Learning A Stroke-Based Representation for Fonts

E. Balashova¹, A. H Bermano¹, V. G. Kim², S. DiVerdi², A. Hertzmann², T. Funkhouser¹

1 - Princeton University

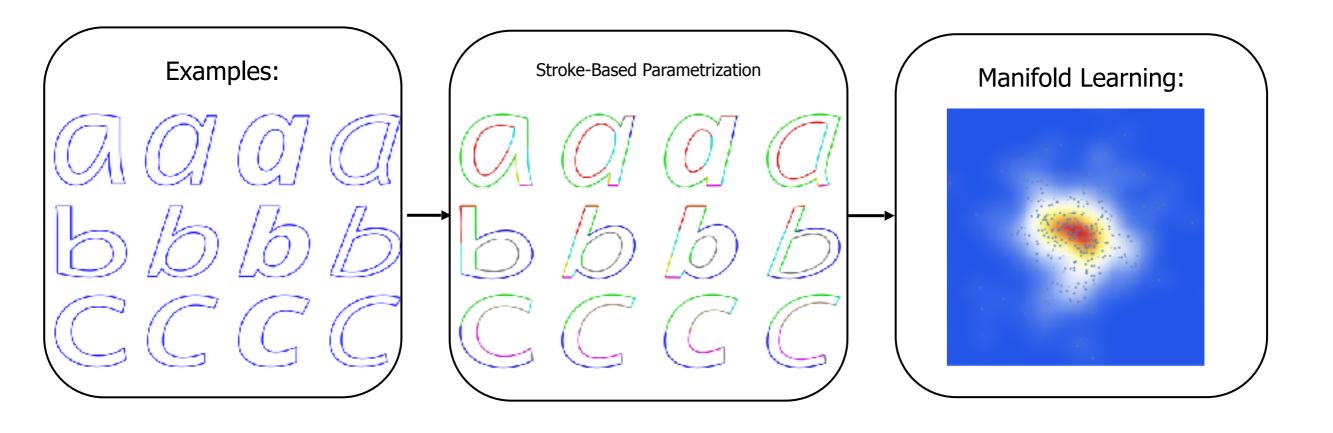
2 - Adobe Research







Goal: Stroke-Based Font Representation Suitable for Learning





Motivation



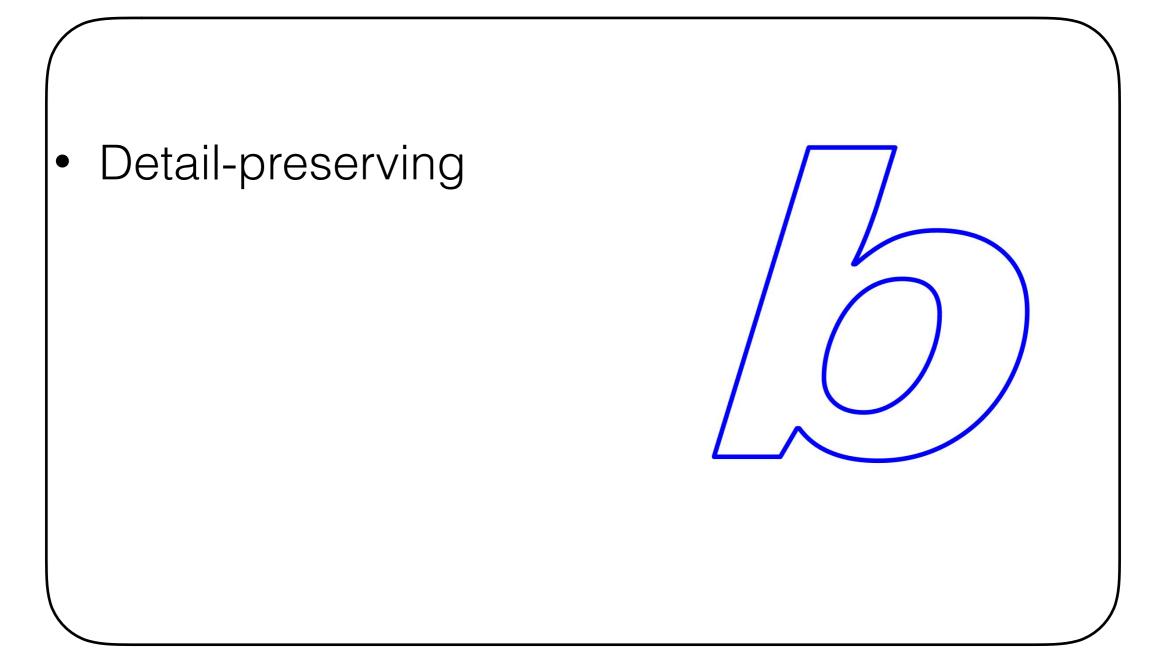


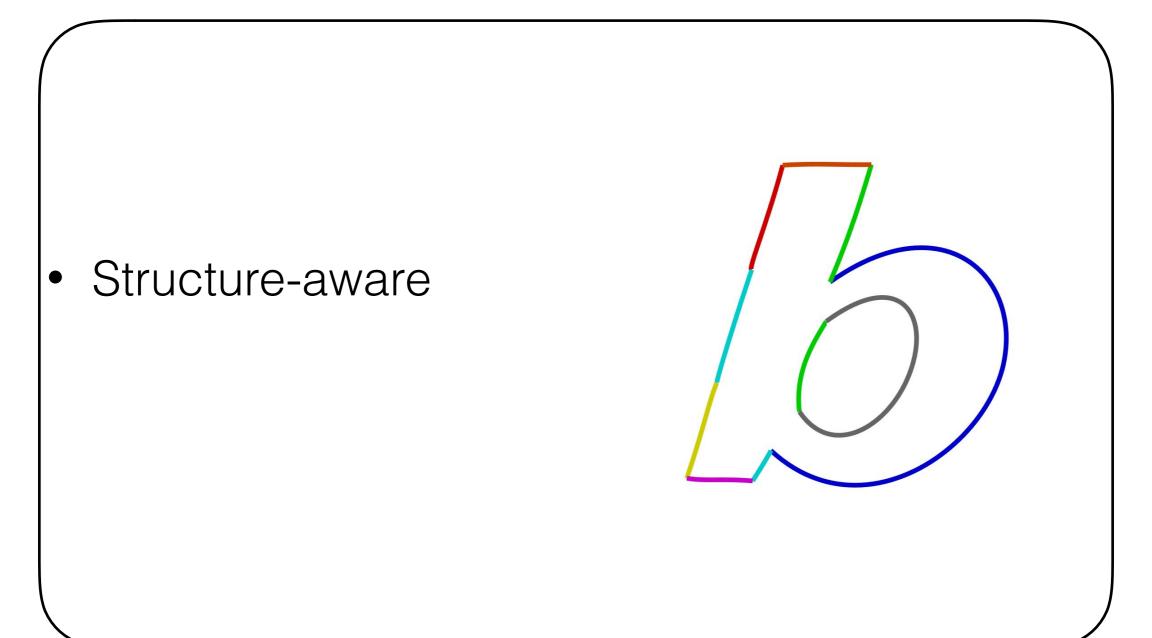
Motivation

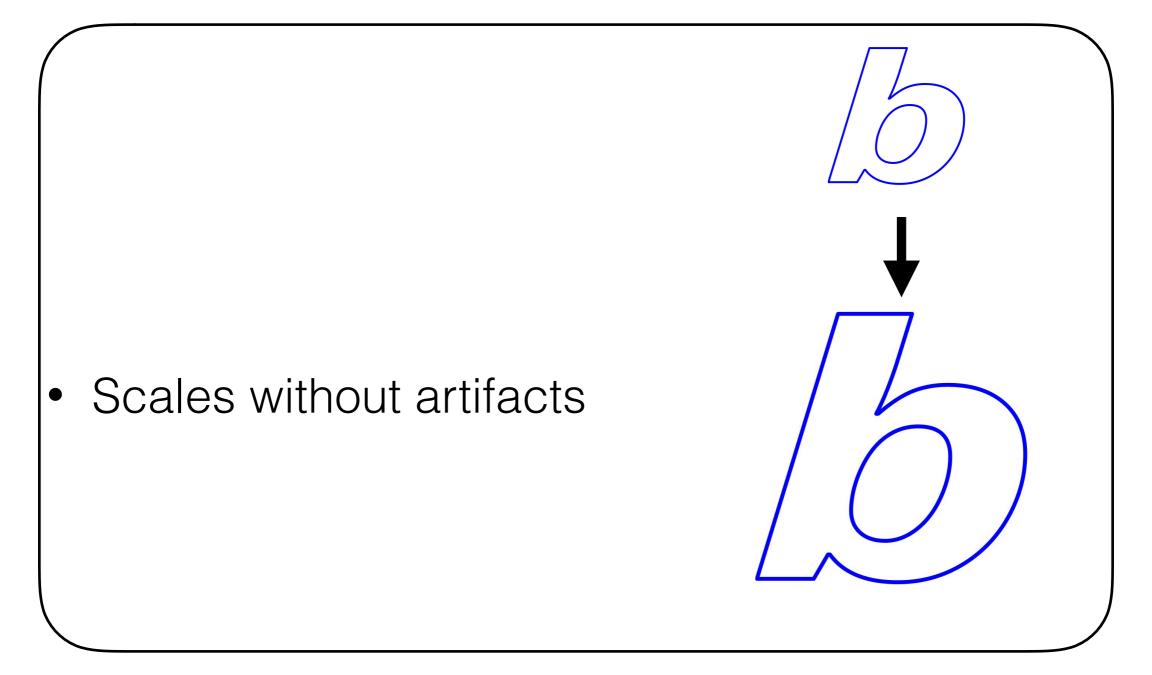


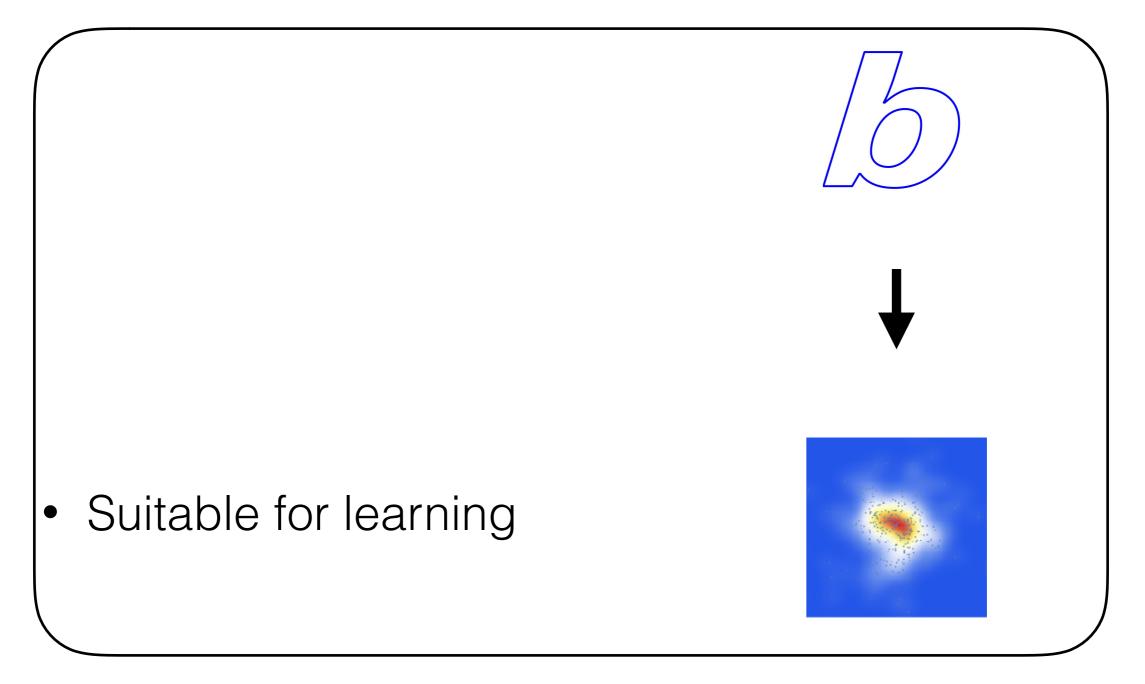
Motivation

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











- Raster Based
- Contour Based



Raster - Based

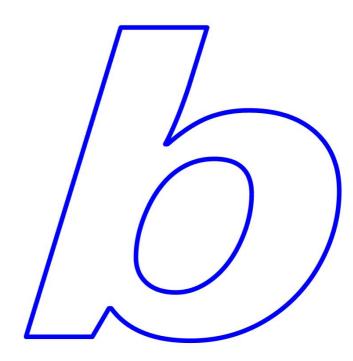
student

Limitations

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



Contour-Based

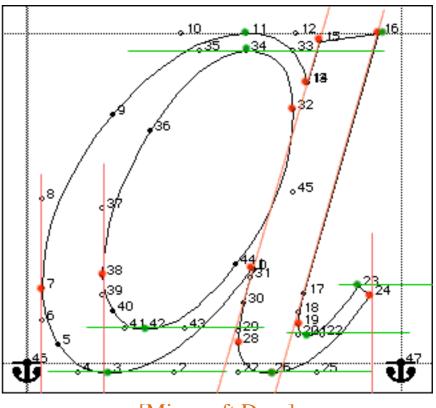




Bezier-Based



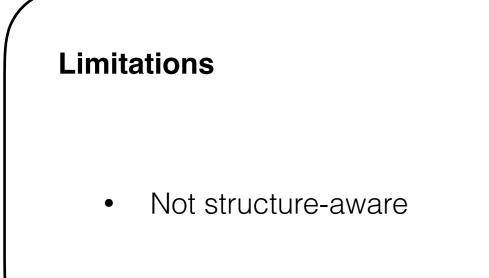
• Not suitable for learning

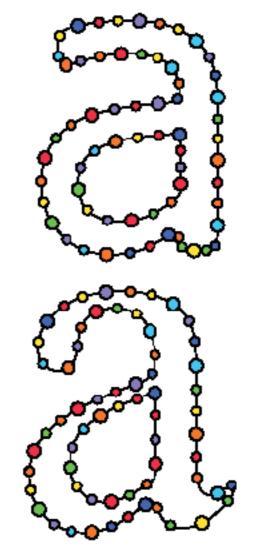


[Microsoft Docs]



Consistent Outline-Based





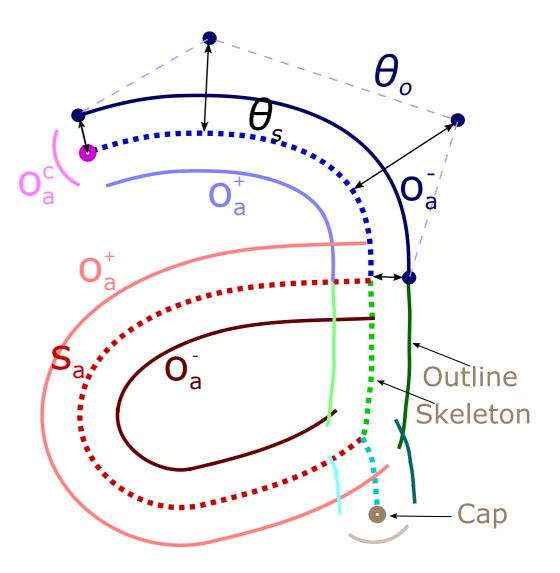
[Campbell '14]



Proposed Representation

Characteristics

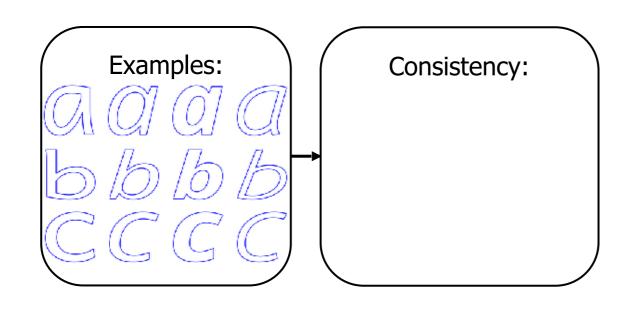
- Detail-preserving
- Structure-aware
- Scales without artifacts
- Suitable for learning

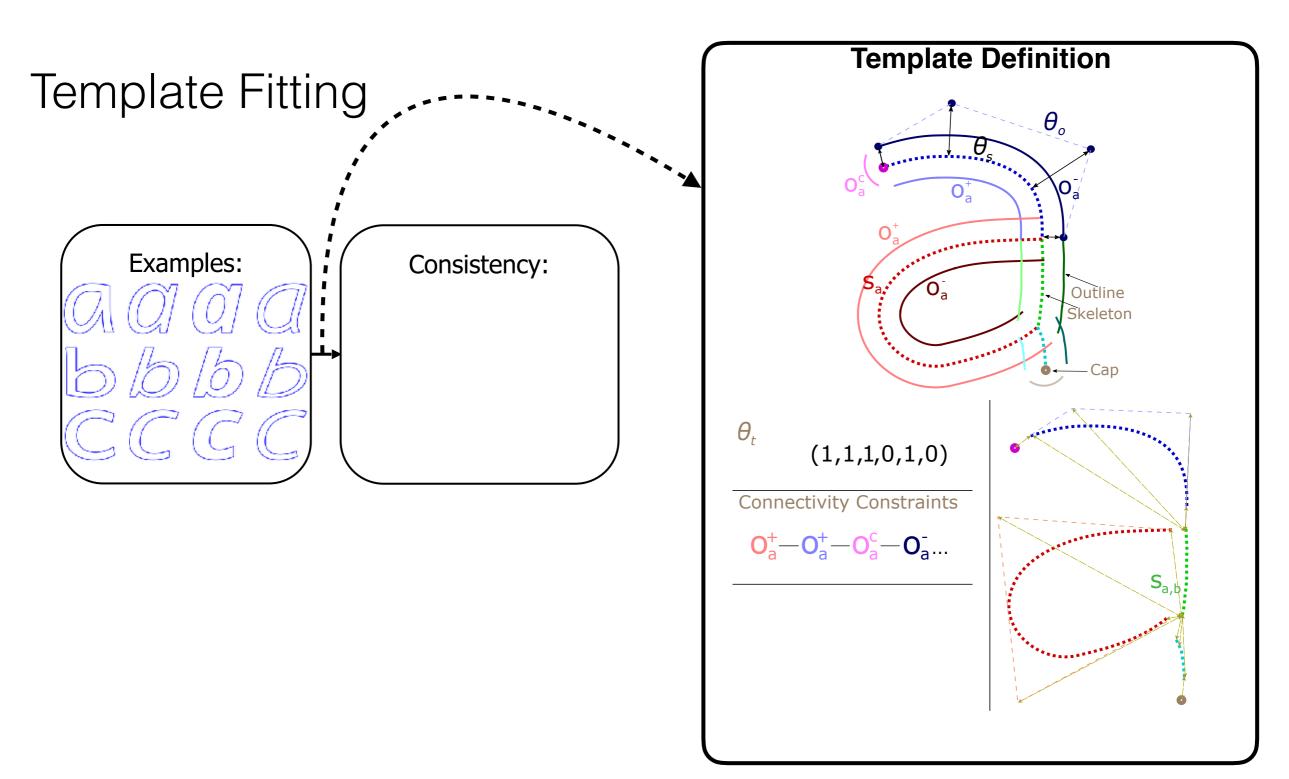


Part-Aware

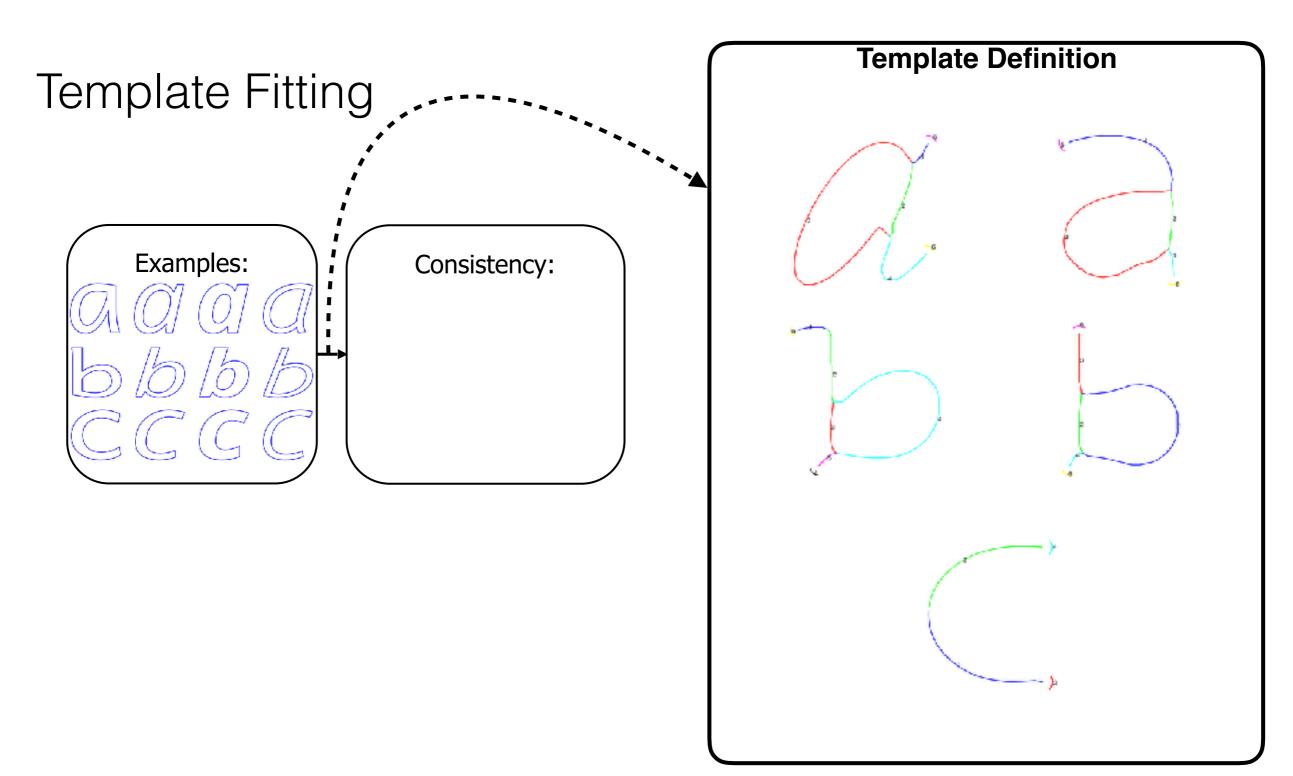
Skeleton-Based Representation



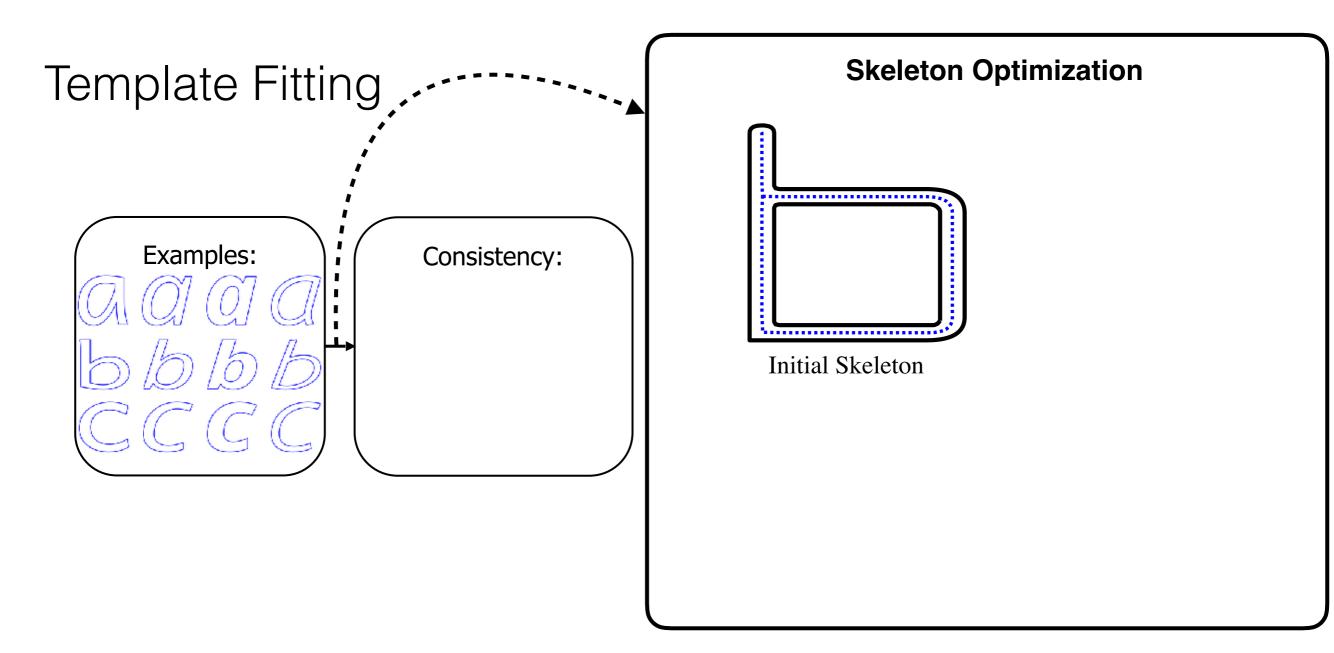




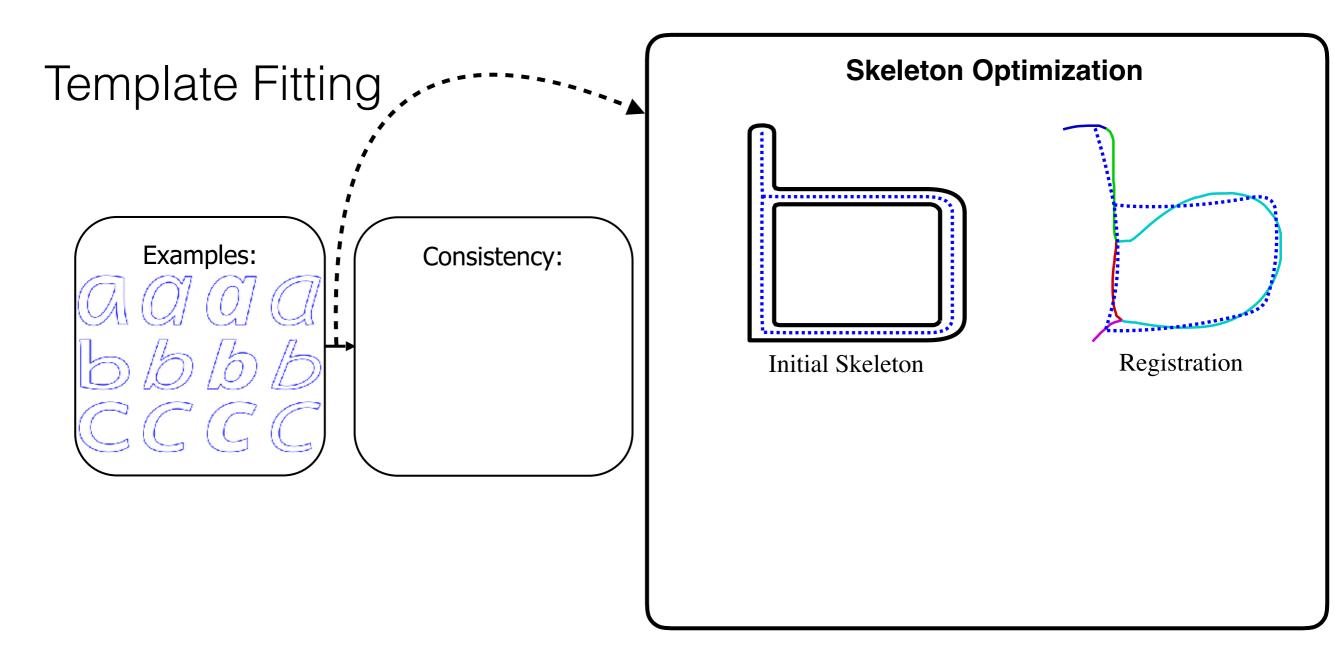




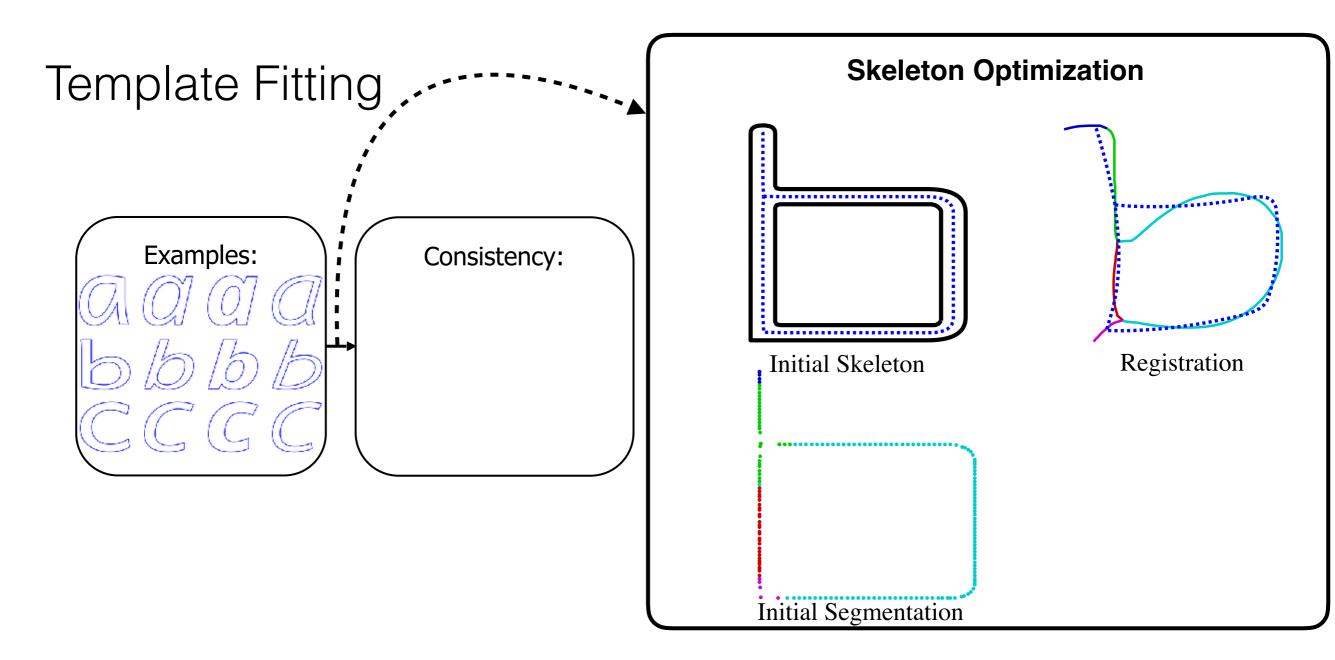




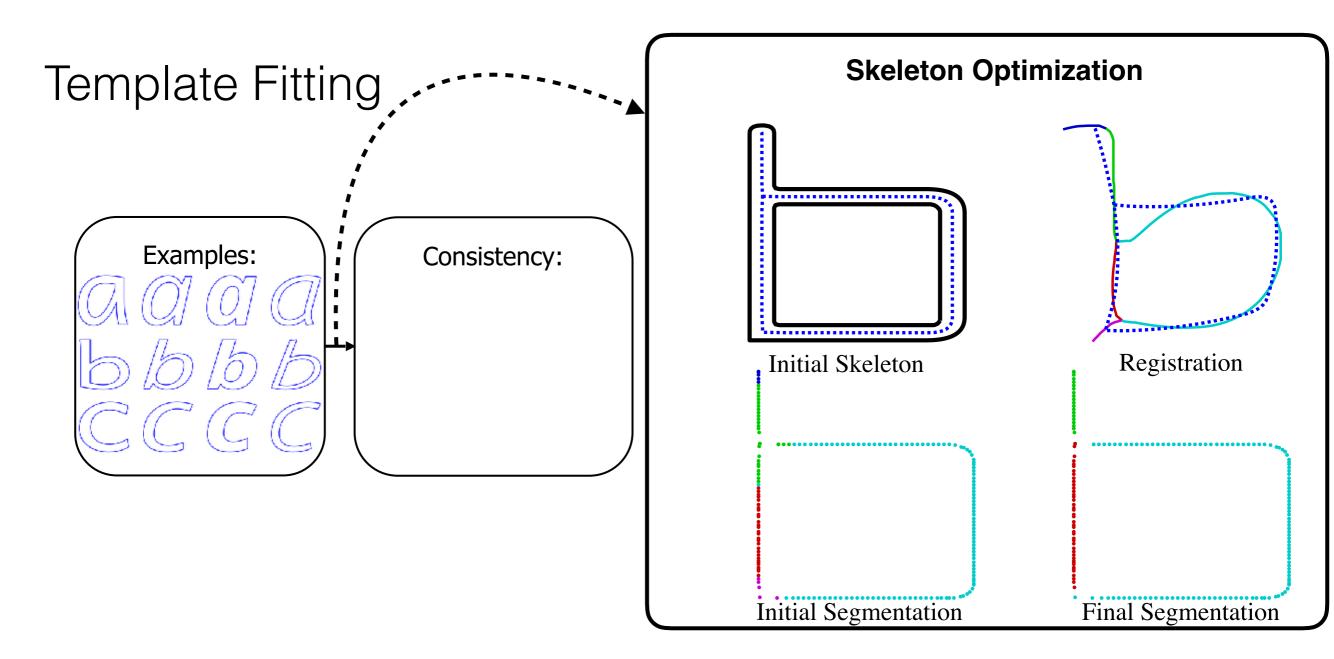




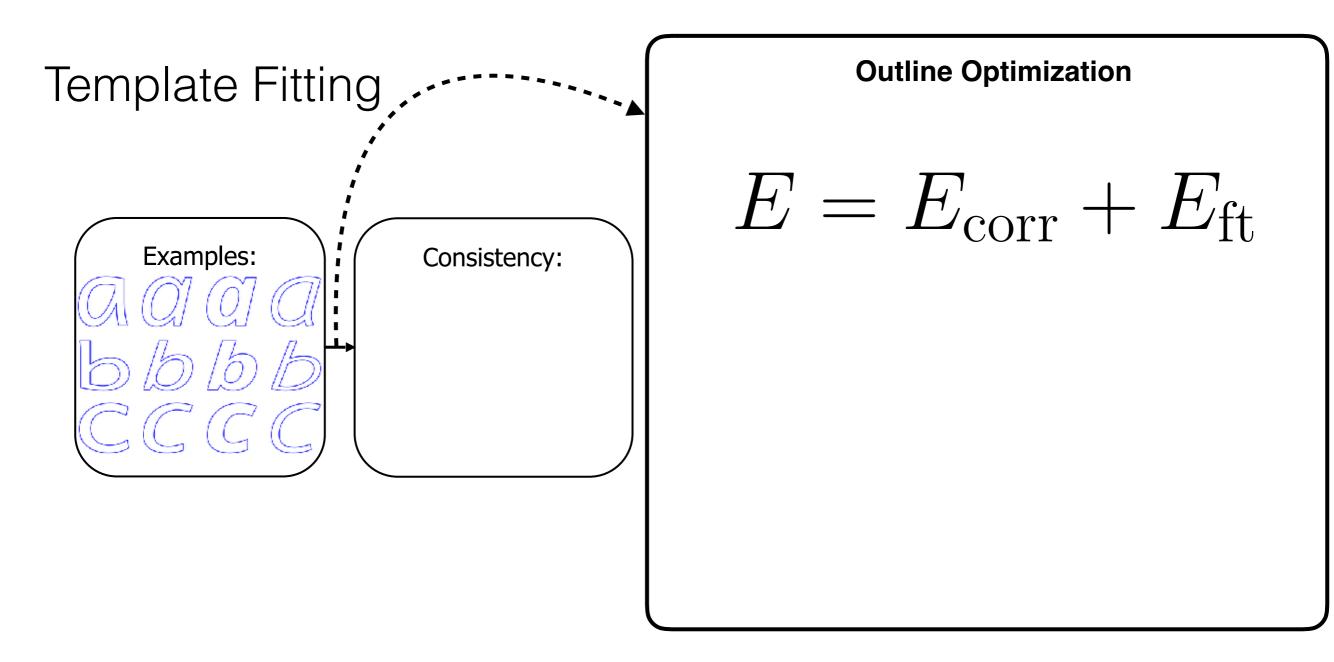




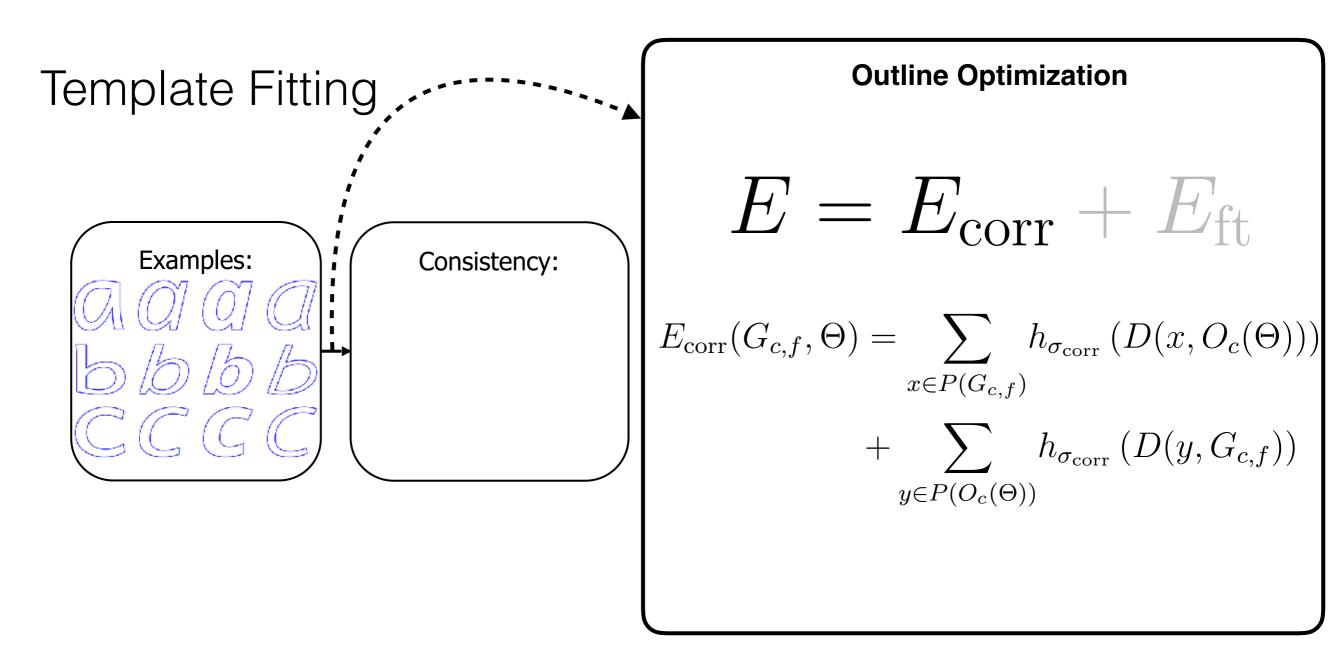




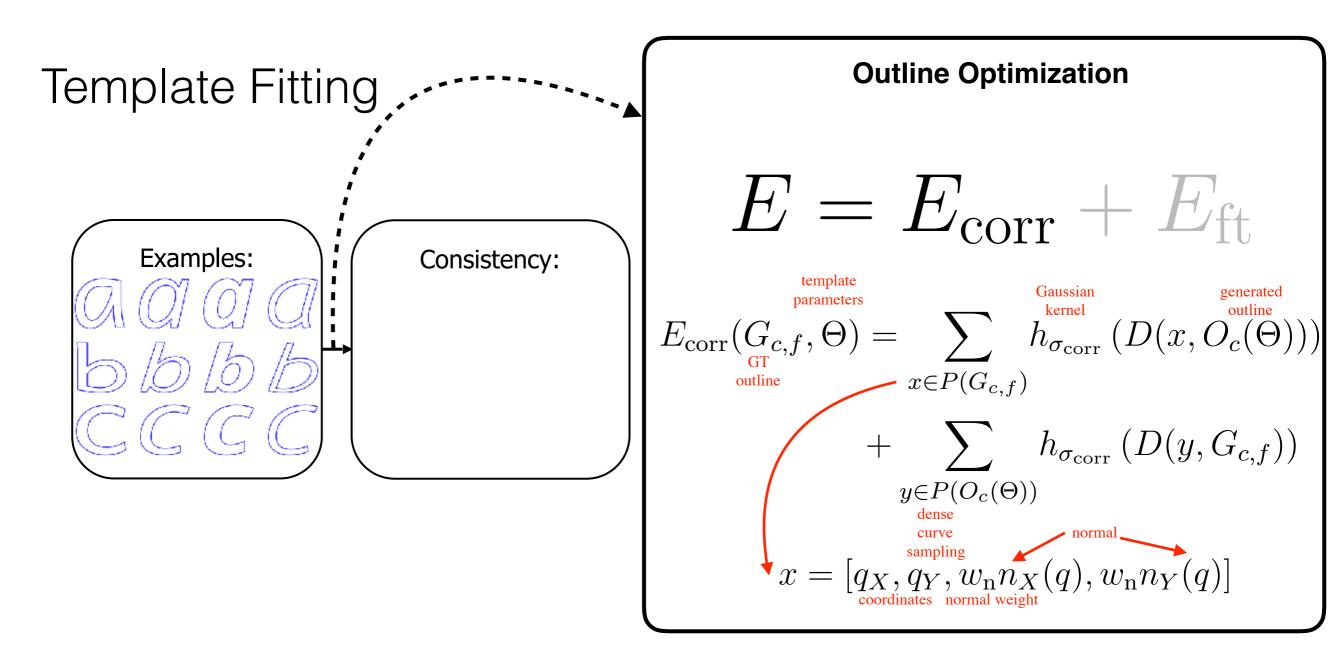




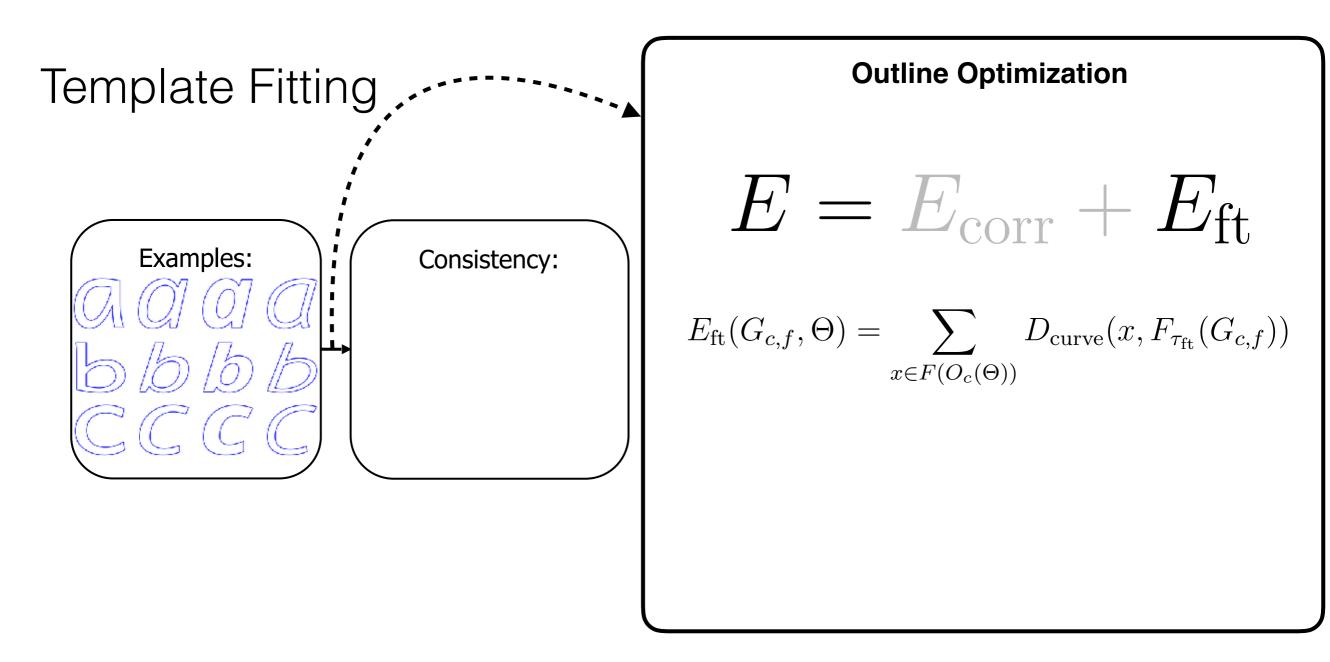




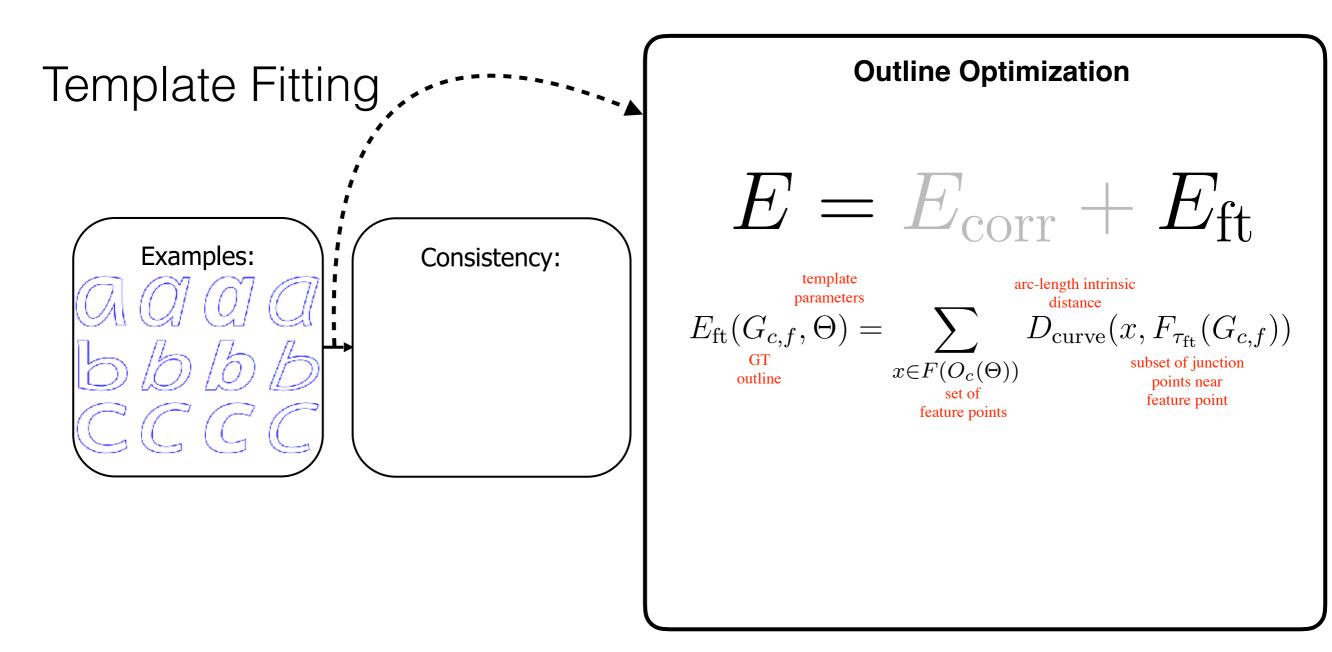




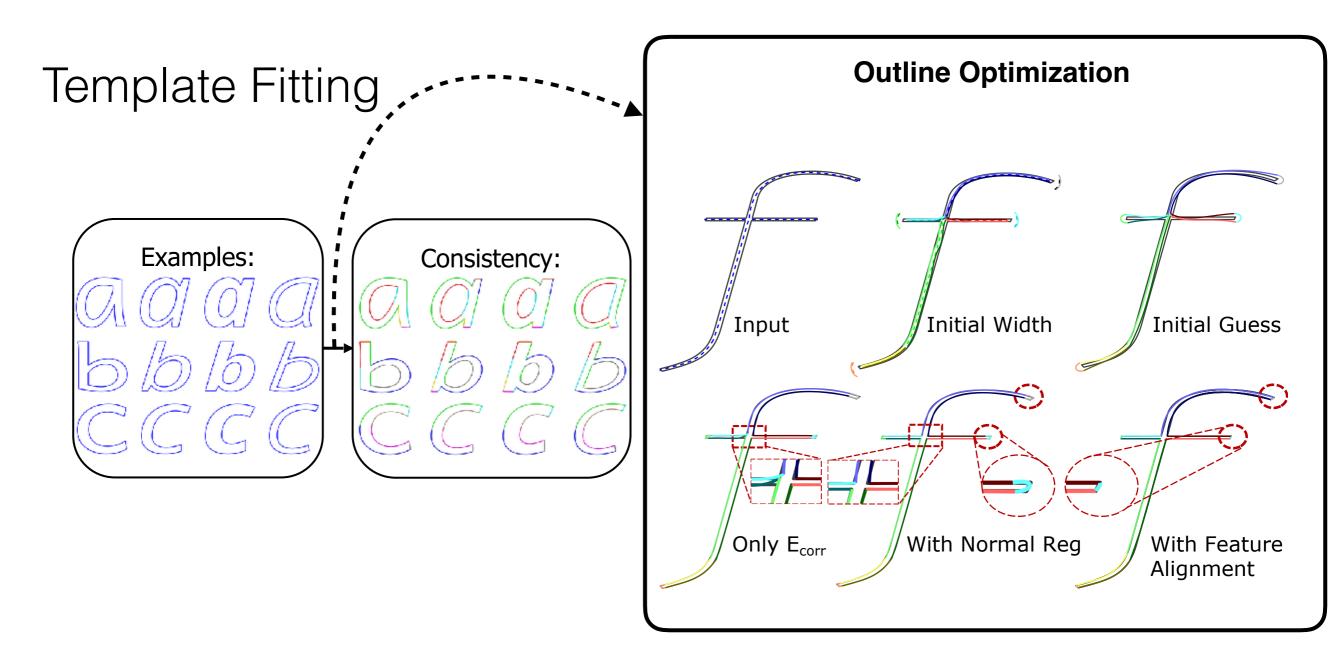




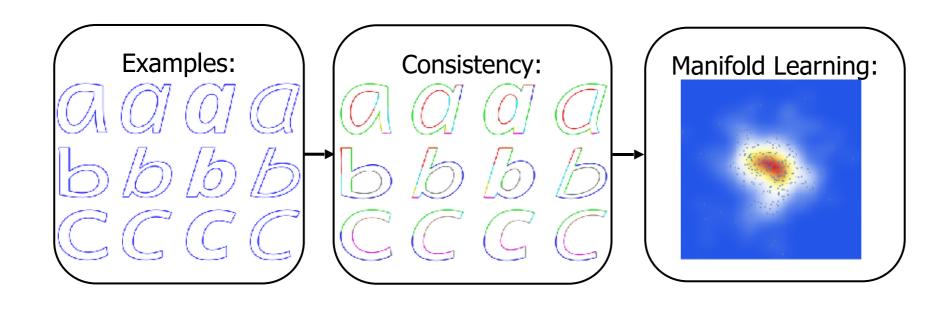




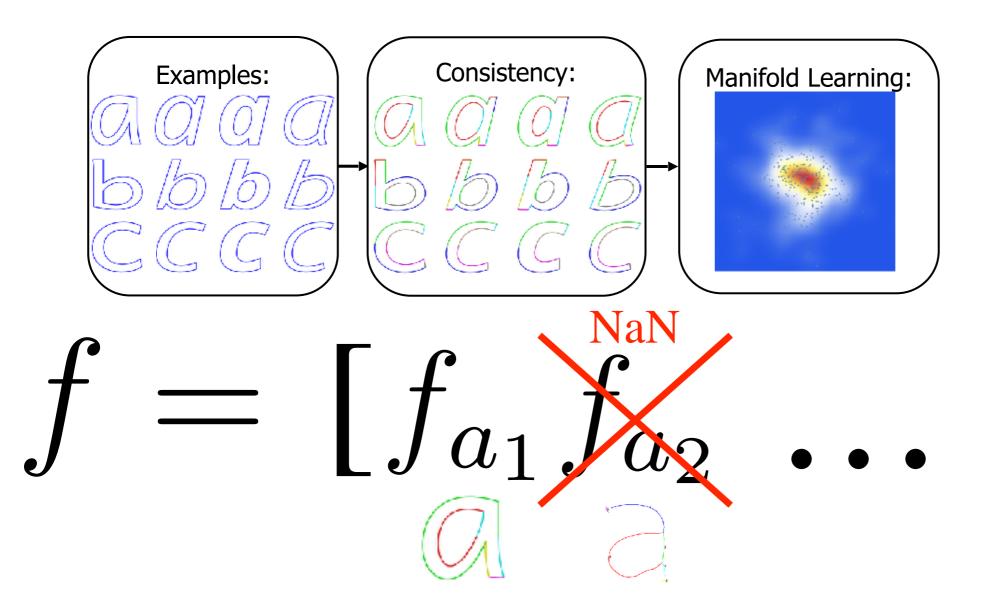




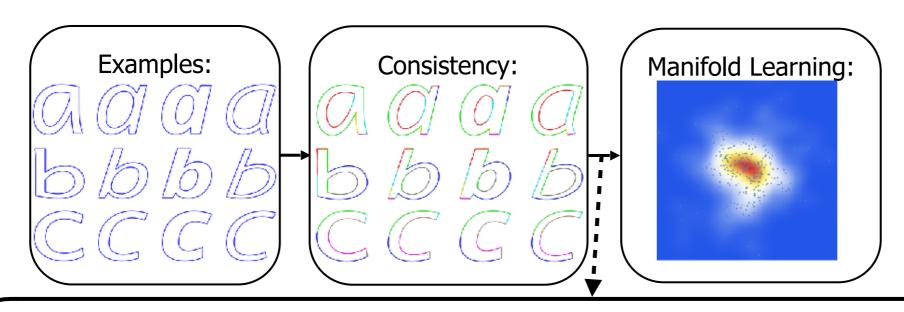






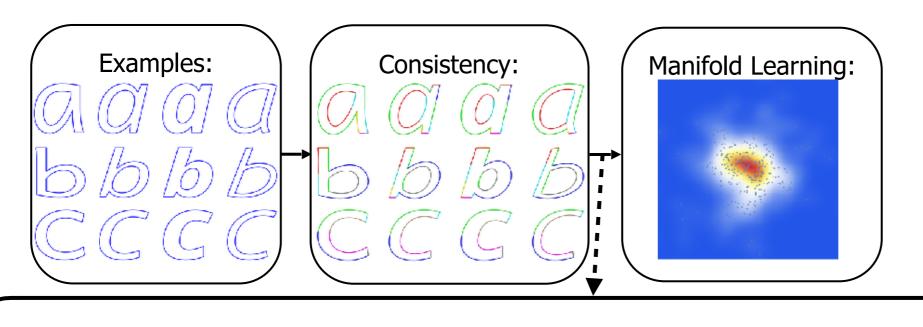






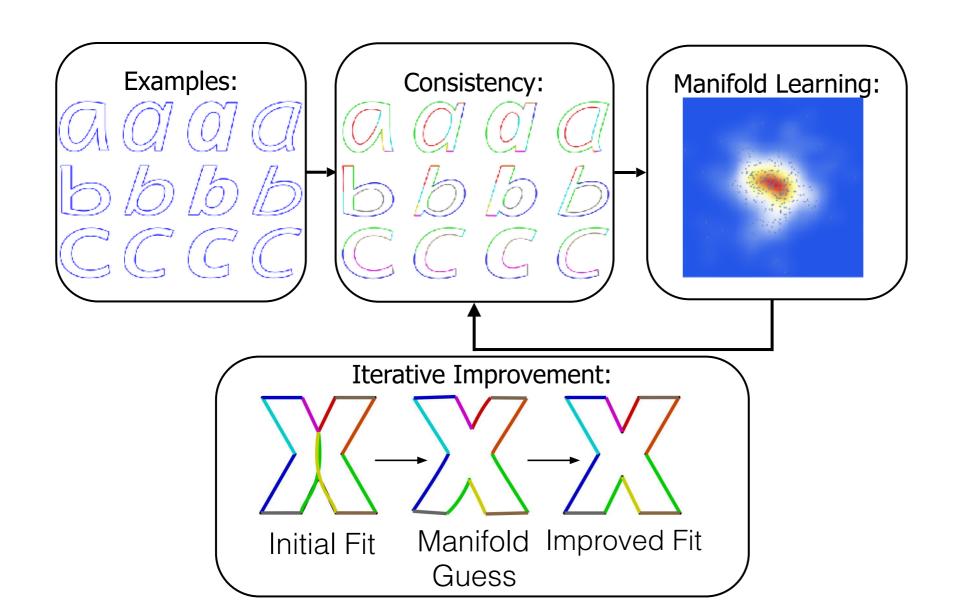
EM-PCA [Row98] Latent Input Vectors coordinates Y = CX + VTransformation Noise Matrix





EM-PCA [Row98] Input Latent Vectors coordinates Y = CX + VTransformation Noise Matrix E-step: $X = (C^T C)^{-1} C^T Y$ M-step: $C^{new} = YX^T (XX^T)^{-1}$



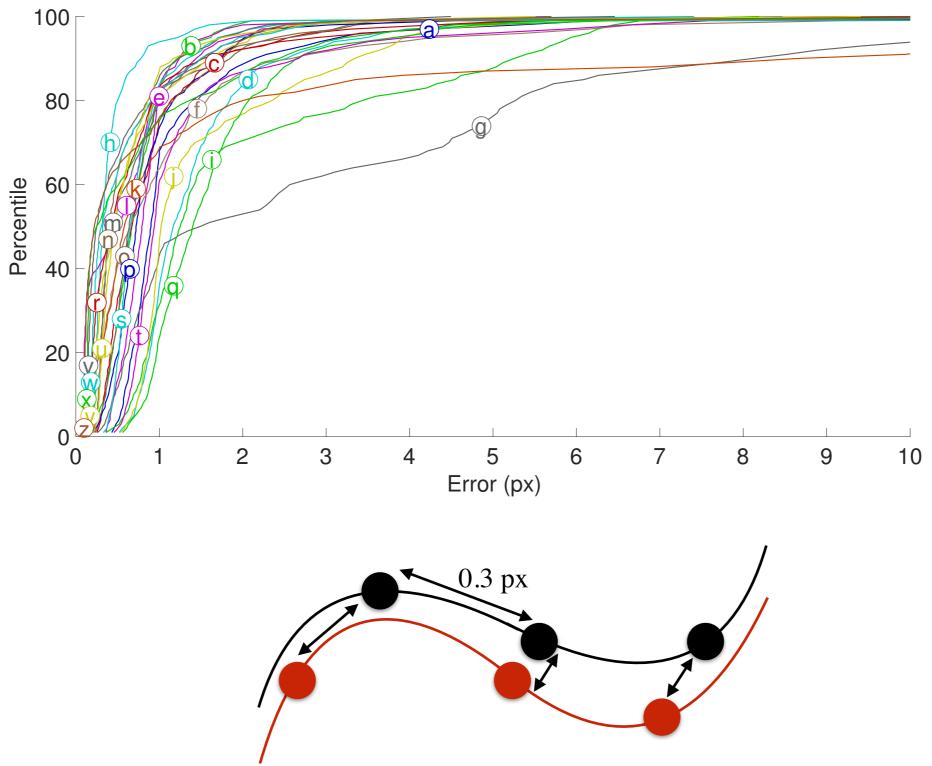




Fitting Results

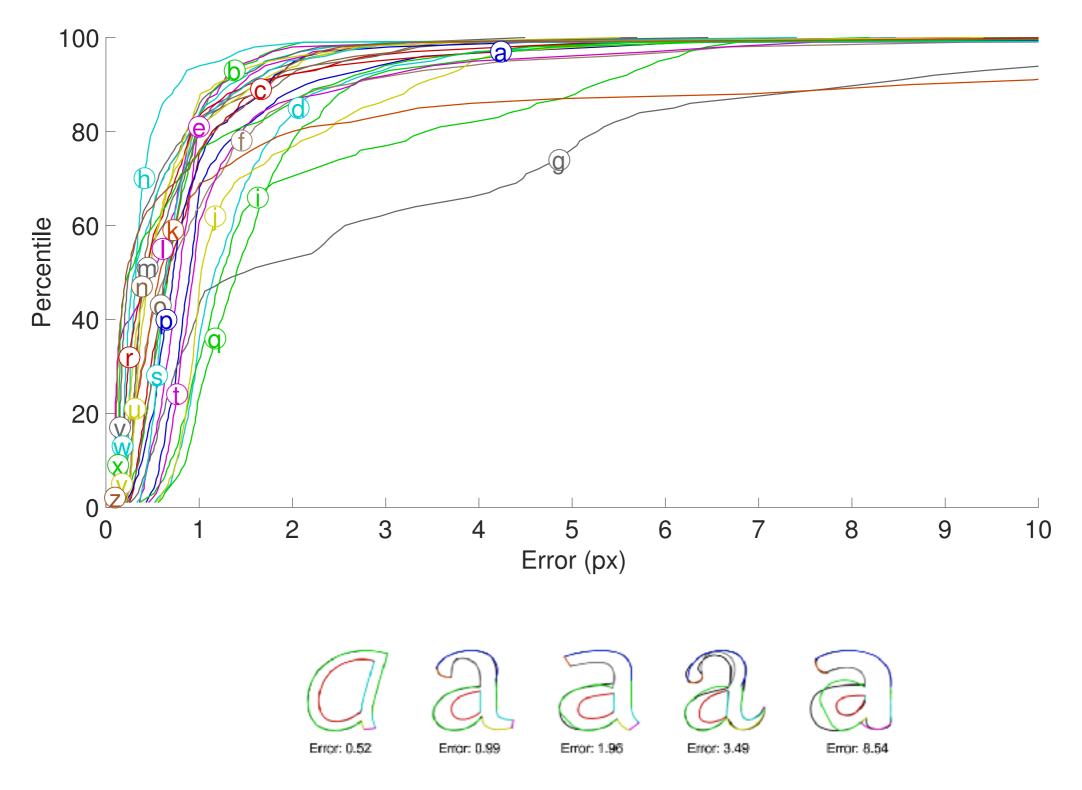


Fitting Results



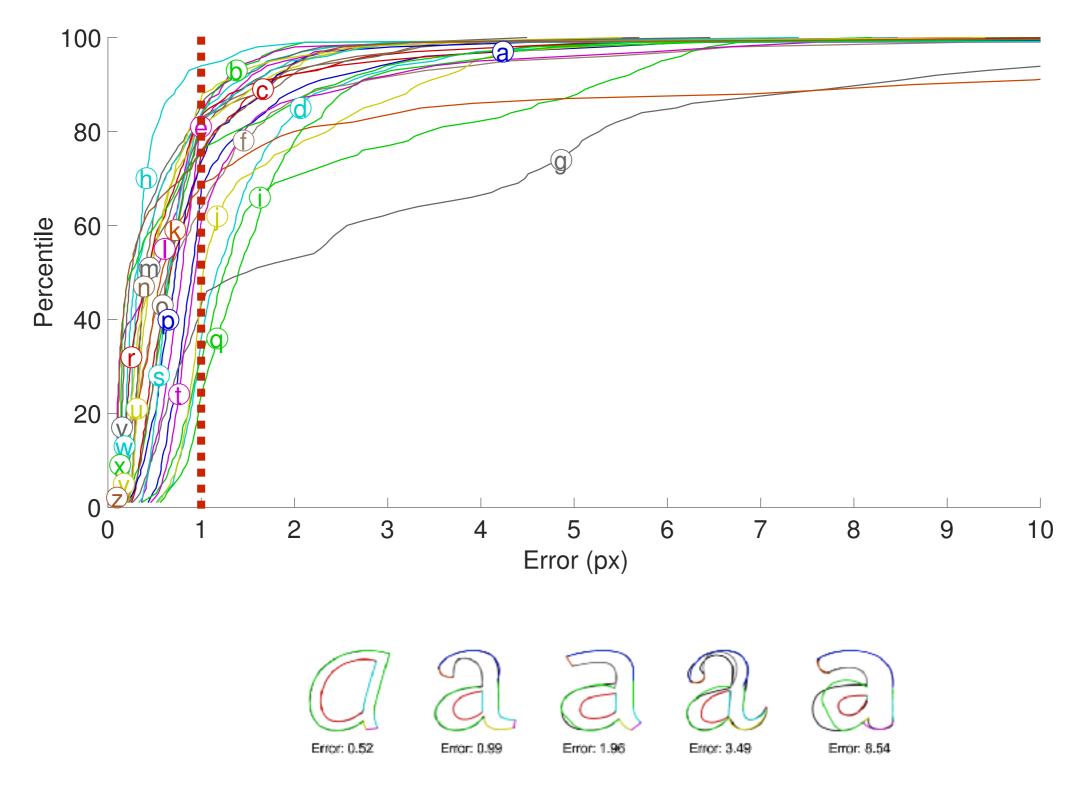


Fitting Results



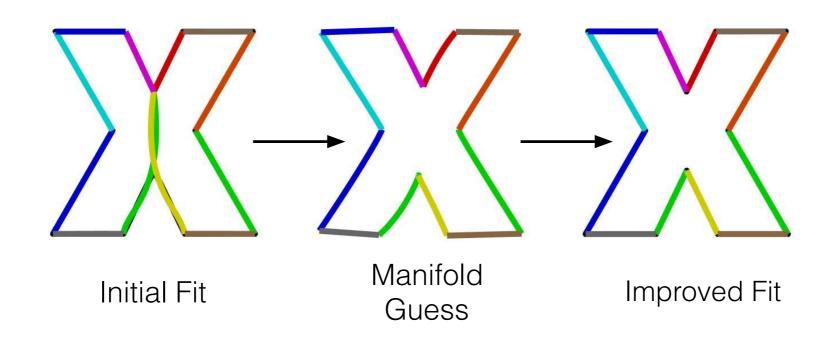


Fitting Results

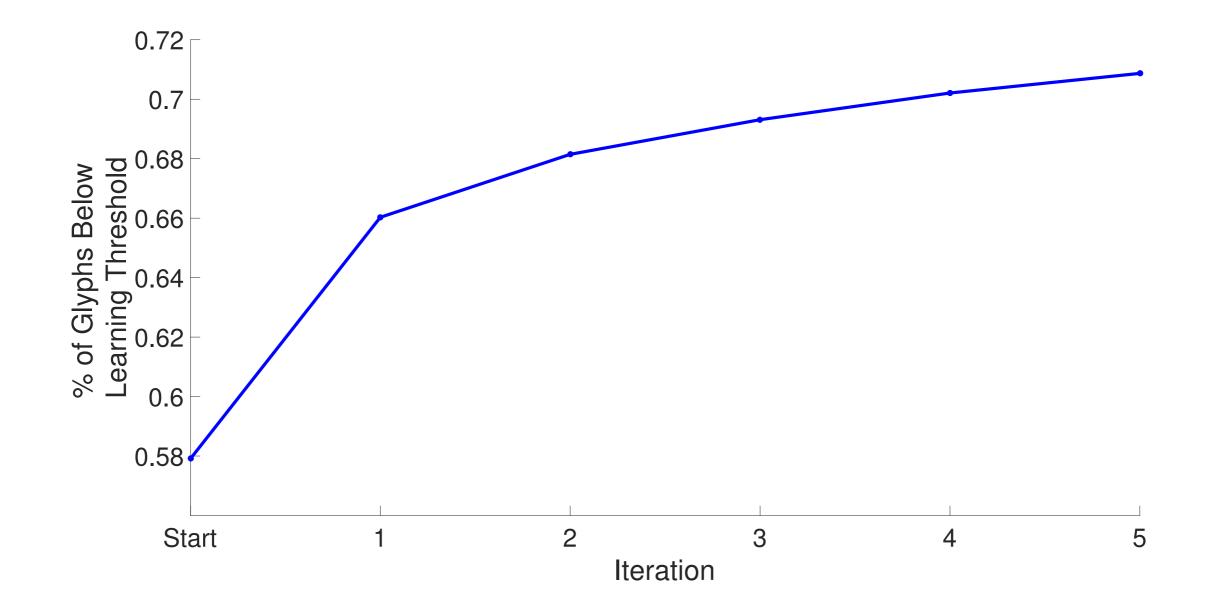




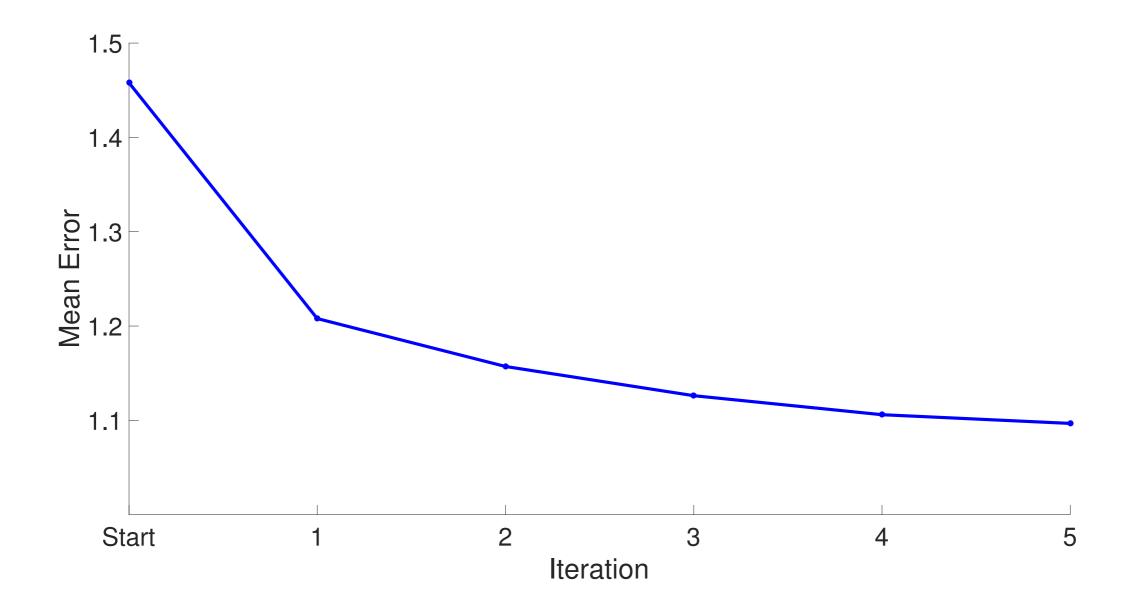














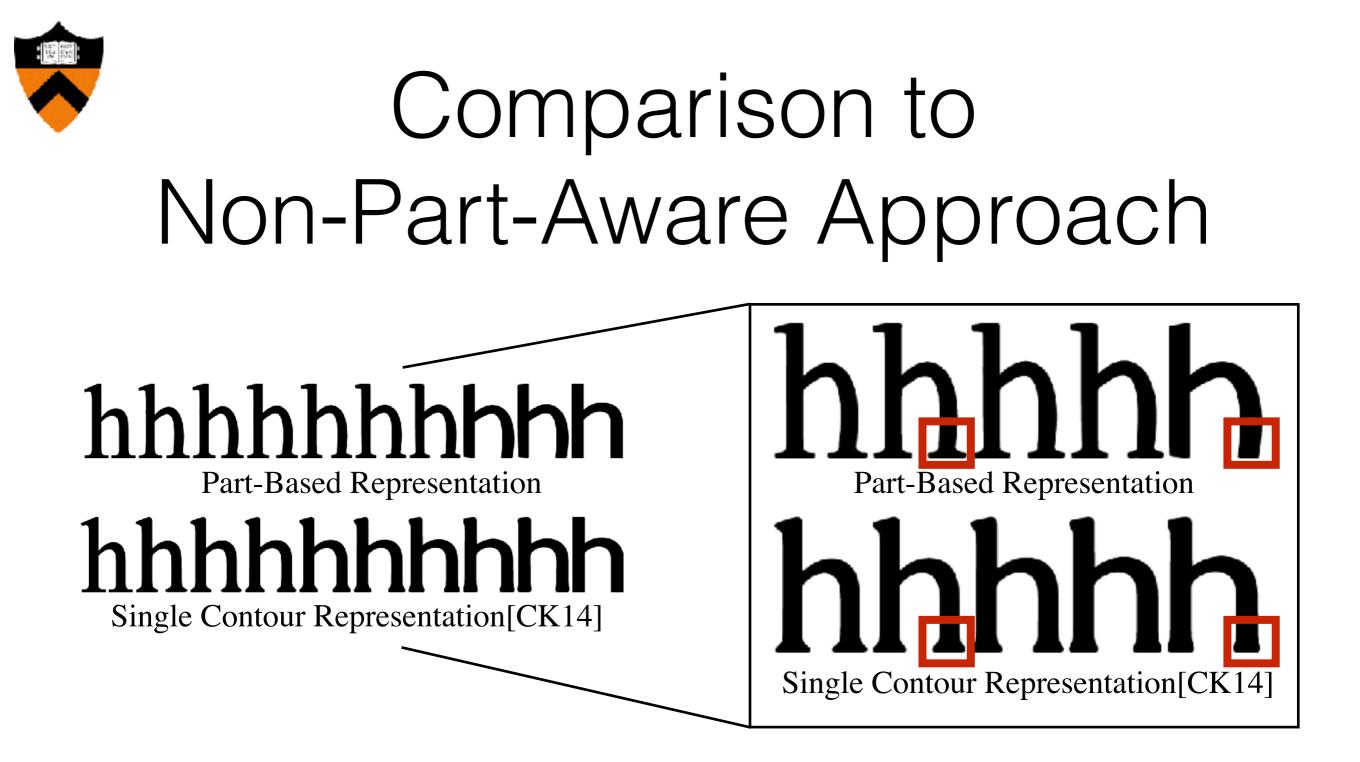
Comparison to Non-Part-Aware Approach

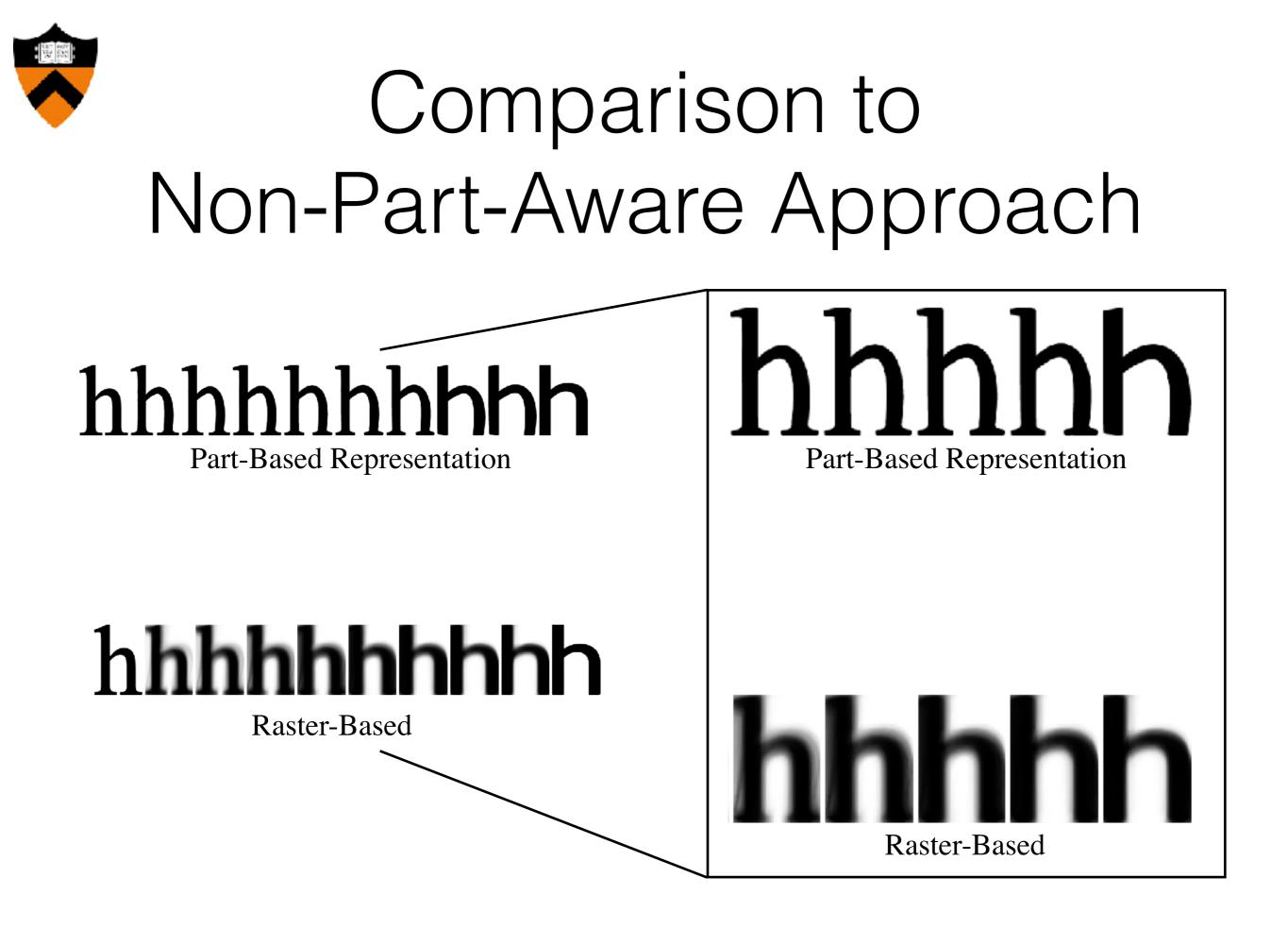


Comparison to Non-Part-Aware Approach

hhhhhhhhhh

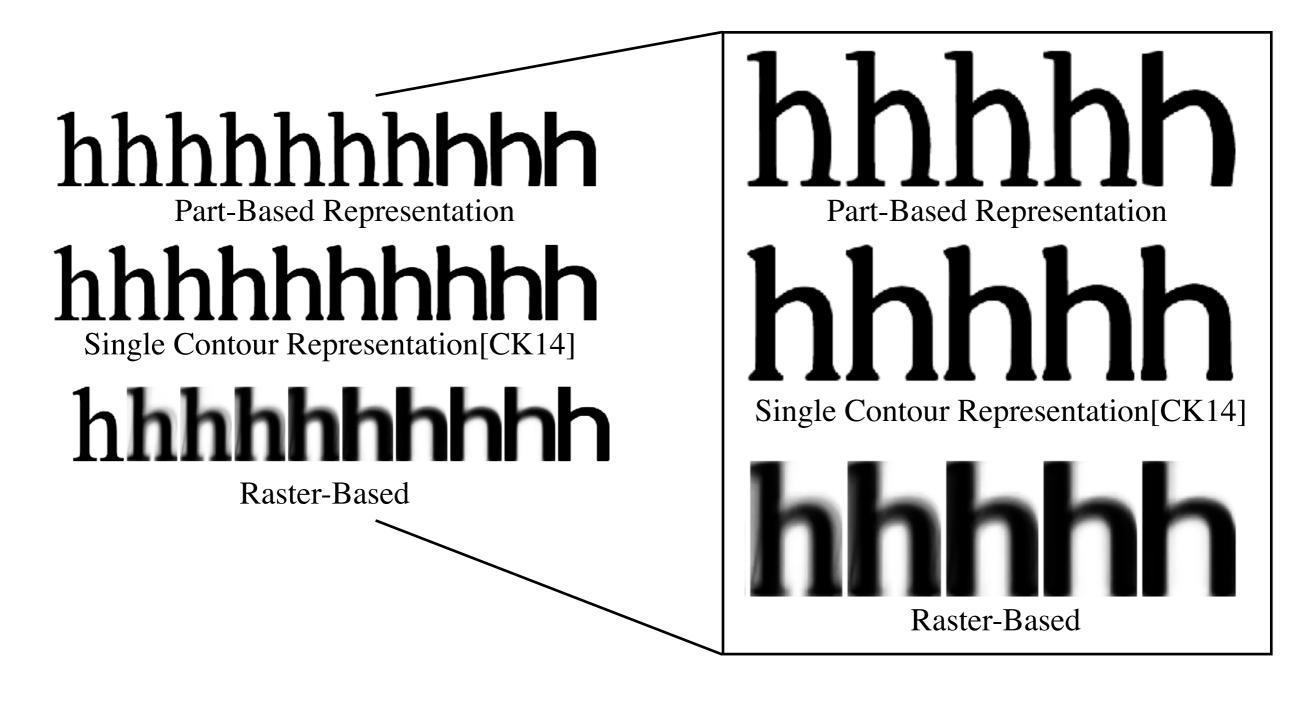
Part-Based Representation







Comparison to Non-Part-Aware Approach

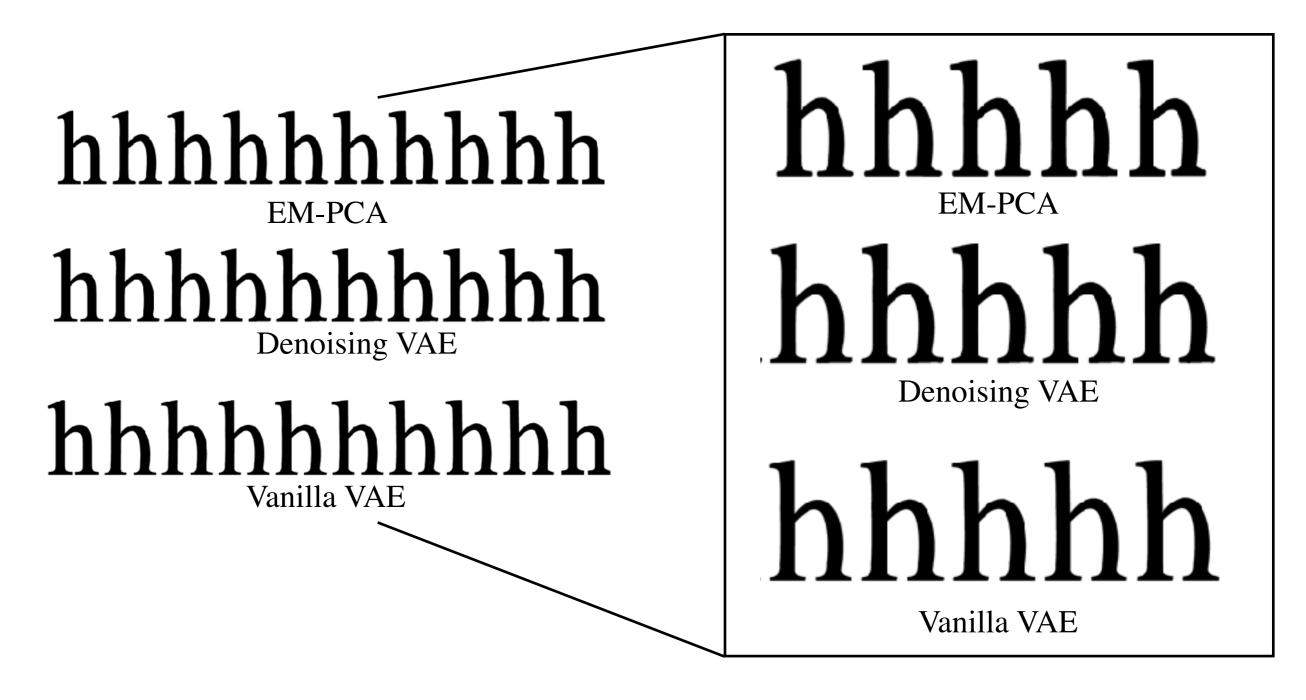




Generative Model Comparison

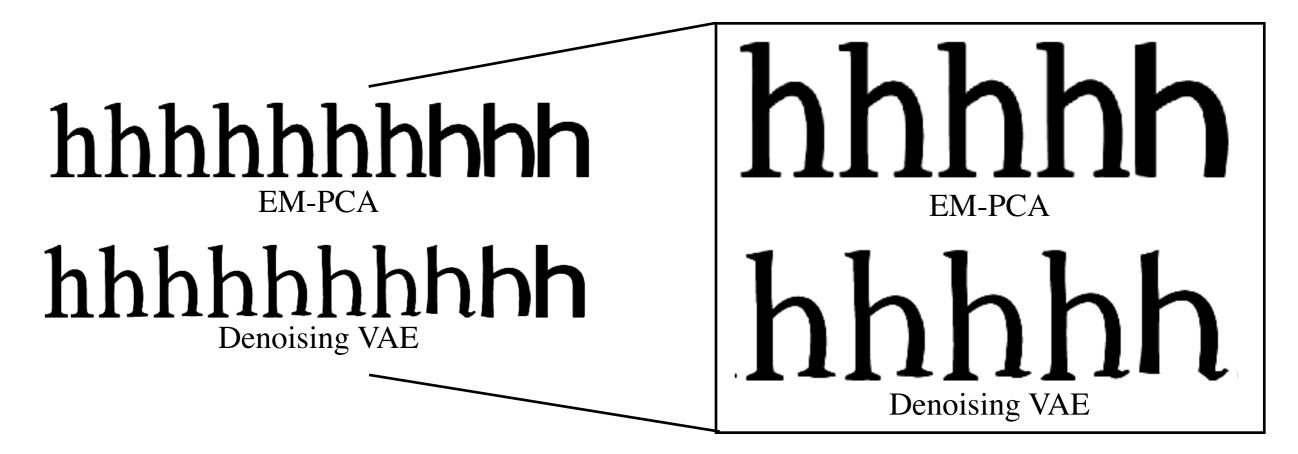


Generative Model Comparison





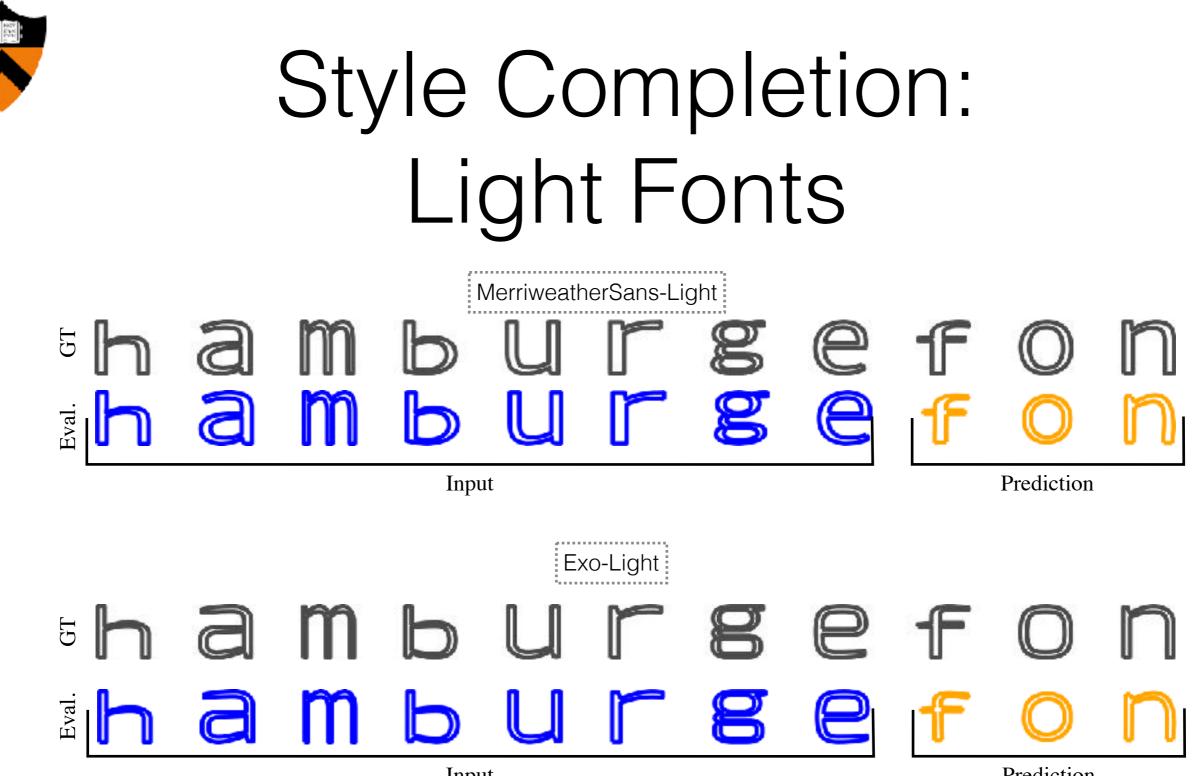
Generative Model Comparison





Applications



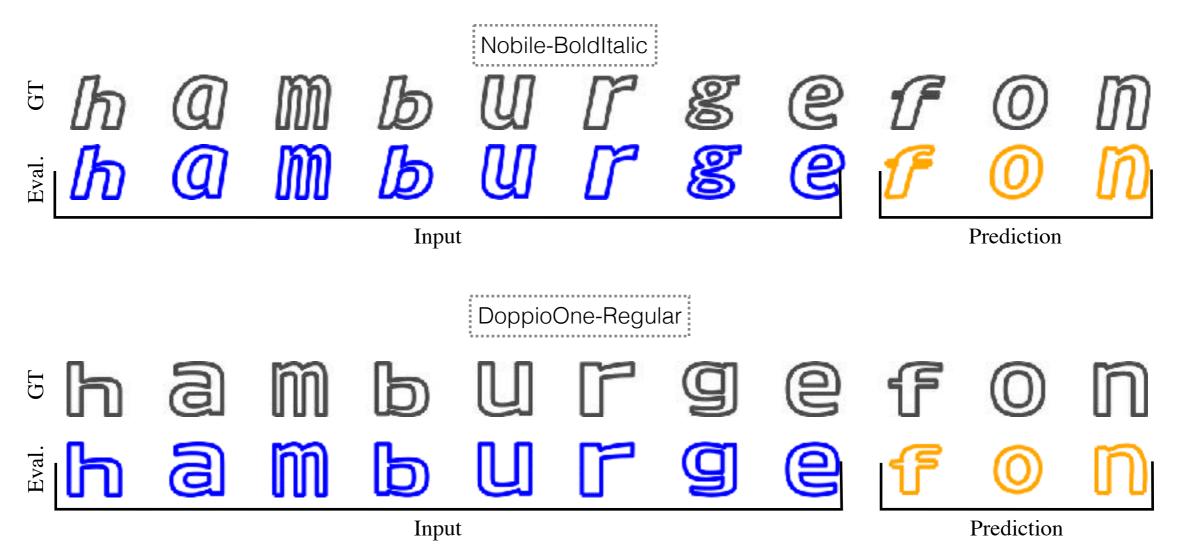


Input

Prediction

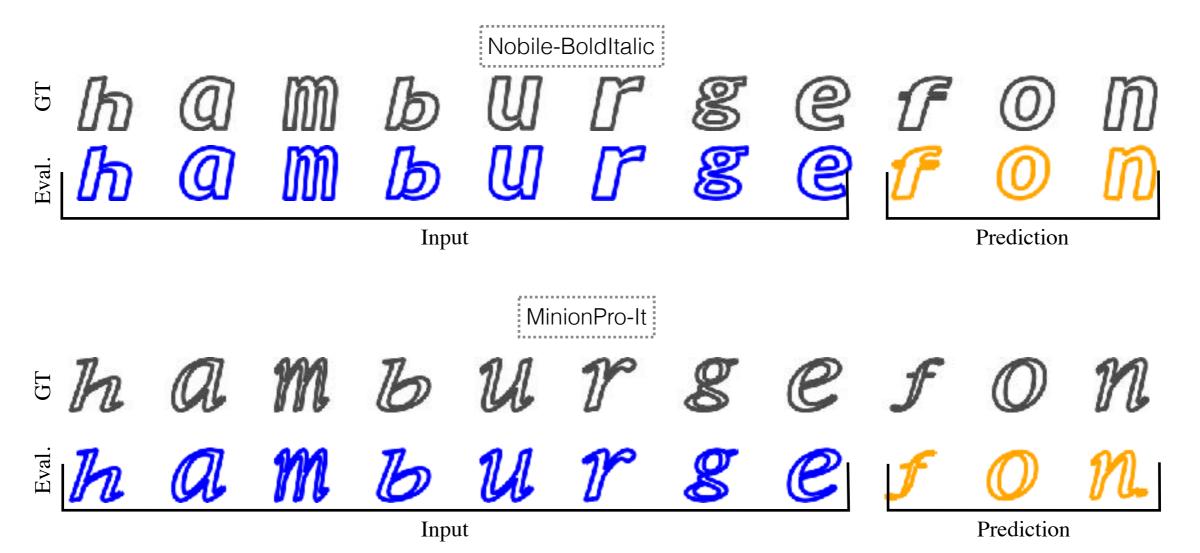


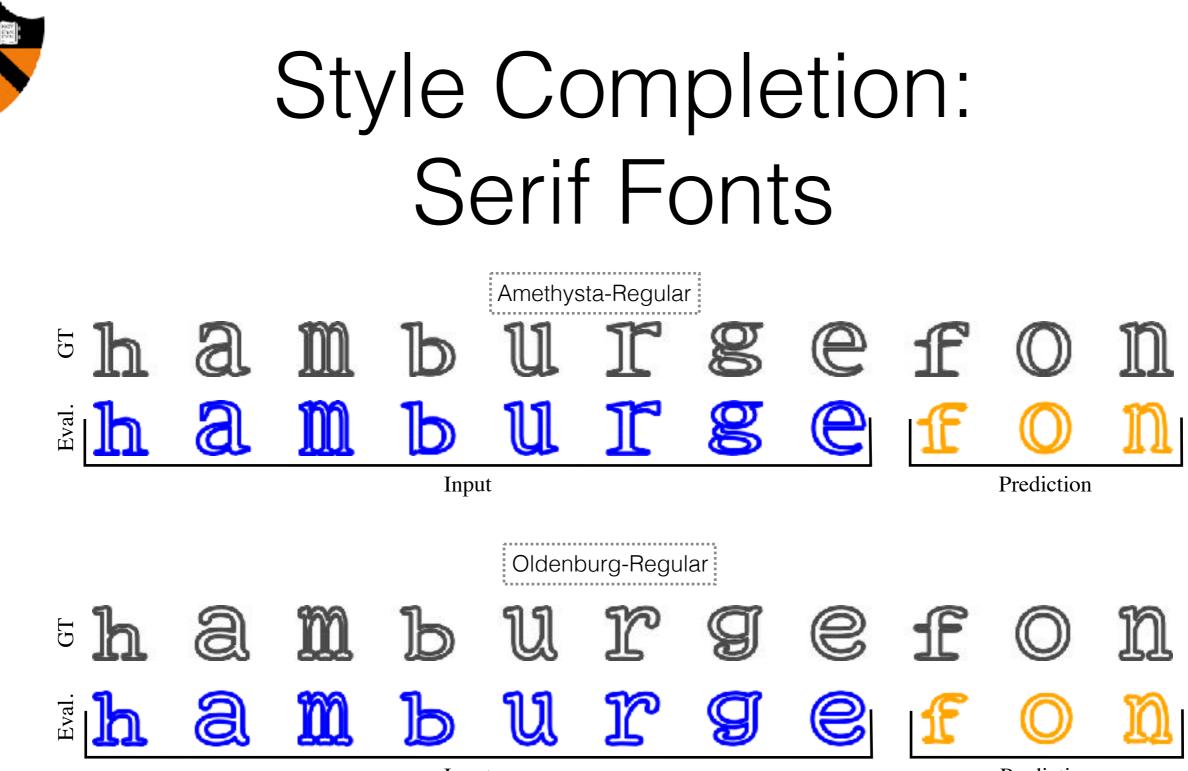
Style Completion: Regular/Bold Fonts





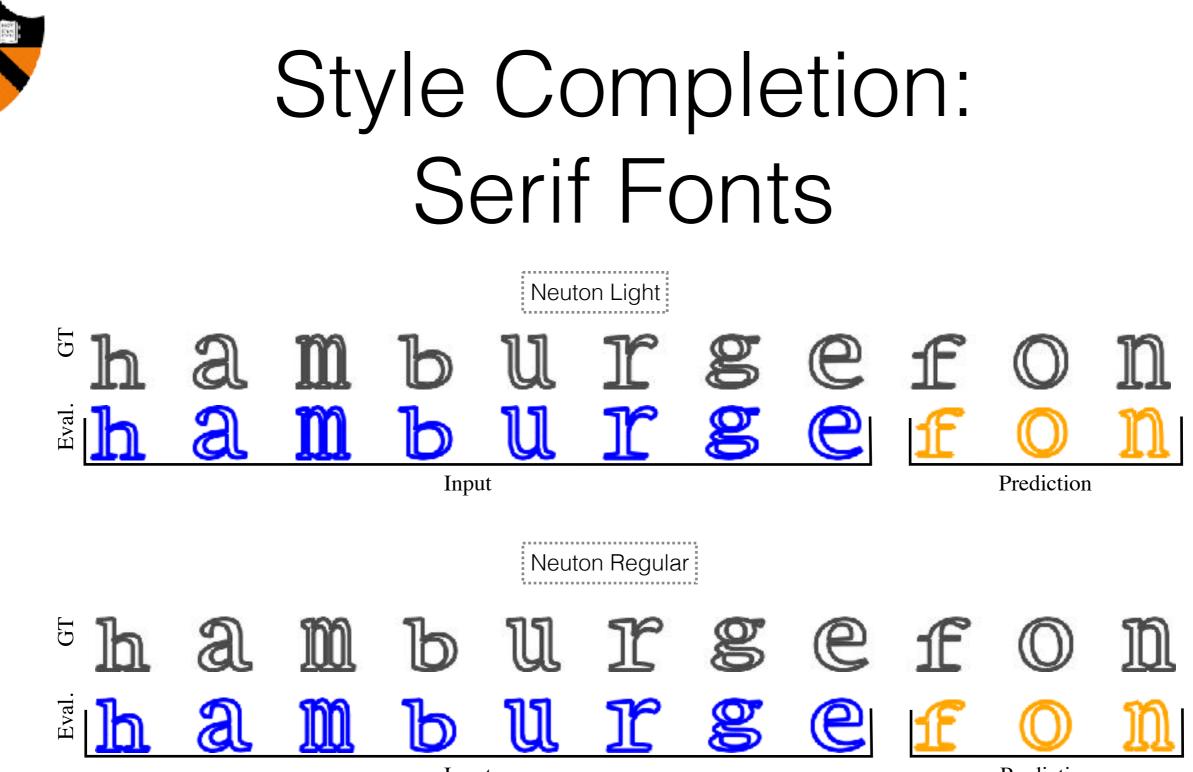
Style Completion: Italic Fonts





Input

Prediction



Input

Prediction







handgzovebcftjkmpqrstuwxyz handgzovebcftjkmpqrstuwxyz



handgzovebcftjkmpqrstuwxyz handgzovebcftjkmpqrstuwxyz handgzovebcftjkmpqrstuwxyz



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h	a	n	đ	g	72	0	V	e	Ь	C	ſ	ž	Ĵ	k	M	P	q	ſ	S	Ċ	U	W	X	ŀ	Z
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h	Ø	n	đ	g	72	0	V	e	Ь	C	ſ	Ń	Ĵ	k	M	P	q	ſ	S	Ċ	U	W	×	Y	Z



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



h a n d 9 Z o V e b C f t j k m p q r s t u w X Y Z h a n d 9 Z o V e b C f t j k m p q r s t u w X Y Z h a n d 9 Z o V e b C f t j k m p q r s t u w X Y Z h a n d 9 Z o V e b C f t j k m p q r s t u w X Y Z h a n d 9 Z o V e b C f t j k m p q r s t u w X Y Z h a n d 9 Z o V e b C f t j k m p q r s t u w X Y Z



and g Z ovebcftjk mpgr h хУZ S ndgzovebcfijkmpqr 5 17- 11 1 W X V ha ndgzovebcfijkmpqr 1E U W X V ha S handgzovebcfijkmpqrstuwxy handgzovebcfijkmpqrstuwxy d g Z O V E b C f t j k M P q F S t U ha n handgzovebcfijkmpqrstUw XV handgzovebcfijkmpqrstuwxy



and gzovebcftjkmpgr h S XYZ ndgzovebcfijkmpqr ha 5 1 II W X V ndgzovebcfijkmpqr ha S handgzovebcfijkmpqrstuw handgzovebcfijkmpqrstu ha ZOVEbCftjkmP9F S n handgzovebcfijkmpqr S h a n d g z o v e b c f t j k m p q r s t u w x y handgzovebcfijkmpqrstUw



and gzovebcftjkmpgr h S XYZ ndgzovebcfijkmpqr ha 5 11-11 XV ndgzovebcfijkmpqr ha S handgzovebcfijkmpqr S te U W handgzovebcfijkmpqrstu ha S n ZOVEbCfijkMP9Г S handg handgzovebcfijkmpqrstu handgzovebcfijkmpqrstuw XY handgzovebcfijkmpqrstuwxy



ebcftjkmpqr and g 72 0 V h Ŝ УZ ijk M P q r ha d g Z O V E b C f 5 XV n ≁ ha nd g ZOVEBCF tjkMP9Г handgzovebcfijkmpqr S 1 U handgzovebcfikmpqr S 17 ha ₹ j k M 5 n e F P qijk M D Q F ha D d ZOVEBCF S ZOVEbCfijkMP9F ha $\square d g$ S handgzovebcfijkmpqrs V ZOVED CffjkMP9r ha nd g S 7 handgzovebcfikmpqr st u X



and g 72 0 V bCftjkmpqr h e Ŝ УZ ijk M P q Г ha d g Z O V E b C f 5 XV n ha ZOVE ЬCf tjkMP9F n d handgzovebcfijkmpqr S £. handgzovebcfikmpqr S 17 ha j k M 5 n e F -Ľ D qha D d 7Z (O) V e Ь C ſF ij k M P 9 F S h a $\square d g$ ZOVEbCfijkMP9F S handg ZOVEbCfijkMP9r S F k m p q r ha n Ne ณี 7 S 7L (O) ha റെ ർ q 7Z (O) M еb C f ijk M P 9 r S handgzovebcftjkhpqrstUw



and gzov CFtjkmpqr h e S y z ijk M P 9 F ha d g Z O V E b C f 5 n ha ZOVe bCf tjkMP9f D d handgzovebcfijkmpqr S 1 handgzovebcftjkmpqr S 17 F ha n e -Ľ j k M \square Ø hand ij k M D Q F 7Z (O) V e Ь C ſF S h a ndgzovebcfijkmpqr S handgzovebcfijkmpqr S ha n Ń k M \square Q 7L (O) e - 1F 7 F ha n \mathcal{N} e デ j k M D Q handgzovebcftjkhpqrstU XYZ handgzovebcfijkhpqrstuwxy



and gzov Cfijkmpqr h e S y z tjk MP9 ha d Q ZOVEBCF 5 n ha 7. OV e bCf tj k M P D d Q F handgzovebcfijkmpqr S 17 handgzovebcftjkmpqr S 17-ĴĒ. ha n e -Ľ j k M \square Ø 式 j k M ha ി രി 7Z (O) V P Б C F D O 5 $\square d g$ ZOVEbCfijkMP9Г ha S handg ZOVEbCfijkMP9ľ S ha n Ń \square Q e ha n e k D F Ť 71 ZOVEbCftjkhPqr ha nd g S t handgzovebcfijkhpqrstü XYZ 12/ handgzovebcfijkmpqrstU WXY Z



and gzov Cfijkmpqr h S y z tjk M P 9 ha Q ZOVEBCF \$ n ha 72 (0) \mathbb{V} e Ь C f tj k M P q handgzovebcfijkmpqr S 17 handgzove bCfijkmpqr S ha F -Ľ ープ k M \square Ø e モゴ k M ha n d 72 (0) V P ſF D 5 D d gZOVEbCfijkMP9Г ha S handg i k M D q r ZOVEBCF S ha D n e TĽ. ha n 71 ZOVE ha n Cftjkmpqrg Ь S handgzovebcfijkmpqrst XV ſ ha $\square d g$ ZOVE Ь *i j k h P q r* St XV \mathbb{Z} handgzovebcfijkmpqrstu XY Z



and gzov Cftjkmpqr h S y z tjk M P 9 Q 7. OV e bC 1F \$ ha n ha 72 (0) \mathbb{V} e Ь C f t j k M \square handgzovebcfijkmpqr S 17 handgzove 6CfijkmP97 S ha F k M \square e ゼ ブ O) ha ി രി 72 (0) V P ſF τ j k D ZOVEbCfijkMP9Г ha റെ ർ q 5 handg i k M D q r ZOVEBCF S ha D n e TĽ. ha n ゴ ZOVE ha Cftjkmpqrn g Ь S handgzoveb CfijkmPqrStXV ha $\square d g$ 7Z (O) ve ſ i j k m P q r S Ь handgzoveb F I J k M P 9 r C S XY handgzovebcfijkmpqrstuw Z



and gzov CFtjkmpqr h Z tjk M P 9 Q 77. ON e bC 1F ha n 5 ha 72 (0) \mathbb{V} e Ь C 1Ē モj k M \square n d handgzovebcfijkmpqr S 17 handgzove $CfijkMPq\Gamma$ S Ь ha n F k M e ゼ 71 D O) ha D d 72 (0) V P ſF τ j k D $\square d g$ ZOVEbCfijkMP9Г ha 5 handg ZOVEBCF i i k M P q S ha n D e TĽ. - 71 ha n Ť 71 ha nd g ZOVE CftjkmpqrЬ S handgzoveb CfijkmPqrstXV ha $\square d g$ 77 (0) ve TĽ. Ĵ k $m \mathcal{D}$ Q S handg 77 O \mathcal{N} e F TIK m Pq handgzoveb CfijkmpqrstXV 7 handgzoveb cffjkmpqrstuwxyZ



Cftjkmpqr nd gzov a h Z tjk M P 9 *a* 77. ON P bCf ha n 5 ha 72 0 \mathbb{V} e Ь C f t j k M \square ha пддхоvеьсfіjкmpqг S handgzove *してチモゴは ア <i>Q G* S ha F k M \square e 71 ブ O) ſ ha n d 72 (0) V P า้ ว้ 🥼 D ZOVEbCfijkMP9Г ha $\square d g$ 5 handg ZOVEBCF i i k M P q S ha n D e TĽ. ha n ゴ ha n Ve Cftjkmpqrg 7Z (O) Ь S đ handgzoveb CfijkmpqrS 12 XV ha nd g 77 (0) Ve า้ Ĵ k $m \mathcal{D}$ q S ha \square d 9 77 (0) \mathbb{N} e 77 ที k m D Q handgzoveb $Cf\pi jkmpqr$ S 17 tikmpqrst handgzoveb CF XV handgzovebcfijkmpqrstu XY



nd gzov ijk M P 9 F a C f h 5 Z 72 (0) \mathbb{V} Ь F ijk M P O1 ha n đ Ø C ha 72 0 \mathbb{V} e C ſ モj k M D D d ha $\square d \mathcal{G}$ ZOVEbCfijkMP9 Г S handg 7Z (O) V C f ij k M P e Ь O F S ha n 71 71 D \square ſ ha n d 77 \bigcirc V P า้ ブ k D റ്റെ രി ZOVEBCF ijk M P 9 ha q r handg 7. OV e Ь CF i i k M P q S ha n e TĽ. \mathcal{D} ha n 71 ha n g 7Z (O) Ve Ь C S đ handgzoveb Cf *1 j k h P Q P* S 17 XV ha nd g 77 0 \mathbb{N} 0 า้ าวิ k ทก D Ø ha \square g 77 O \mathbb{N} e 77 ที k D đ handgzove Ь C - 1F πjkmPqr S handgzove Ь *tiskmpqr* 1° S 7/-ha ndgzove S handgzoveb CfijkmpqS 12 XY Z



nd gzov tjk m pgr a C f h S \mathbb{Z} ĩ j k M P 72 (0) \mathbb{V} Ь F O1 ha n đ Ø C \$ ha 72 0 \mathbb{V} ſ ij k M 0 D ha $\square d \mathcal{G}$ ZOVEbCfijkMP9 Г S handg 7Z (O) V Cfijkmp e Ь 0 r S ha 71 71 D ha ി രി 72 P ſF า้ ブ D ZOVEBCF ijk M P 9 ha n q r ୌ h a D d q 7. OV e Ь CF i i k M P q S ha n e Ť ha n 71 ha Cftjkmpqrn g 7Z (O) Ve Ь S handgzoveb CfijkmpqrS 17 XV ha n q 77 0 0 า้ าวิ k ทก D a đ ha \square g 77 O \mathbb{N} e 77 ที D đ πjκmpqr handgzove Ь C 1 S handgzove $\pi j k m P q r$ Ь 1° S 7/ha nd g ZOVe t j k M P Q 7Z (O) \mathbb{V} 77 ha D q P Ĵ k m P đ handgzovebcfijkmpqrst



handgzov tjk M P 9 F C f S Zĩ j k M P 72 (0) \mathbb{V} F ha n d a Ø Б C O1 \$ ha 72 0 \mathbb{V} ſ モj k M n d 0 Ь D handg ZOVEbCfijkMP9 ſ S 1 handg 7. OV e Cfijkmp Ь 0 r S ha n k M F 71 ブ D O) ha D d 72 (0) V P ſF า้ ว้ 🥼 D ZOVEBCF ha D d gijk M P 9 r handg 7. OV e Ь C f i i k M P q S ha n e TĽ. - 71 D ha n Ť ゴ ha n Cftjkmpqrd 9 7Z (O) Ve Ь S handgzoveb CfijkmpqrS 12 XV ha nd g 77 0 \mathbb{N} e TĽ. Ĵ k $m \mathcal{D}$ Ø S handg 77 O \mathbb{N} e 77 ที k m \square πjkmpqr handgzove Б CT S 7 πjκmpqr handgzove Ь CF S 7/ha nd g 7Z (O) Ve TJ k M P Q \bigcirc \mathbb{V} ha D q 72 Ĵ D Cfijkmpqrha ndgzoveb S Z 12 handgzovebcfijkmpqrst XY Z



nd 97.0V ijk M P 9 F a C f h F 72 (0) \mathbb{V} Ø Ь ĩ j k M P O1 ha n đ C ha 72 0 \mathbb{V} e f モj k M ി ർ Ь C D ha $\square d \mathcal{G}$ ZOVEbCfijkMP9 ſ S handg 7Z (O) V Cfijkmp e Ь 0 r S ha F k M n e 71 ブ D \mathcal{O} ſ ha ി രി 72 (0) V P า๊ ว้ k D ZOVEbCfijkMP9 ha $\square d g$ r handg 7. OV e Ь C f i i k M P q S ha n D e TĽ. - 71 ha n ゴ ha n Cftjkmpqrd 9 7Z (O) Ve Ь S handgzoveb CfijkmpqrS 17 ha nd g 77 0 \mathbb{N} e า้ Ĵ k $m \mathcal{D}$ Ø S handg 77 O \mathbb{N} e 77 ที k m D πjkmpqr handgzove Б CI S handgzoveb πjκmpqr CF S 7/ha nd g ZOVe TJ k M P Q 77 0 \mathbb{V} ha D q ที D h a nd g 72 0 Ve Ь CF ĨĴĸħ₽� handgzovebcf л j k ln P G Г S 12 h a n a g z o v e b c f t j k m P q r 12



and gzov tjk m pgr C f h 5 ſF 72 (0) \mathbb{V} ijk M P ha n đ Ø Ь C O1 5 ha 72 0 \mathbb{V} e f モj k M D Ь C ha $\square d \mathcal{G}$ ZOVEbCfijkMP9 Г S 1 handg 7Z (O) V Cfijkmp S e Ь 0 r ha F k M 71 71 D \square ha n d 72 \bigcirc V P ſF า้ ブ k D D d gZOVEBCF ijk M P ha Ø r h a nd g 7. OV e Ь CF ¬ĩ, j k M ₽ q S ha n e TĽ. 7 \mathcal{D} ha n 71 ha n Cftjkmpqrđ g 7Z (O) Ve Ь S handgzoveb CfijkmpqrS 17 ha nd g 77 0 \mathbb{N} e ſ TĽ. Ĵ k ทก D a ha \square g 77 O \mathbb{N} e 77 ที k D đ handgzove Ь C - 1F πjkmPqΓ S πjkmpqr handgzove Ь 1° S ha $\square d g$ 7Z (O) Ve T J k m D Q \bigcirc \mathbb{N} ha n q 77 ที h aD d g72 0 Ve Ь CF ſſſĸŀm ₽ đ ĨĴĸħ₽� ha ndgzovebcf S ndgzove ha t j k m P đ Б C fi j k m P hQ ndgzoveb \mathbf{Q} S Z



ijk m pgr nd gzov Ô. F h C Z 77 k M ha n đ \bigcirc V Ø ſF -ĩ Ť D O1 ha f 1 k 77 \bigcirc 71 7Z (O) ha $\square d \mathcal{G}$ \mathbb{V} C f ij k M P e Ь q S hand 17 i j k M q 7Z (O) \mathbb{V} e Ь C \square q S ha 77 ha ി രി ſF 71 71 ha n q 77. (0) \mathbb{V} e Ь 1F -ĩ j k M D đ C Ø F ha D d q 72 0 \mathbb{V} e Ь C ĺı́k M ₽ q 5 ha n e Ń \mathcal{D} hQ n ゴ ha *ጚjk*mP9r n g 77 \bigcirc \mathbb{N} e C F S ZOVe F -1 j k h P Q P handg Ь C S $\sim V$ ha n q 77 e า้ าวิ k กก D đ đ ha \square g 77 77 ที k m D đ handg 7Z (O) V e Ь 1 7 1 k m P 9 S h a n d g z o v e *ti j k m P 9 F* Ь S ha റെ ർ T J k 7/ \bigcirc e m D Q ha n 77 \bigcirc \mathbb{N} า้า ha n d q 72 0 \mathbb{N} Б ſſſĸ lm P đ ĨĴĸMP9 ndgzoveb F hQ \bigcirc ha n d g 72 7 \mathcal{M} e ที k h hQNdgzOV CfjjkmPq Ь



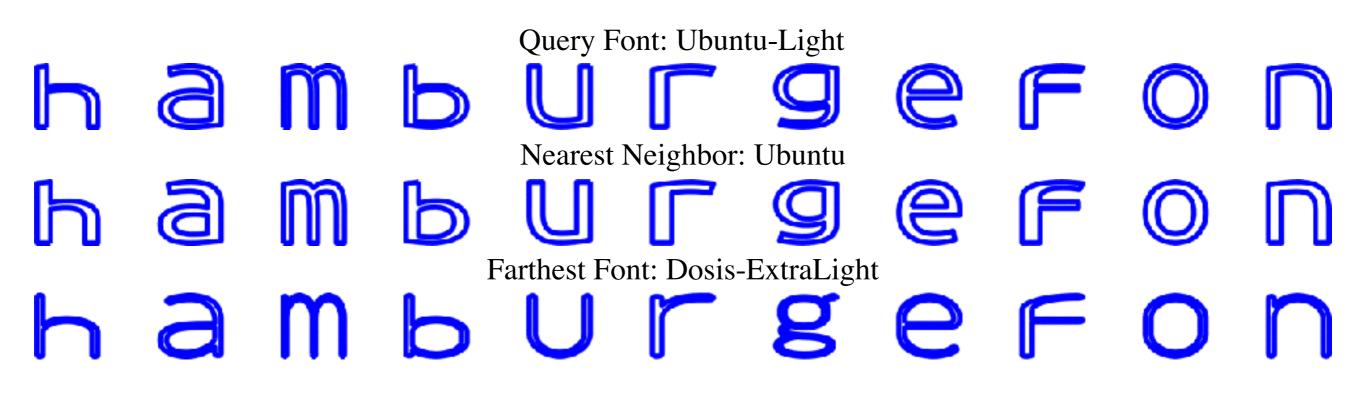
ijk m p q hândġZŎV F k M ha n 77 ъĩ Ť D ha 1 k 77 f 71 ſ ha D d 72 0 \mathbb{V} t j k M g e Ь C \square q S hand 17 i j k M q 77 O \mathbb{N} e Ь C D O) \$ ha ha n 71 ΤĽ F h a n 77 \mathbb{N} า้ 71 ke M D Q \bigcirc e Ь Ø F ha n q 77 \bigcirc \mathbb{N} e Ь 71 j k M D đ C ha n ฑ ha n -77 F ha jkmP q n 77 \bigcirc e Ľ S handg \mathbb{V} -1 j k h P Q P 72 (0) e Ь F C S $\sim V$ ha n q 77 71 าวิ k ทก D đ đ e ha \square g 77 ที k D đ handg 72 0 V e π f k m P Q S hqndgzov e $\pi j k m P q$ Ь r S ha റെ ർ T J k g 77 0 m D P ha n 77 ha D d q 77 0 \mathcal{N} T J & M P đ Б ha ndgzoveb T ĨĴĸMP Q ha n q 71 า ke h ha ndgz 15 パプ \bigcirc \mathbb{N} 15 k m Q F h a h d g z o e Ь Z



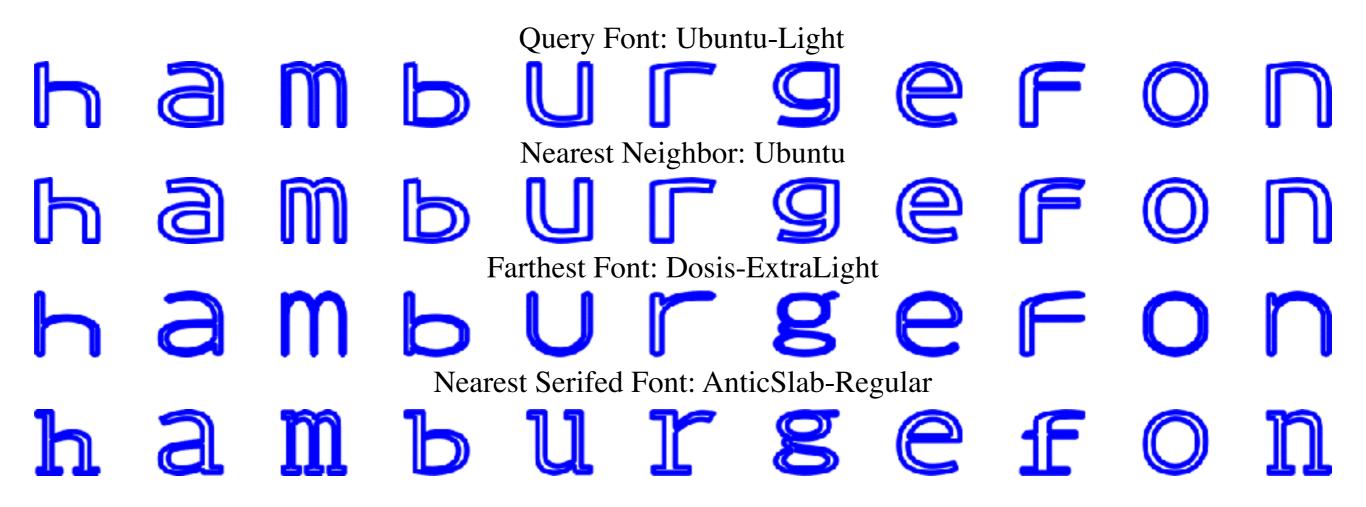
Font Retrieval



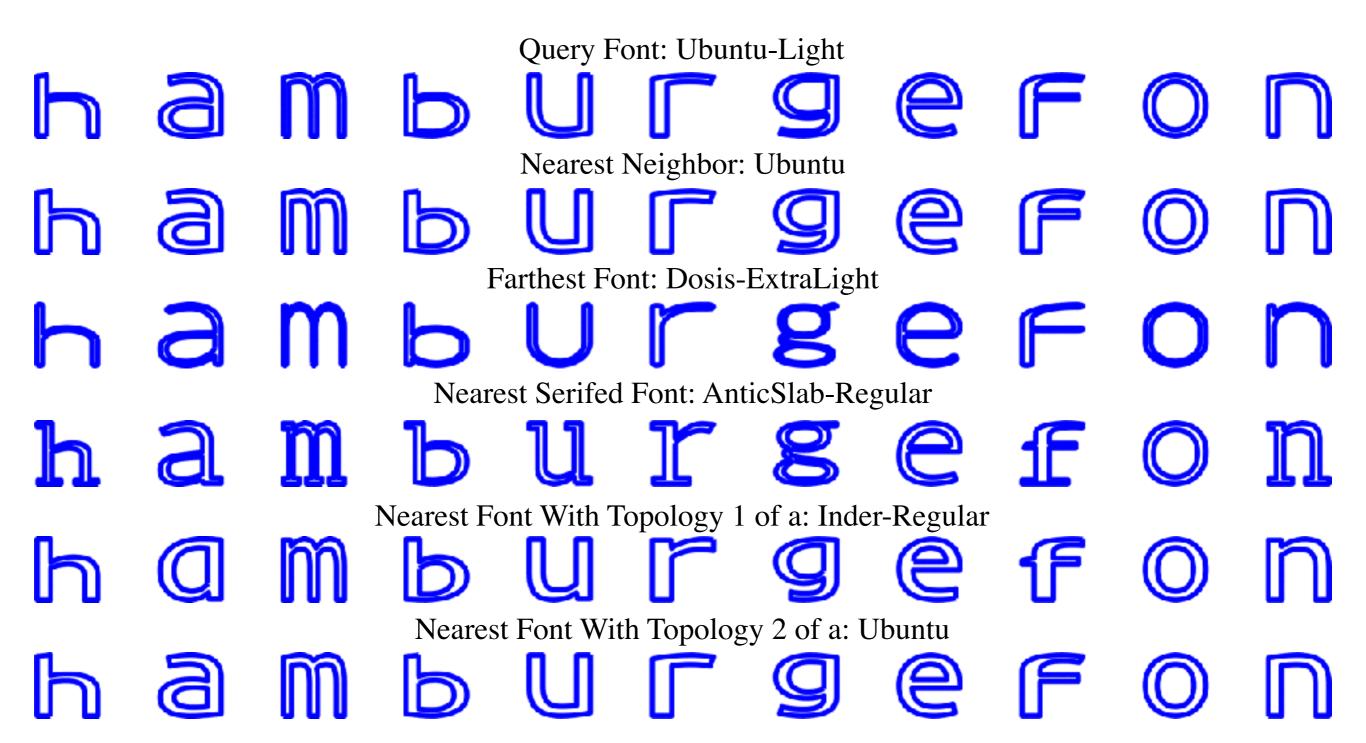
Font Retrieval



Topology-Aware Retrieval



Topology-Aware Retrieval



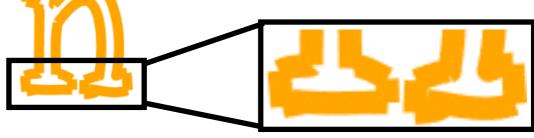








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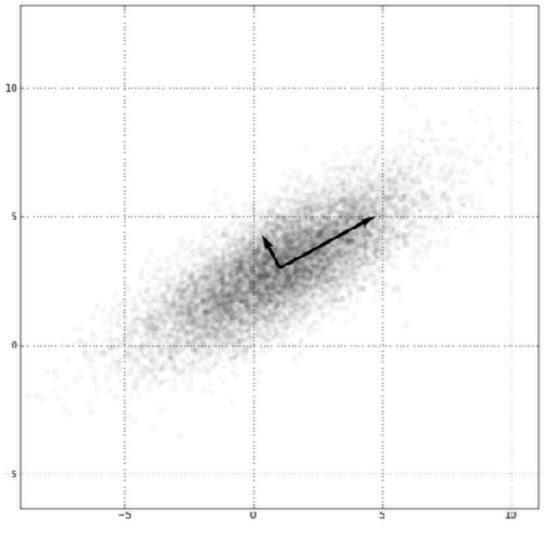






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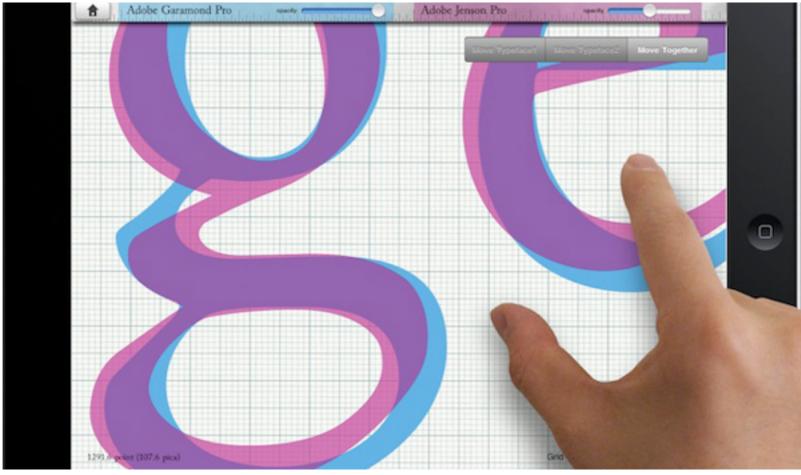
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Future Work



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Future Work

把德德德登地。

[<u>Nejati '16]</u>



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Thank You!