Contour - Based



# Font Representations

Raster - Based

student

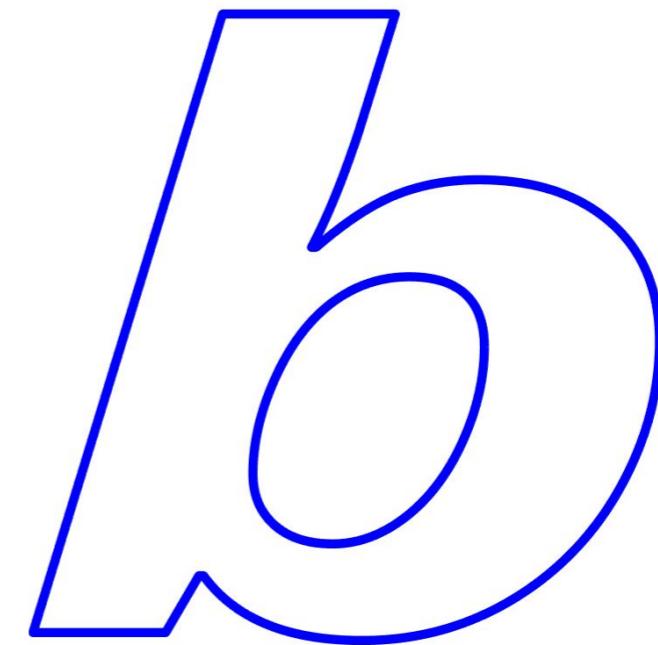
## Limitations

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



# Font Representations

Contour-Based



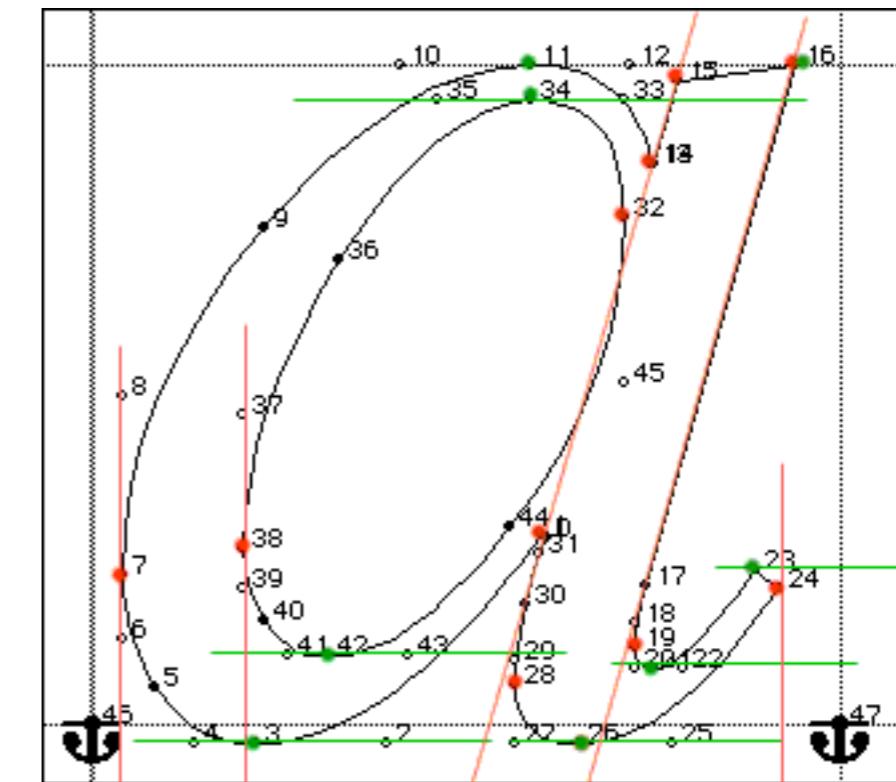


# Font Representations

Bezier-Based

## Limitations

- Not suitable for learning



[Microsoft Docs]

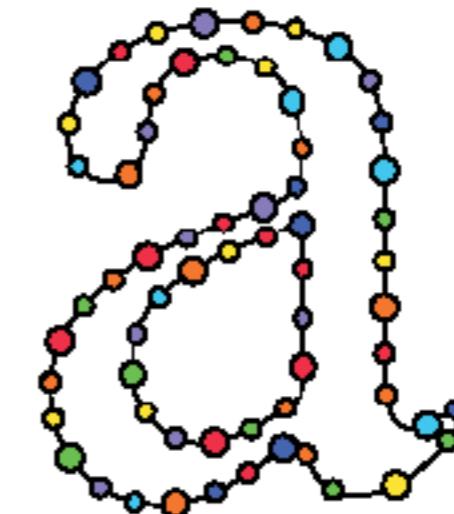
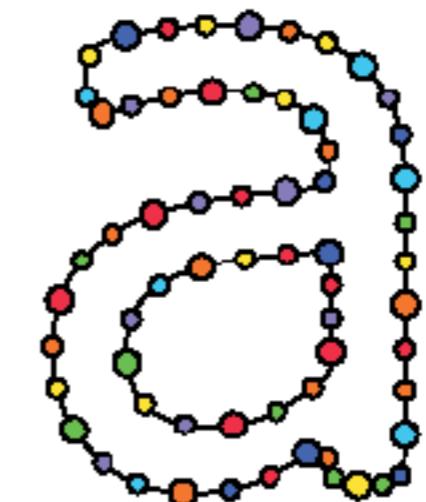


# Font Representations

Consistent Outline-Based

## Limitations

- Not structure-aware



[Campbell '14]

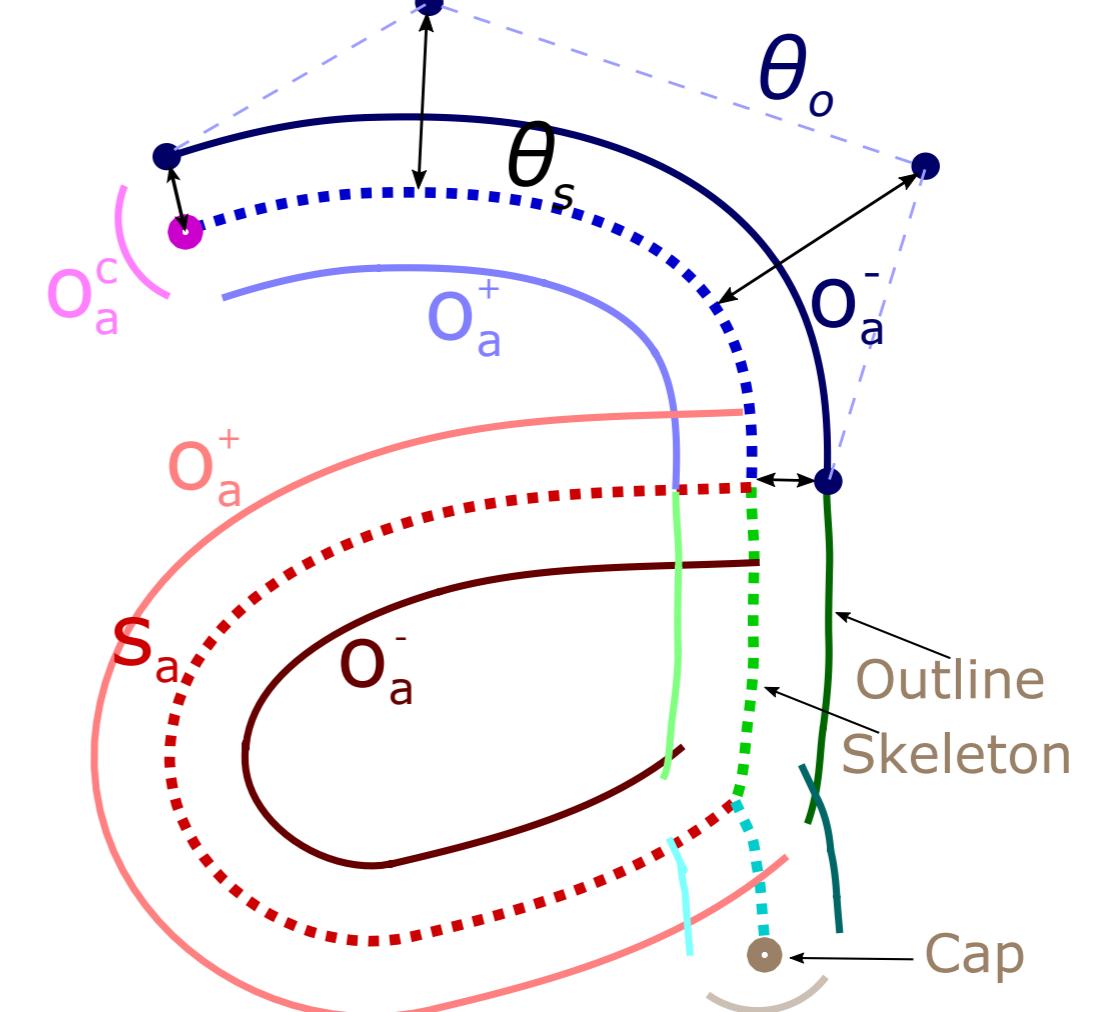


# Font Representations

Proposed Representation

## Characteristics

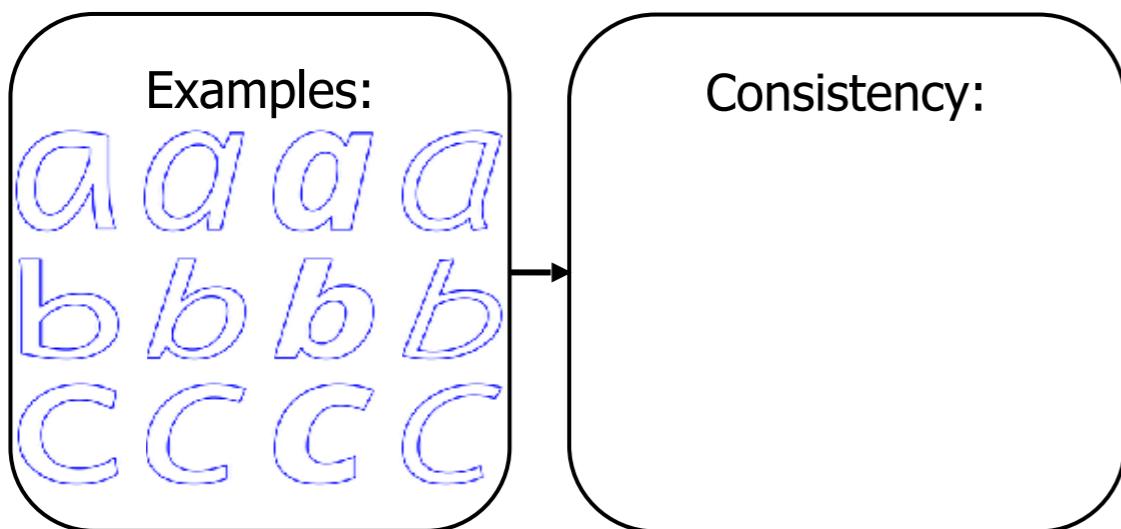
- Detail-preserving
- Structure-aware
- Scales without artifacts
- Suitable for learning



Part-Aware  
Skeleton-Based Representation



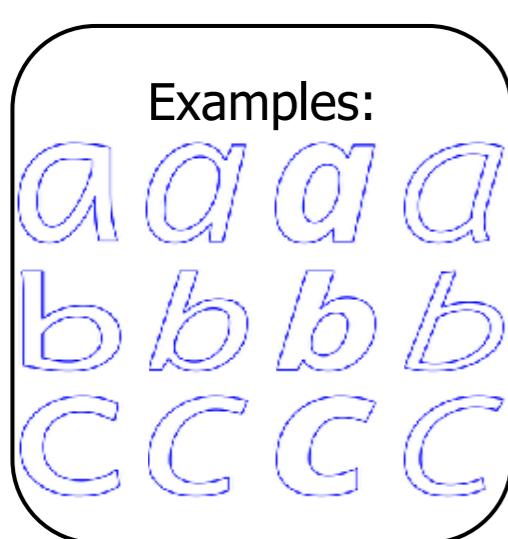
# Our Approach





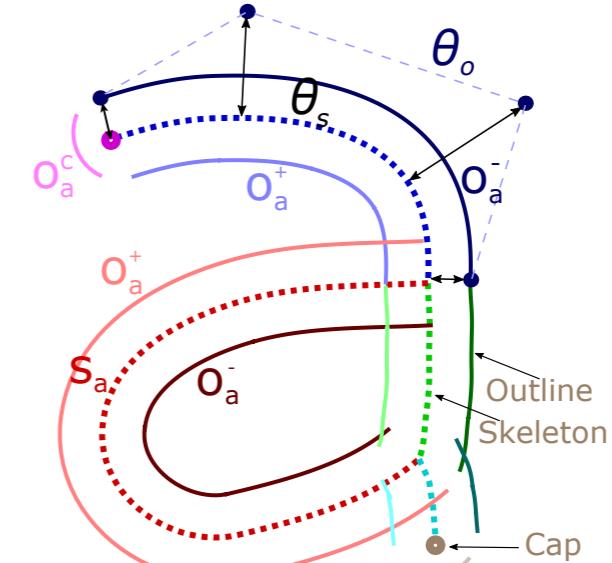
# Our Approach

## Template Fitting



Consistency:

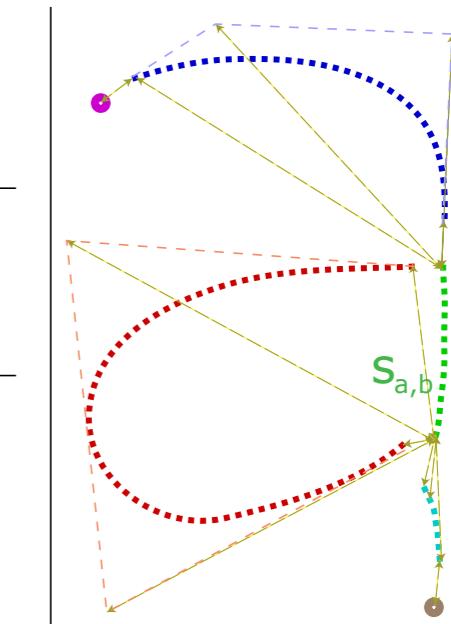
## Template Definition



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

Connectivity Constraints

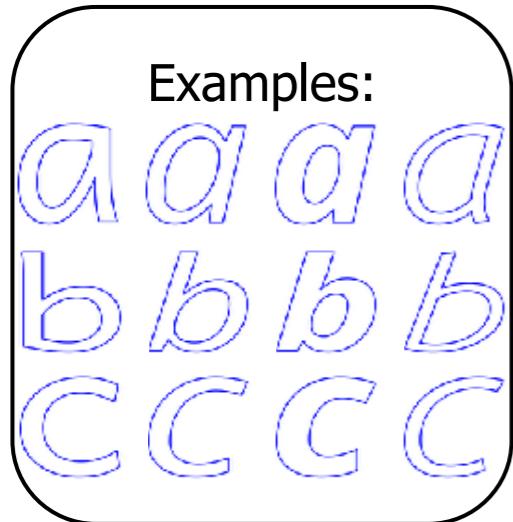
$$O_a^+ - O_a^+ - O_a^c - O_a^- \dots$$





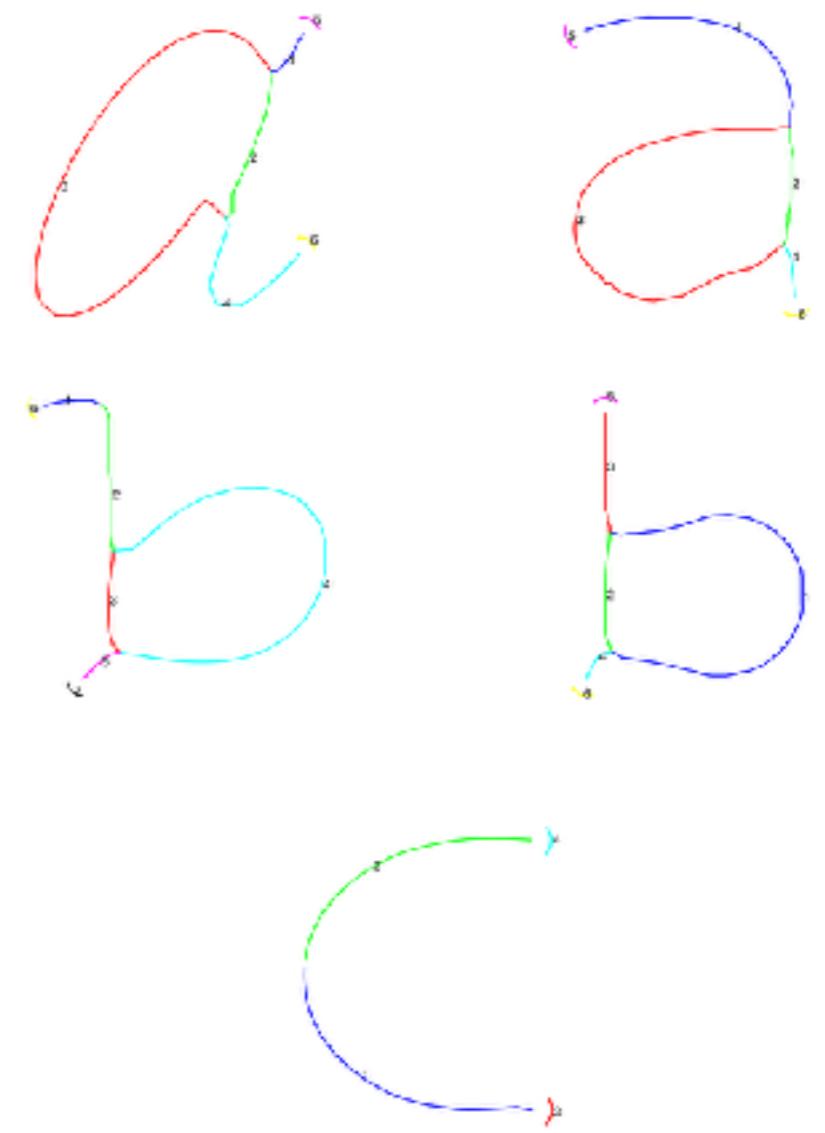
# Our Approach

## Template Fitting



Consistency:

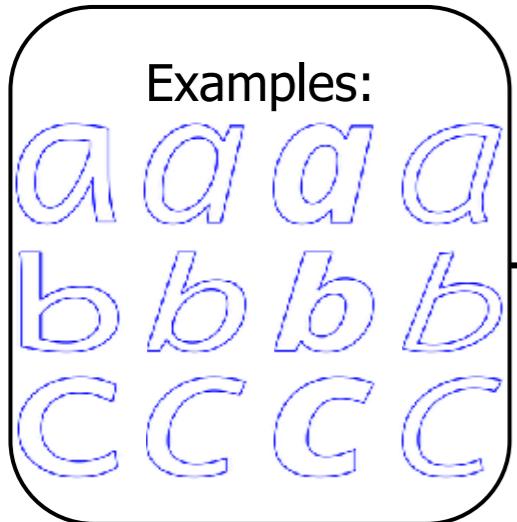
## Template Definition





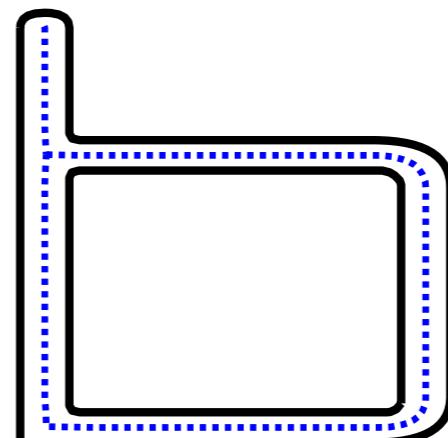
# Our Approach

## Template Fitting



Consistency:

## Skeleton Optimization

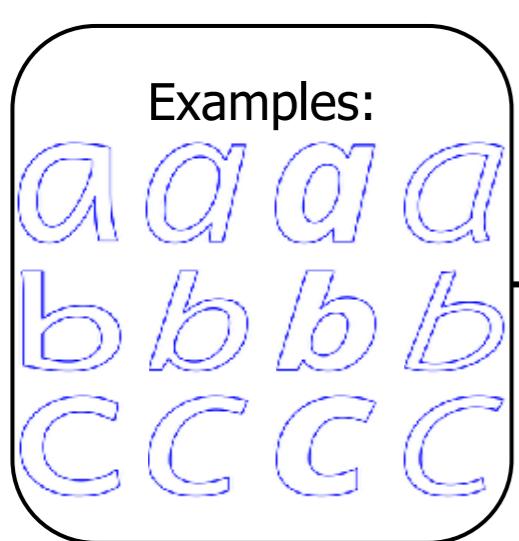


Initial Skeleton



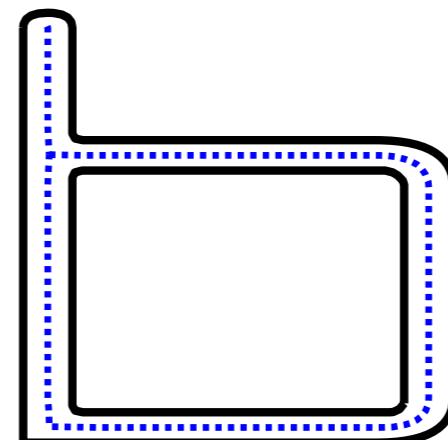
# Our Approach

## Template Fitting

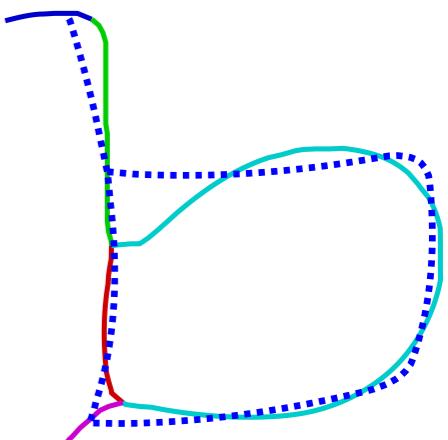


Consistency:

## Skeleton Optimization



Initial Skeleton

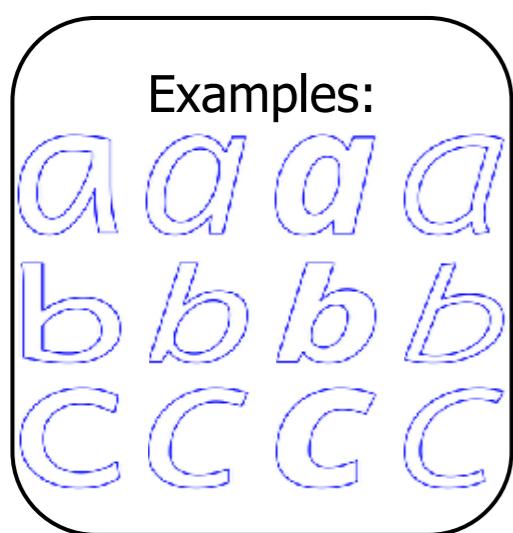


Registration



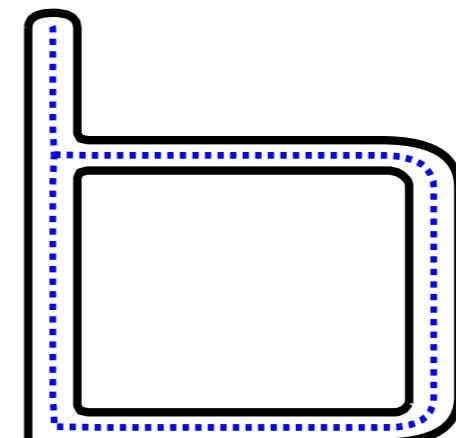
# Our Approach

## Template Fitting

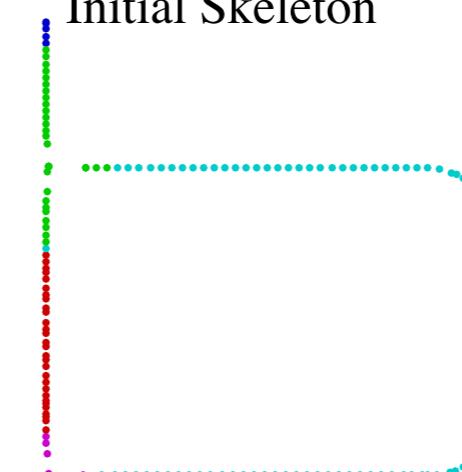


Consistency:

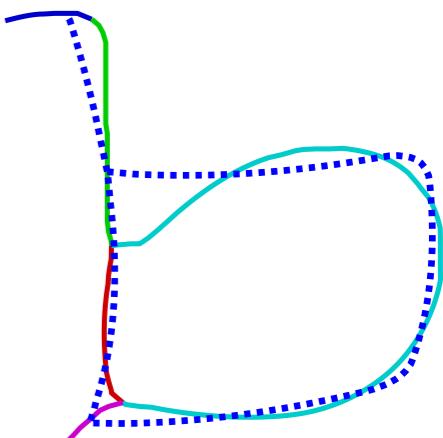
## Skeleton Optimization



Initial Skeleton



Initial Segmentation

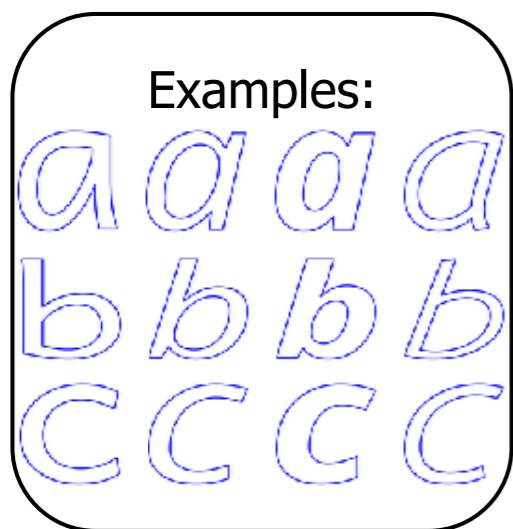


Registration



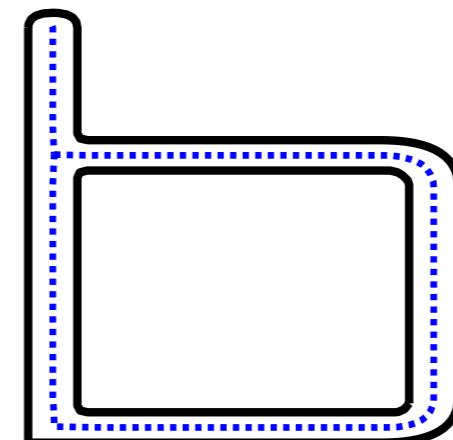
# Our Approach

## Template Fitting

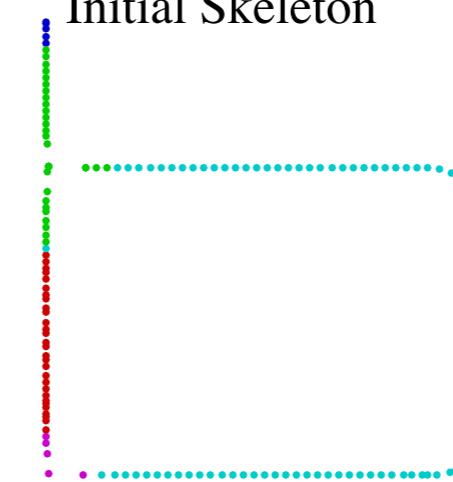


Consistency:

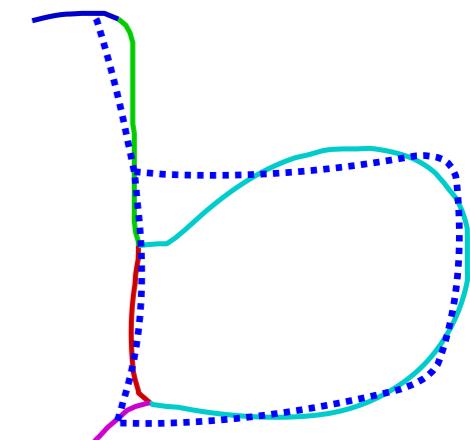
## Skeleton Optimization



Initial Skeleton



Initial Segmentation



Registration

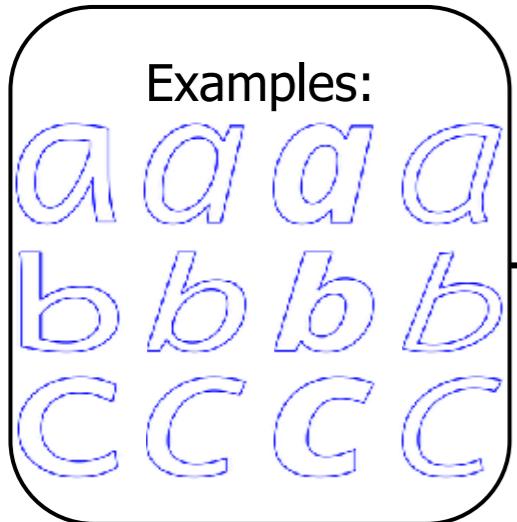


Final Segmentation



# Our Approach

Template Fitting



Consistency:

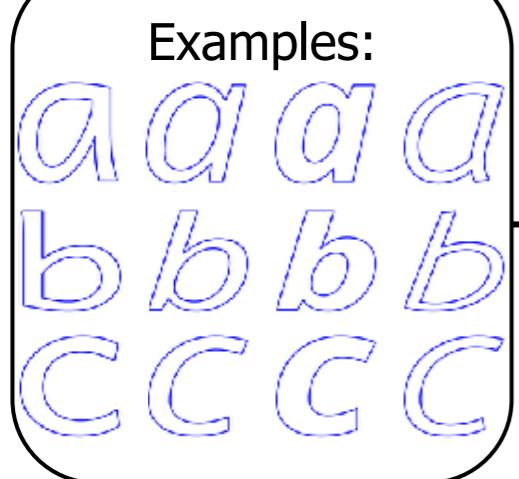
**Outline Optimization**

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



# Our Approach

## Template Fitting



Consistency:

## Outline Optimization

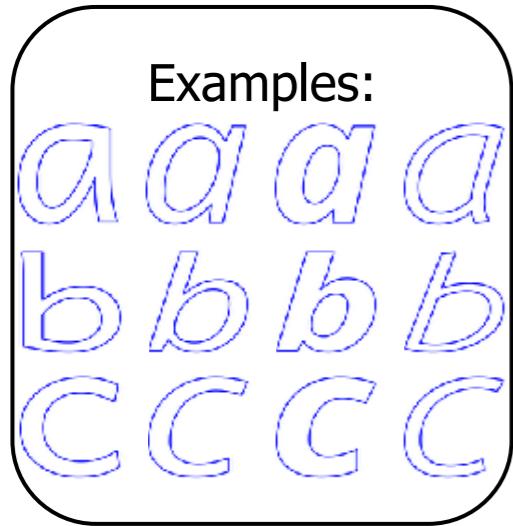
$$E = E_{\text{corr}} + E_{\text{ft}}$$

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



# Our Approach

## Template Fitting



Consistency:

## Outline Optimization

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

$$\begin{aligned} E_{\text{corr}}(G_{c,f}, \Theta) &= \sum_{\substack{x \in P(G_{c,f}) \\ \text{template} \\ \text{parameters} \\ \text{GT} \\ \text{outline}}} h_{\sigma_{\text{corr}}} (D(x, O_c(\Theta))) \\ &\quad + \sum_{y \in P(O_c(\Theta))} h_{\sigma_{\text{corr}}} (D(y, G_{c,f})) \end{aligned}$$

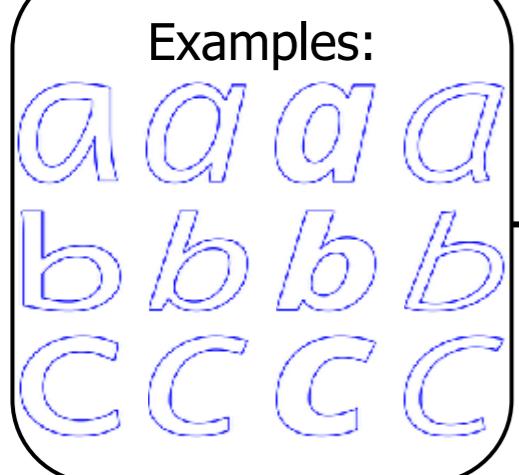
*x* = [q<sub>X</sub>, q<sub>Y</sub>, w<sub>n</sub>n<sub>X</sub>(q), w<sub>n</sub>n<sub>Y</sub>(q)]

template parameters  
Gaussian kernel  
generated outline  
GT outline  
dense curve sampling  
normal  
coordinates normal weight



# Our Approach

## Template Fitting



Consistency:

## Outline Optimization

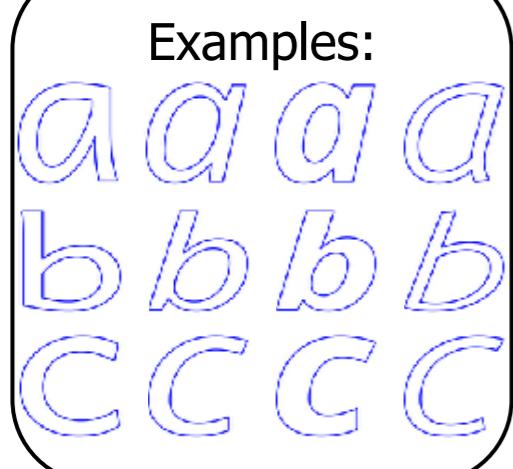
$$E = E_{\text{corr}} + E_{\text{ft}}$$

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



# Our Approach

## Template Fitting



Consistency:

## Outline Optimization

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

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

template  
parameters

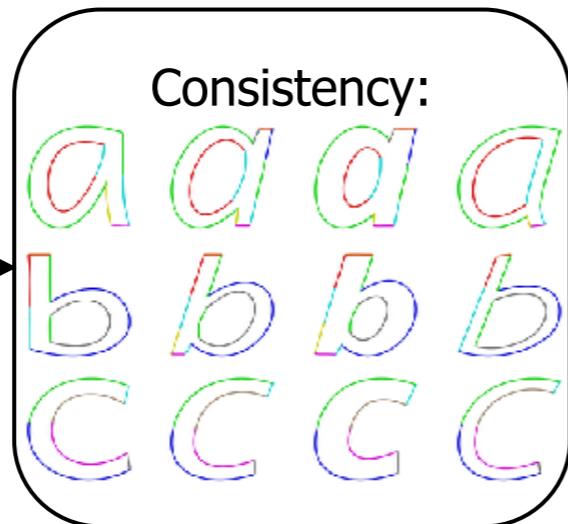
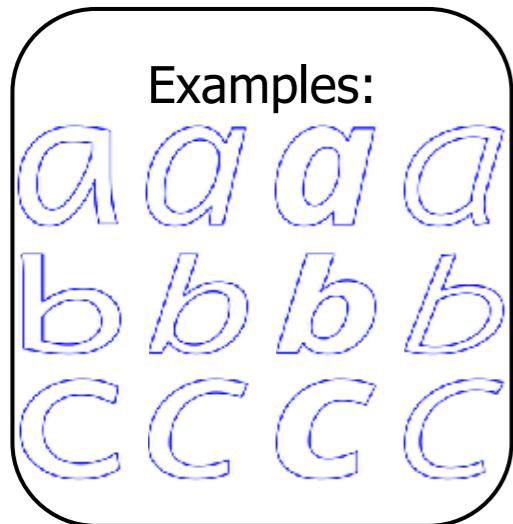
arc-length intrinsic  
distance

subset of junction  
points near  
feature point

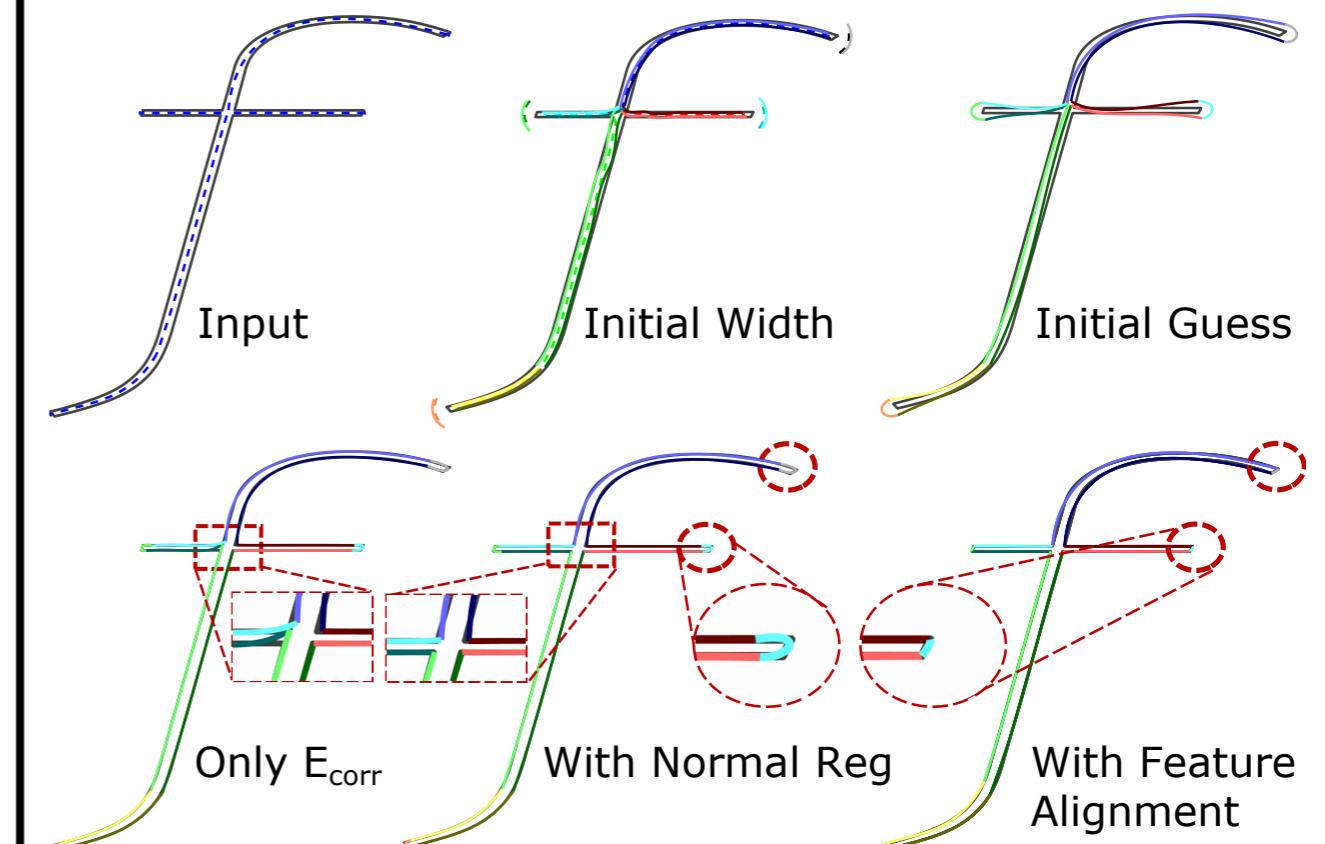


# Our Approach

## Template Fitting

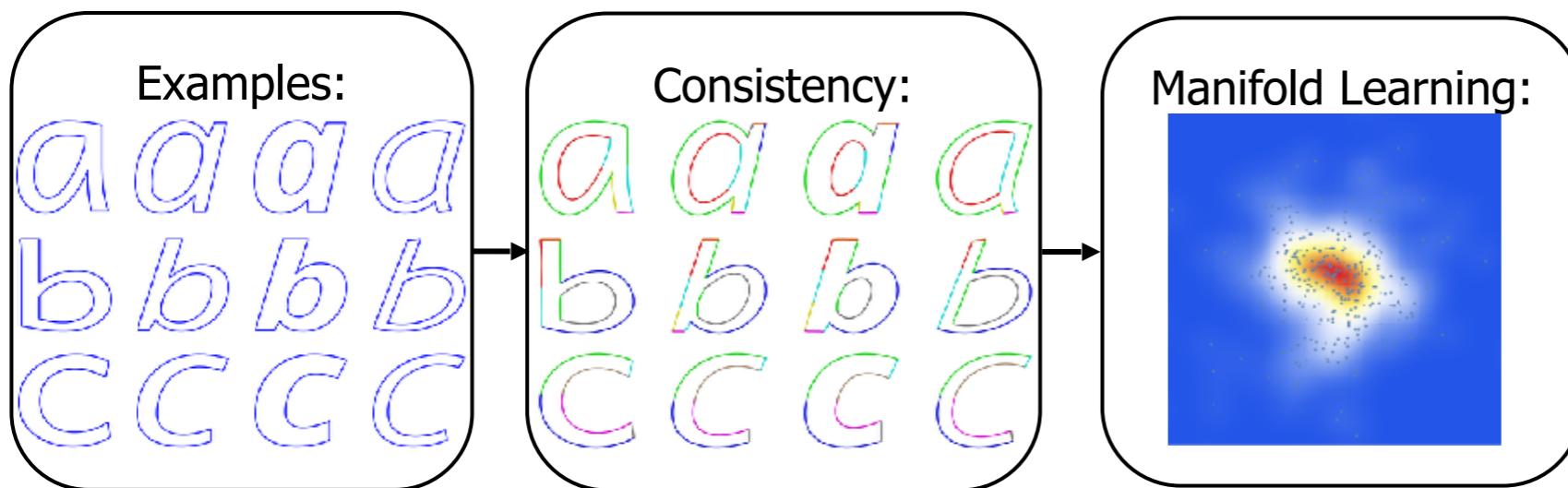


## Outline Optimization



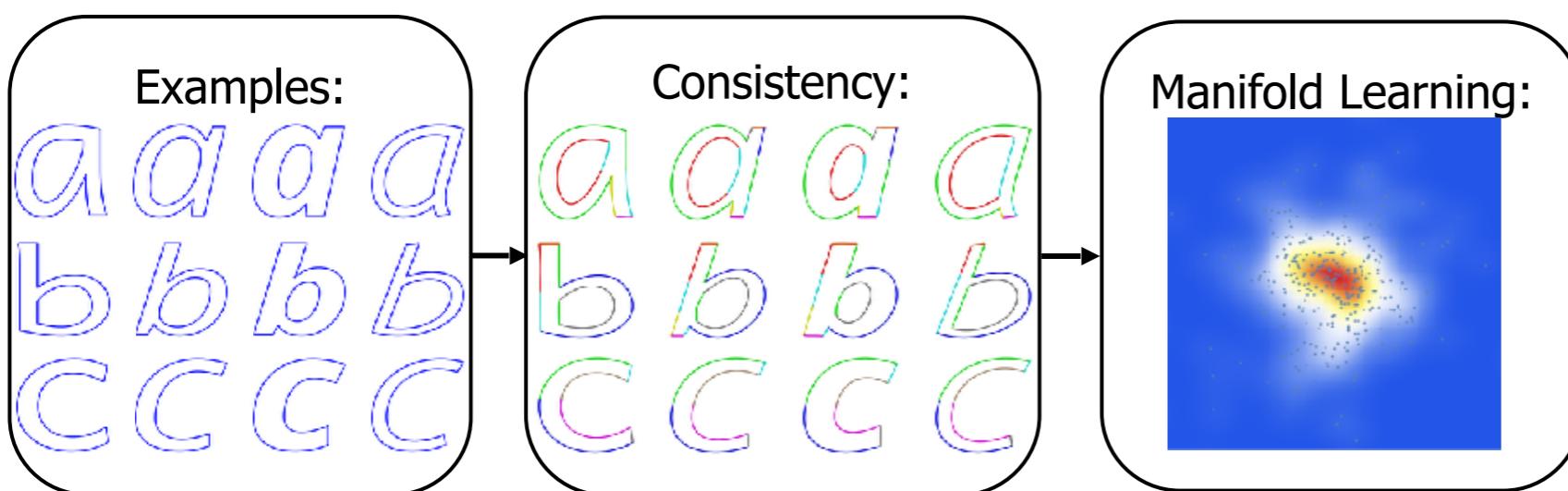


# Our Approach





# Our Approach

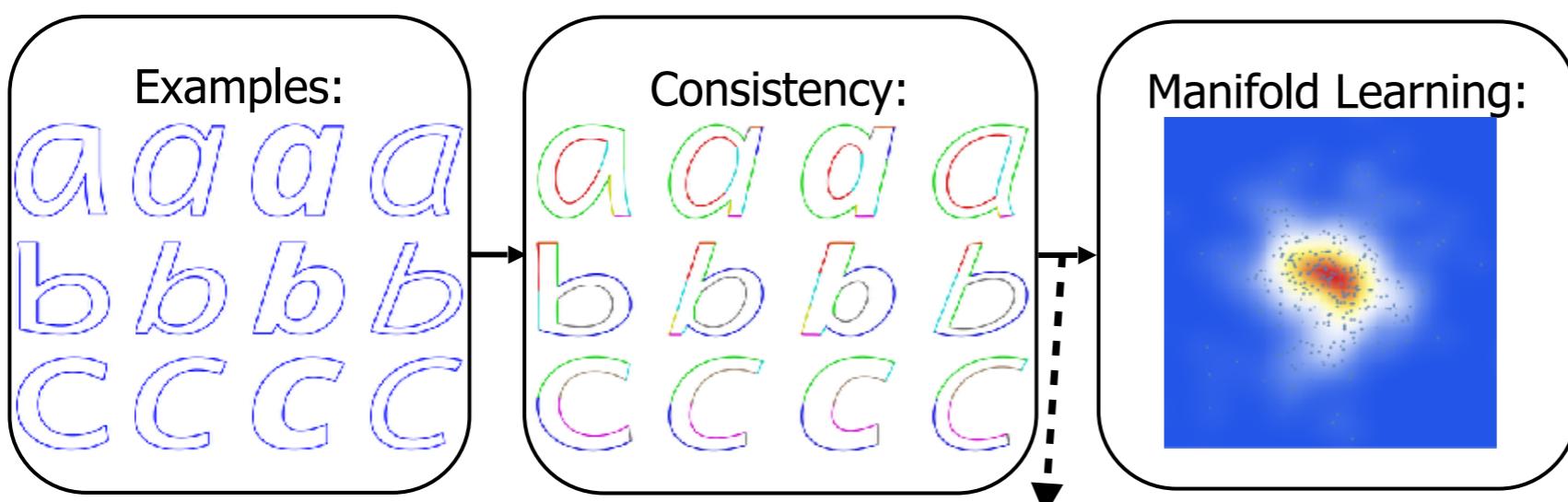


$$f = [f_{a_1}, f_{a_2}, \dots]$$

A red 'X' is drawn over the term  $f_{a_2}$ , with the text "NaN" written above it in red. Below the first two terms, there are two small handwritten 'a's, one green and one blue.



# Our Approach

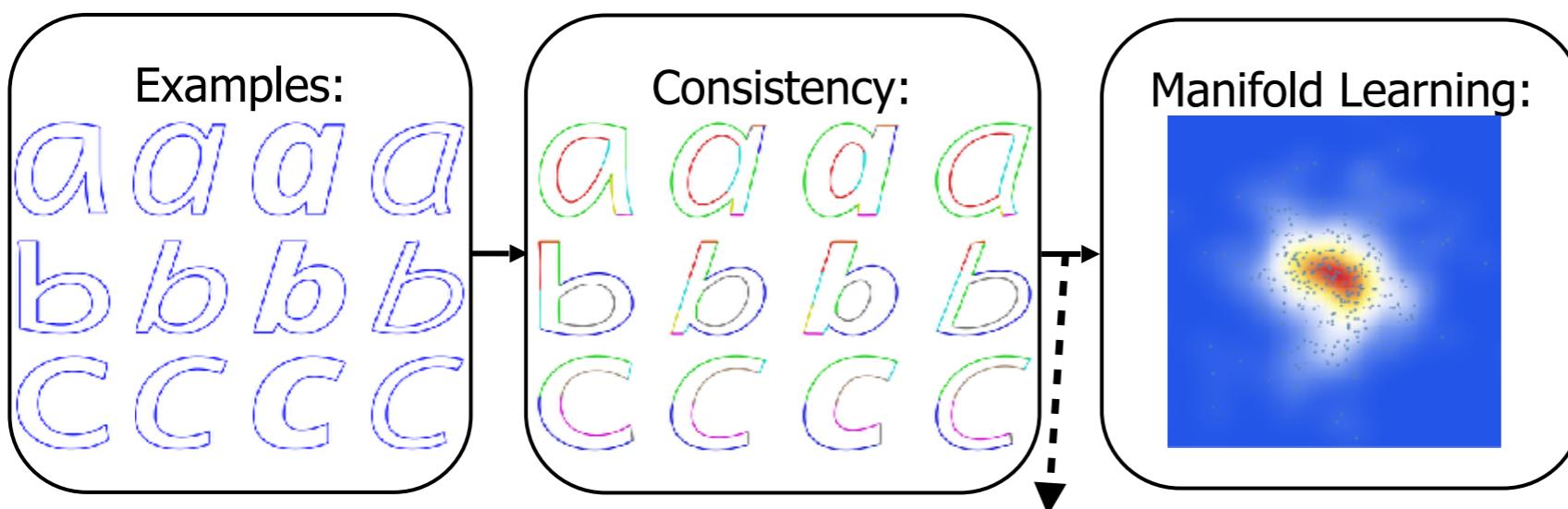


**EM-PCA**  
[Row98]

Input Latent  
Vectors coordinates  
 $Y = CX + V$   
Transformation Noise  
Matrix



# Our Approach



**EM-PCA**  
[Row98]

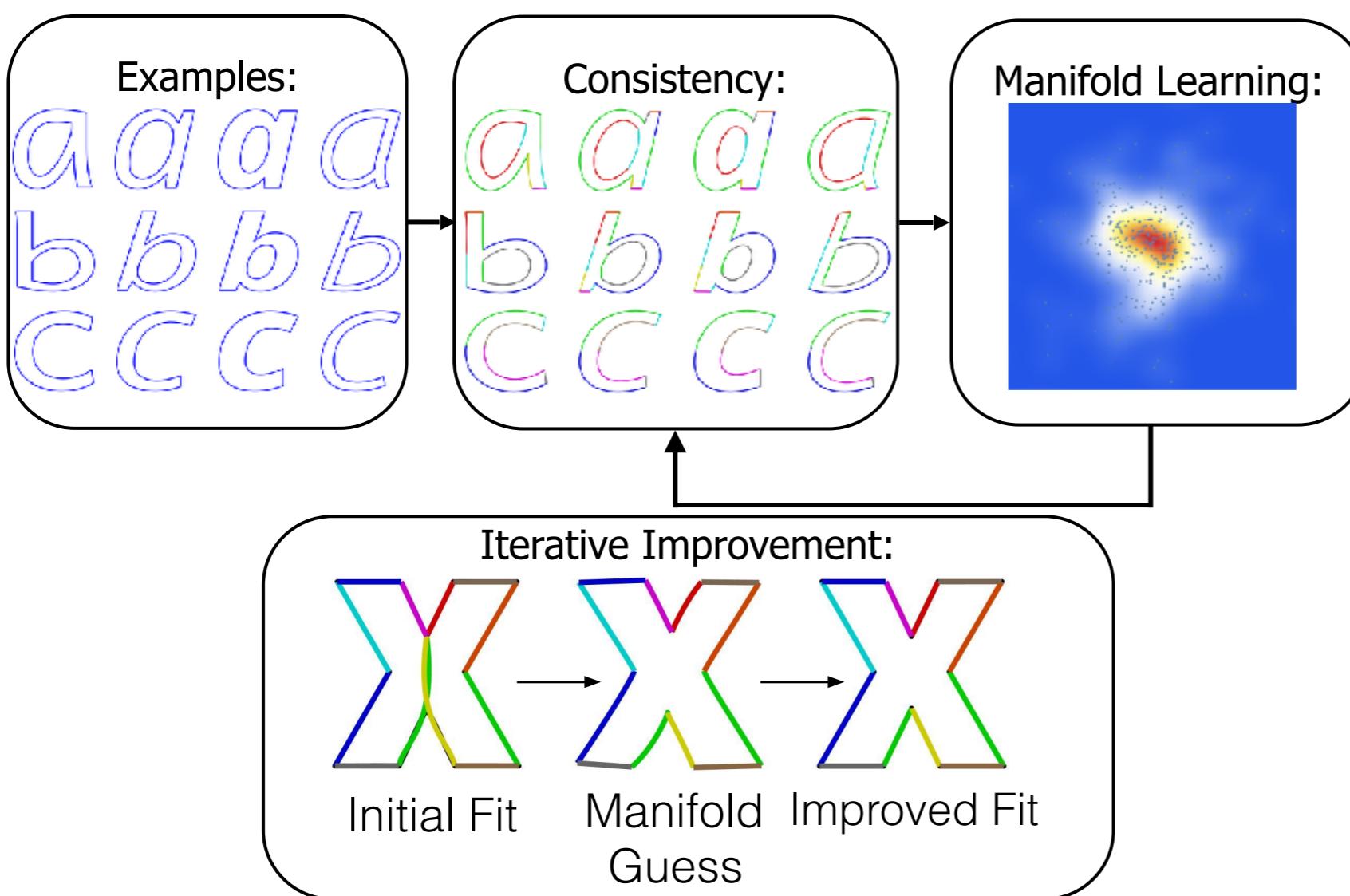
Input Vectors  
Latent coordinates  
 $Y = CX + V$   
Transformation Matrix  
Noise

**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

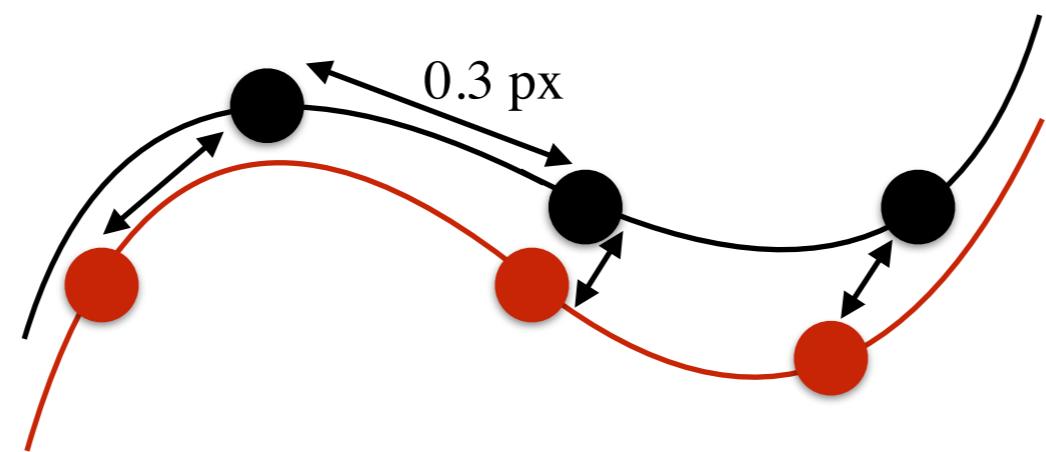
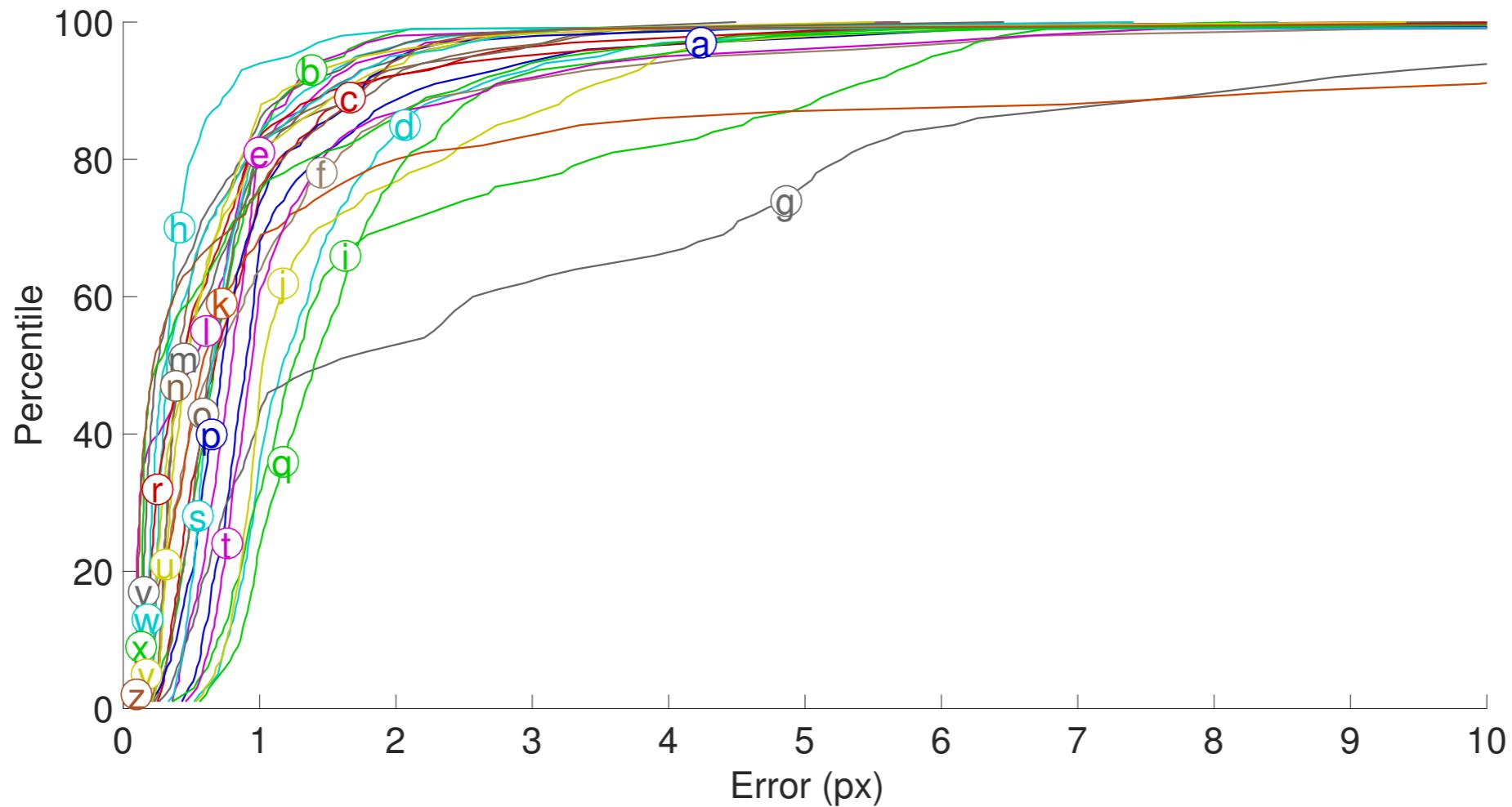




# Fitting Results

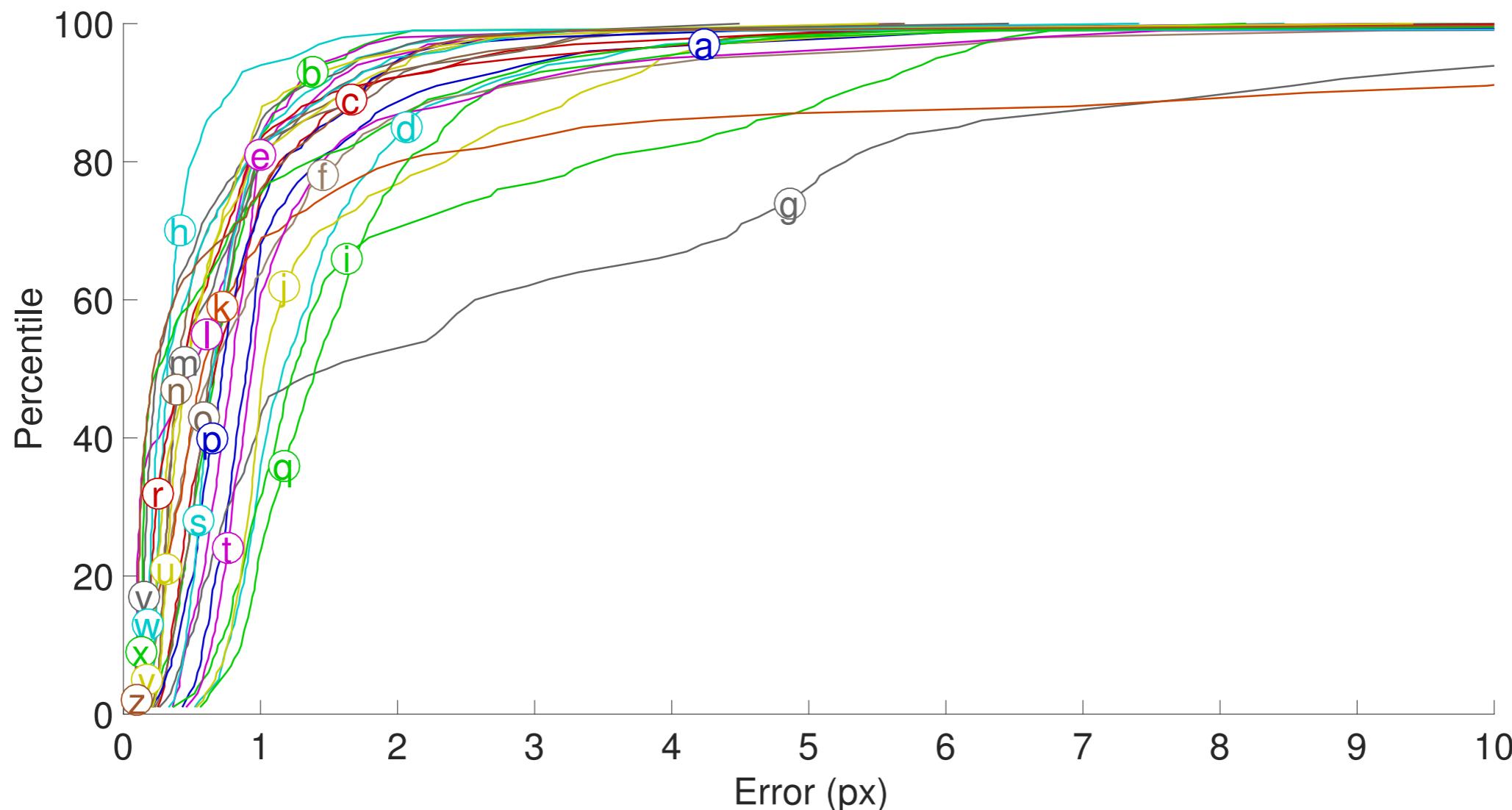


# Fitting Results





# Fitting Results



a  
Error: 0.52

a  
Error: 0.99

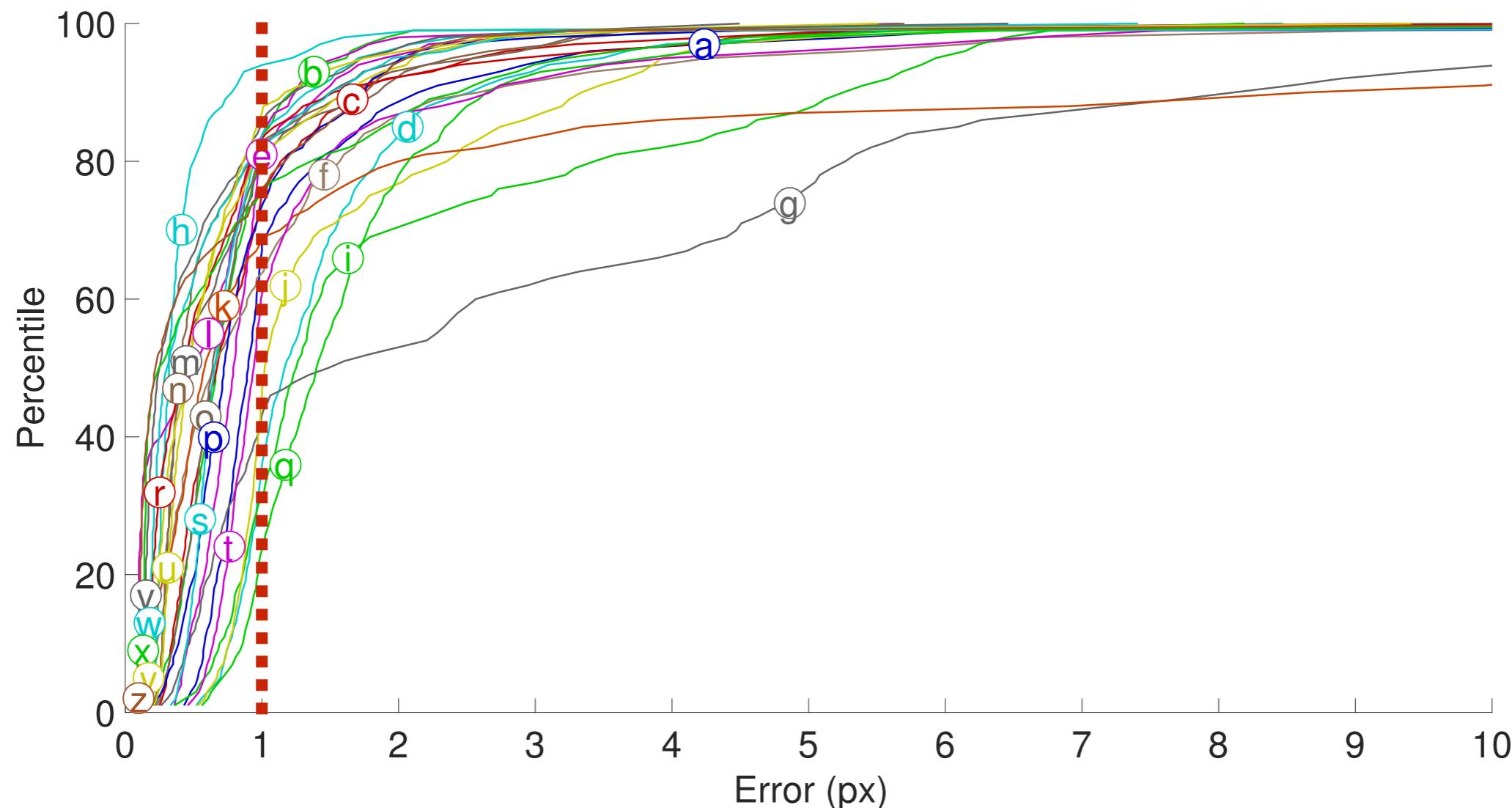
a  
Error: 1.96

a  
Error: 3.49

a  
Error: 8.54



# Fitting Results



a

Error: 0.52

a

Error: 0.99

a

Error: 1.96

a

Error: 3.49

a

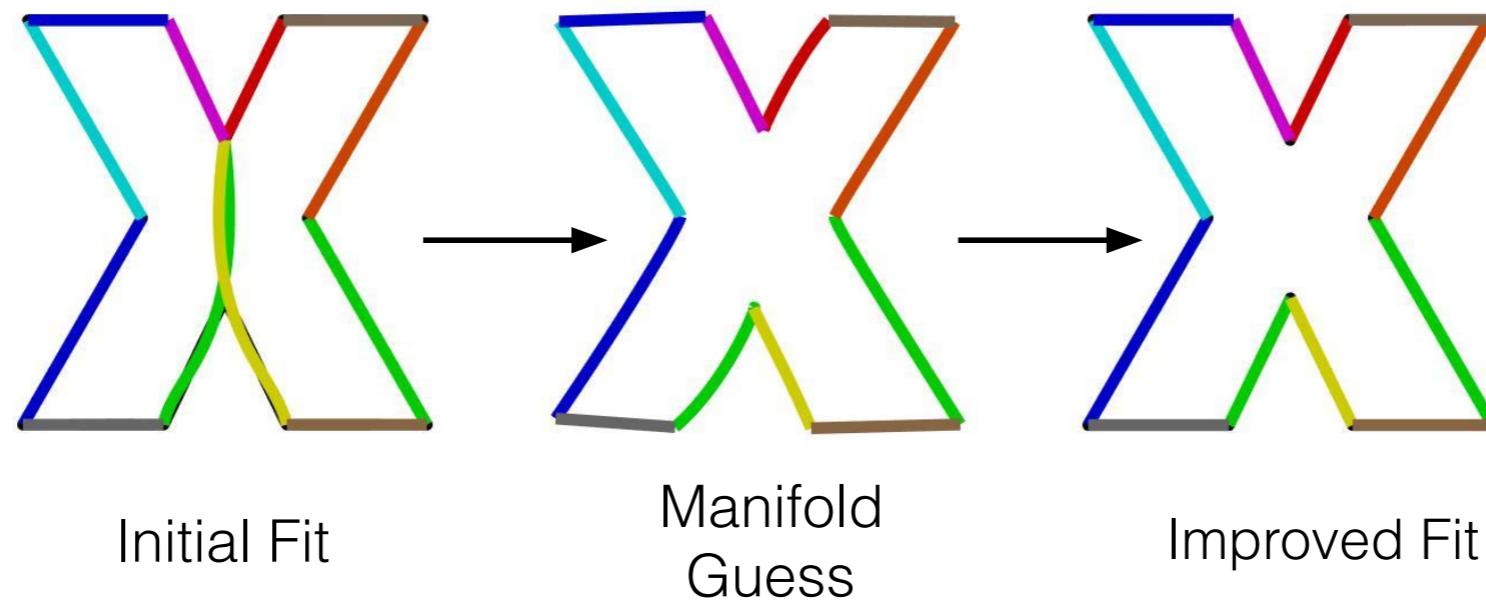
Error: 8.54



# Iterative Improvement Evaluation

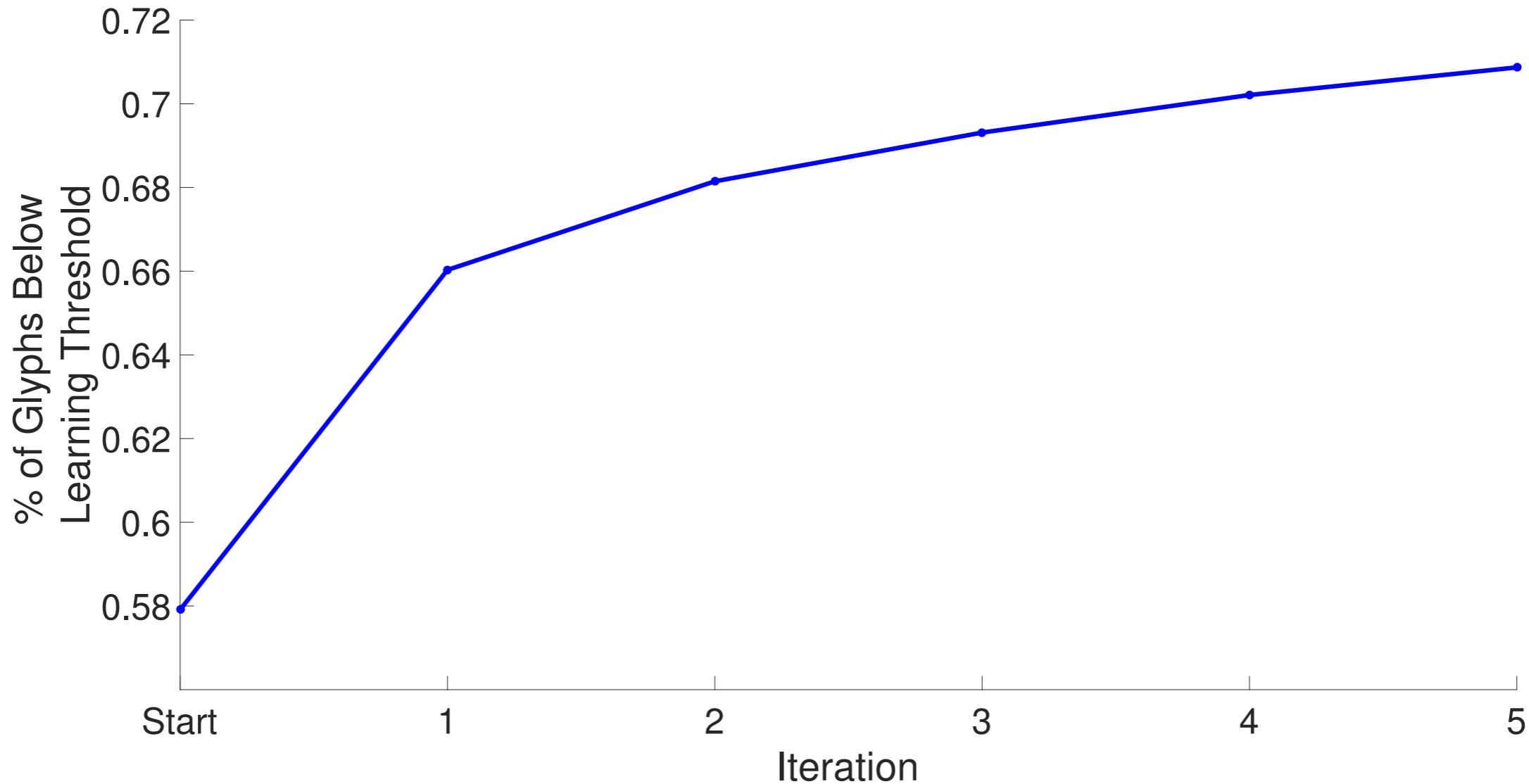


# Iterative Improvement Evaluation



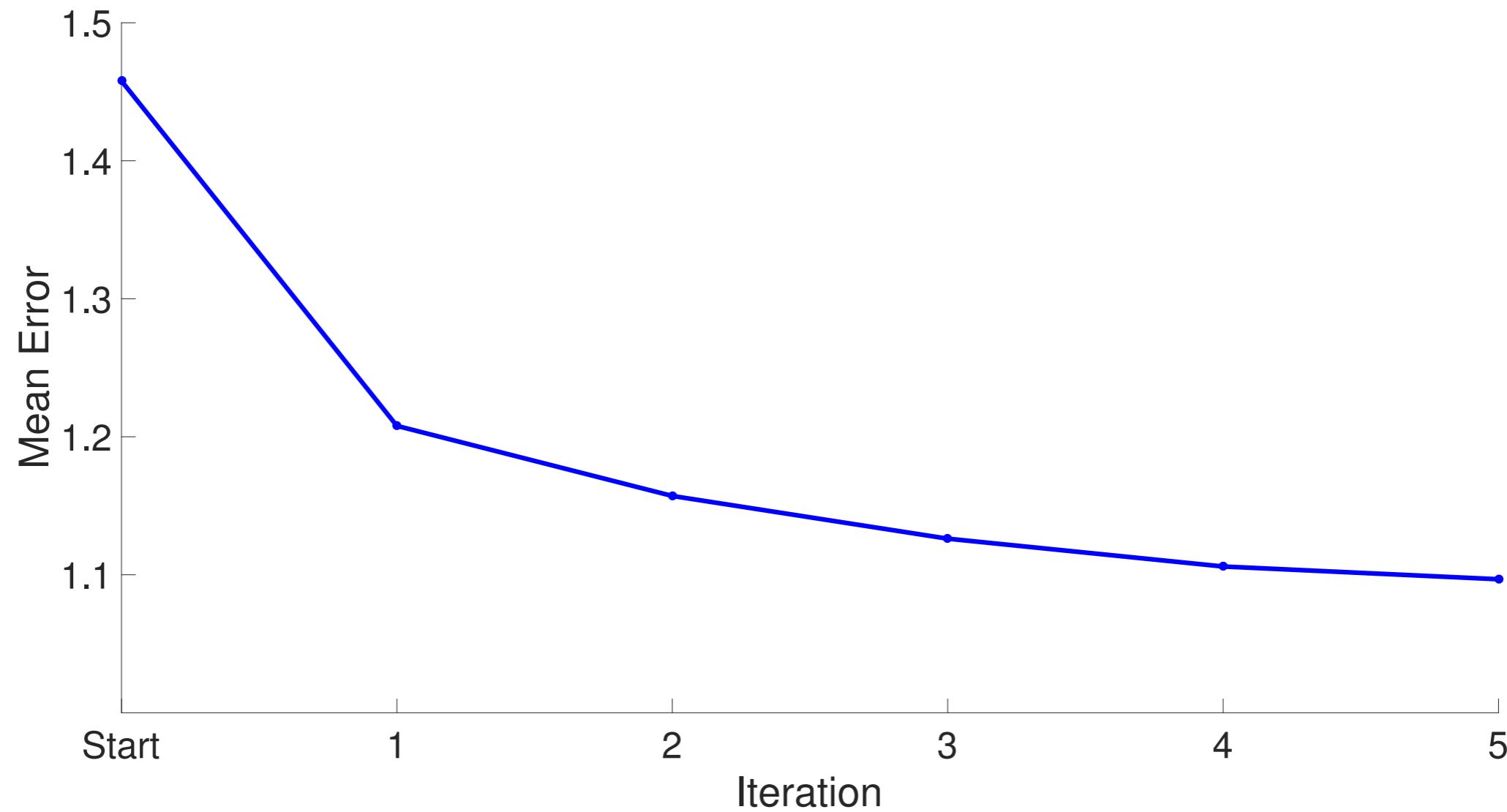


# Iterative Improvement Evaluation





# 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

hhhhhhhhhhh

Part-Based Representation

hhhhhhhhhhh

Single Contour Representation[CK14]

hhhhhhhhh

Part-Based Representation

hhhhhhhhh

Single Contour Representation[CK14]



# Comparison to Non-Part-Aware Approach

hhhhhhhhhh

Part-Based Representation

hhhhhh

Part-Based Representation

h hh hh hh hh hh

Raster-Based

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

hhhhhhhhhhh

EM-PCA

hhhhhhhhhhh

Denoising VAE

hhhhhhhhhhh

Vanilla VAE

hhhhhhhhh

EM-PCA

hhhhhhhhh

Denoising VAE

hhhhhhhhh

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

GT

Eval.

Input

Prediction

GT

GT

Exo-Light

Input

Prediction



# Style Completion: Regular/Bold Fonts

Nobile-BoldItalic

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

Input

Prediction

DoppioOne-Regular

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

Input

Prediction



# Style Completion: Italic Fonts

Nobile-BoldItalic

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

Input

Prediction

MinionPro-It

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

Input

Prediction



# Style Completion: Serif Fonts

Amethysta-Regular

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

Oldenburg-Regular

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



# Style Completion: Serif Fonts

Neutron Light

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

Neutron 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



# 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 z 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 z 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



# Style Completion



# Style Completion



# Style Completion



# Style Completion



# Style Completion



# Style Completion



# Style Completion



# Style Completion



# Style Completion



# Style Completion

hand glove



# Style Completion



# Style Completion



# Style Completion



# Style Completion



# Style Completion



# Style Completion



# Style Completion



# Style Completion



# Style Completion



# Style Completion



# 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

f

O

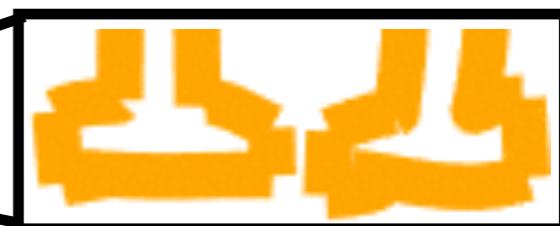
m



f

O

n





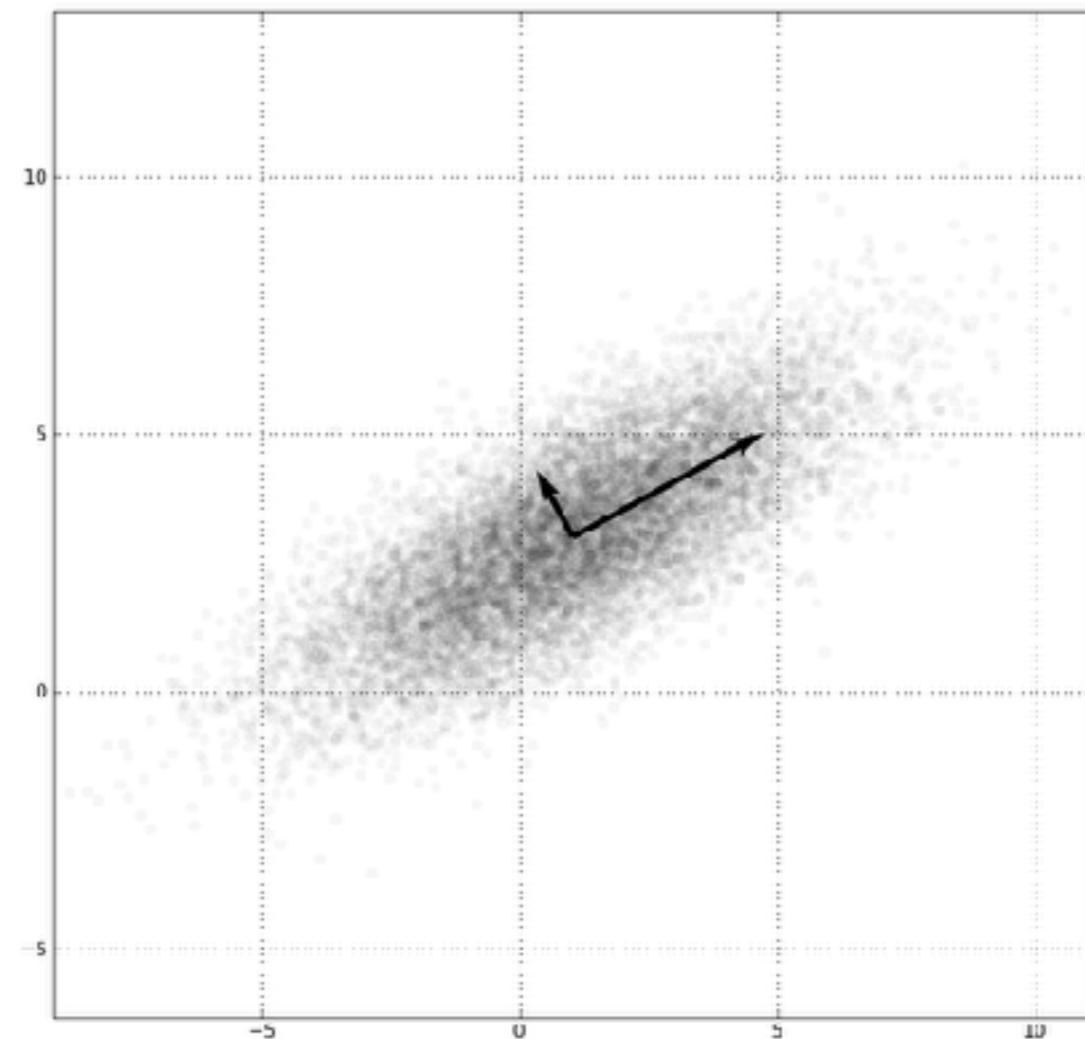
# Limitations



[<https://design.google>]



# Limitations



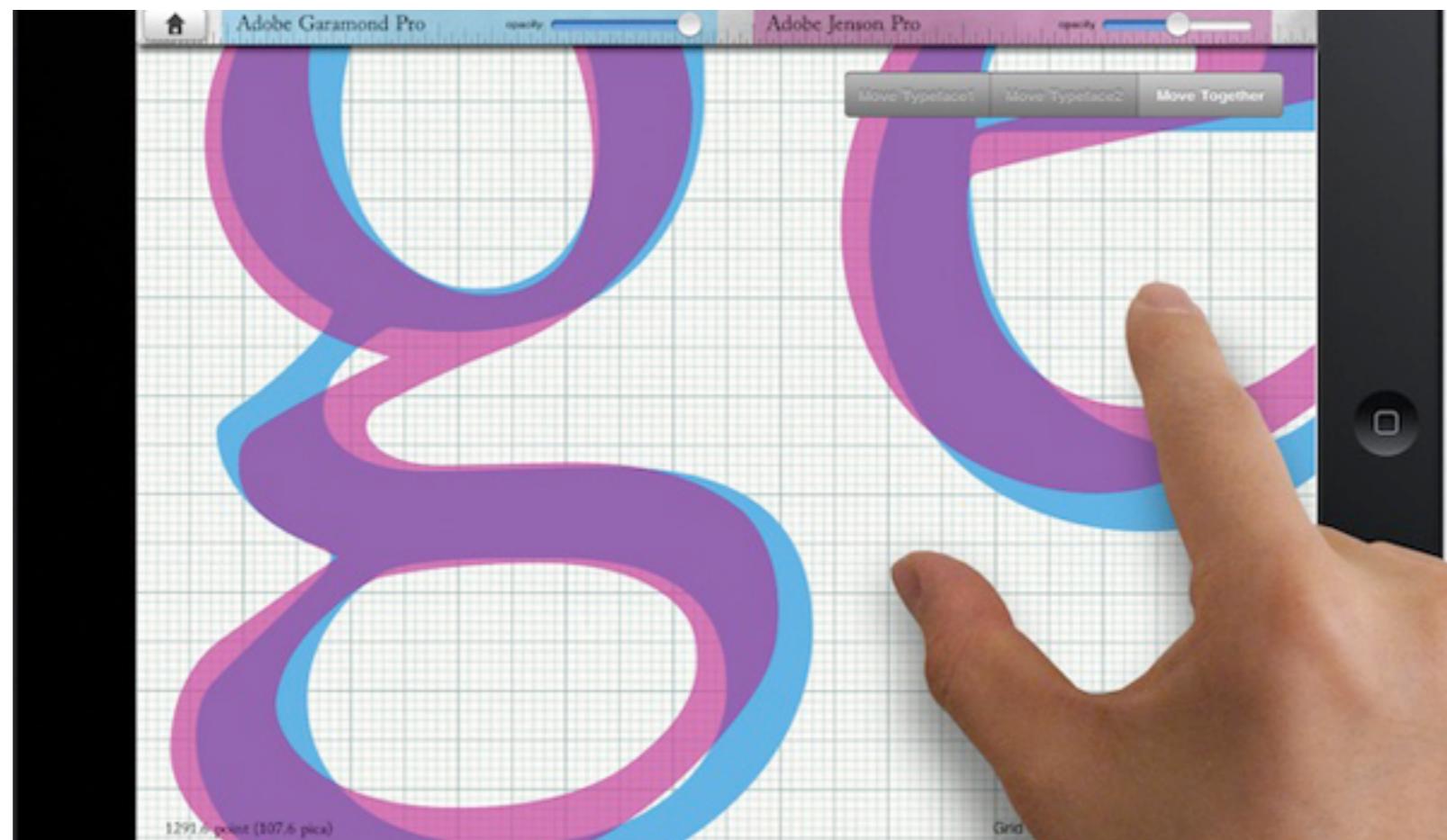
[<https://inventingsituations.net>]



# Future Work



# Future Work



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



# Future Work

**АБВГДЕЁЖ  
ЗИЙКЛМНО  
ПРСТУФХЦЧ  
ШЩЬЫѢЮЯ  
0123456789**

[<https://www.123rf.com/>]



# Future Work

ગુજરાતી લિપિ ને આજે કાંઈ રીતે  
કર્ણાની લિપિ ને આજે કાંઈ રીતે

[Nejati '16]



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