SIGGRAPH ASIA 2016 MACAO

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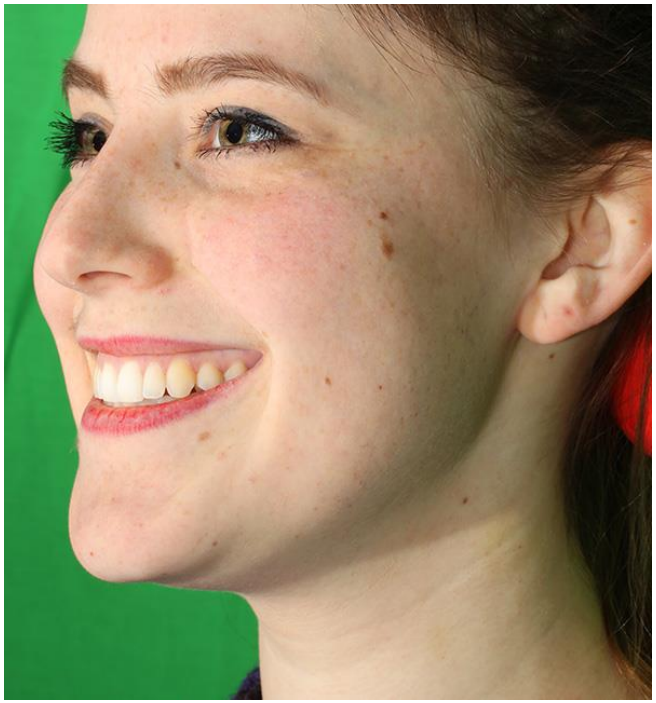
Model-Based Teeth Reconstruction

Chenglei Wu[2], Derek Bradley[1], Pablo Garrido[3], **Michael Zollhöfer**[3],
Christian Theobalt[3], Markus Gross[1,2], Thabo Beeler[1]

[1]Disney Research *[2]ETH Zurich* *[3]Max Planck Institute for Informatics*

MOTIVATION

MOTIVATION



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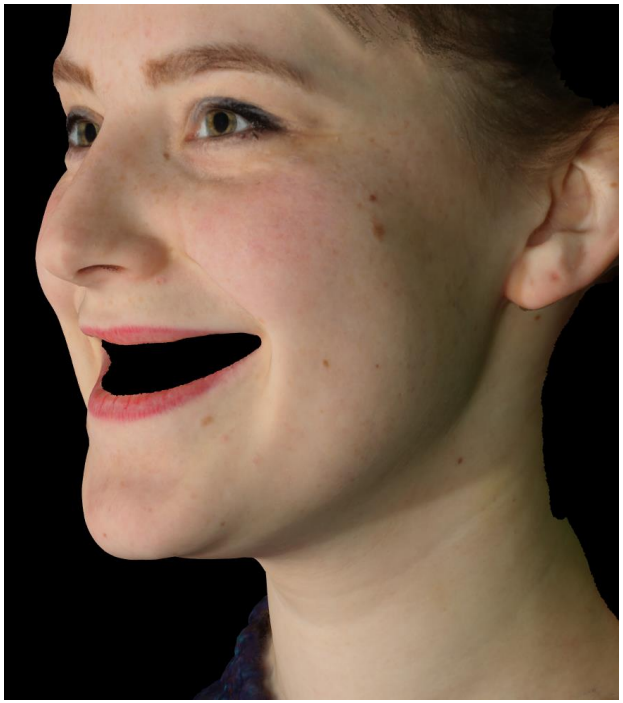

Beeler11

MOTIVATION

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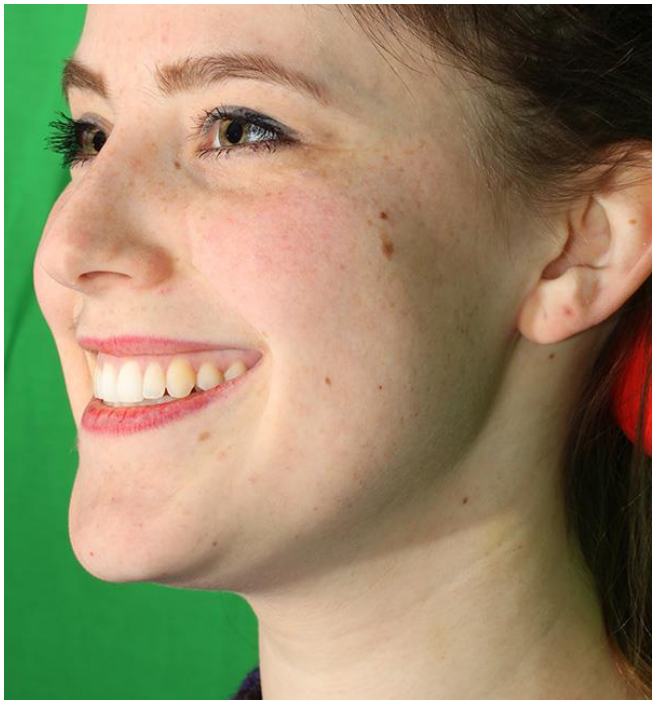

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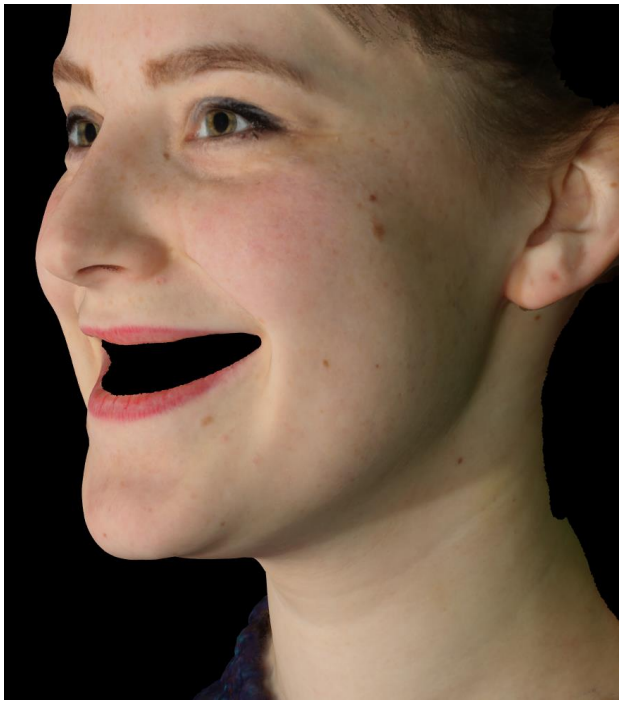

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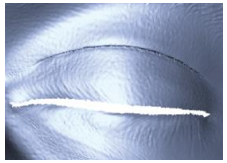

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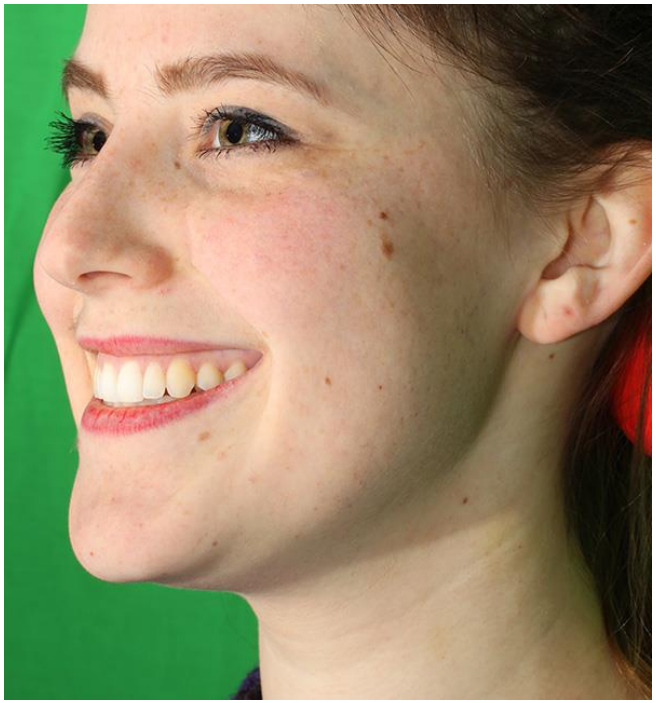

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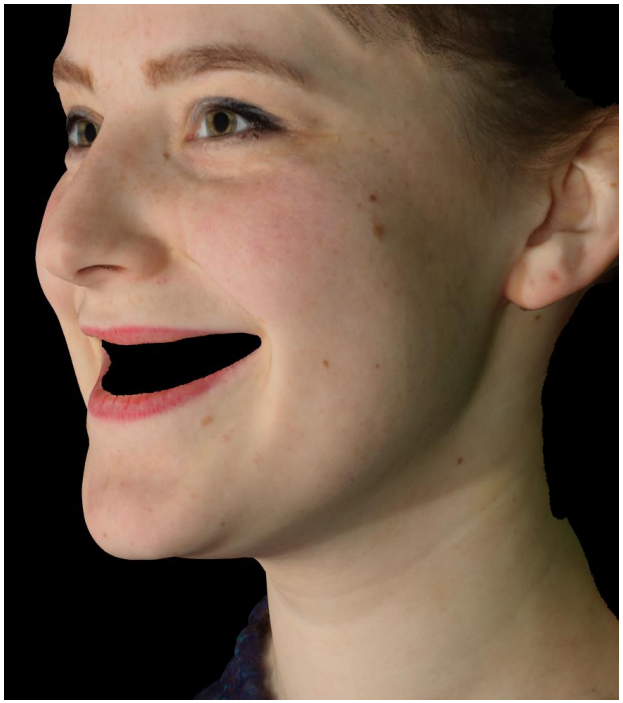

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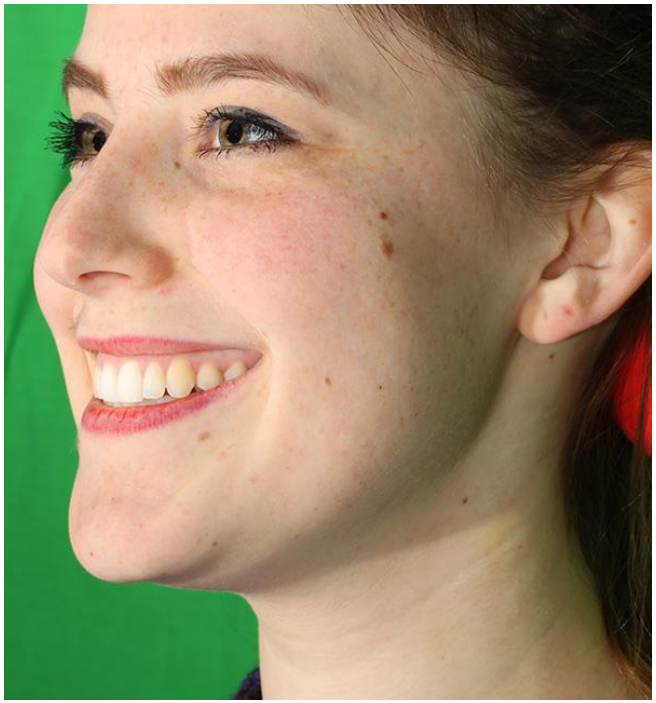

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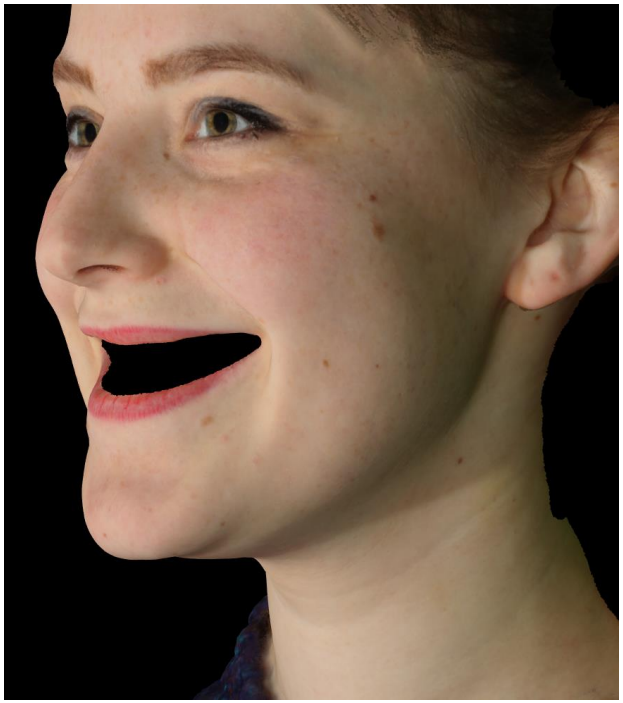

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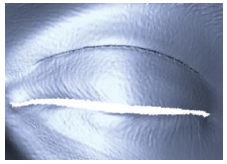

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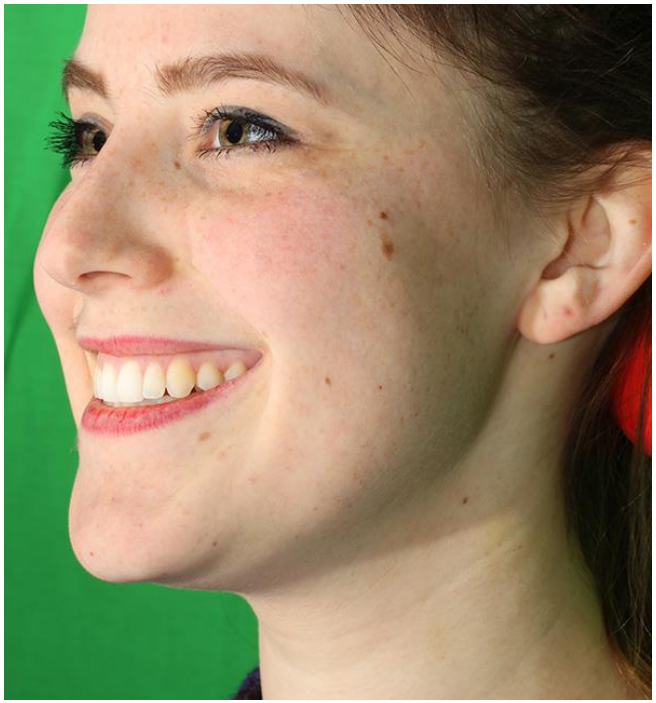

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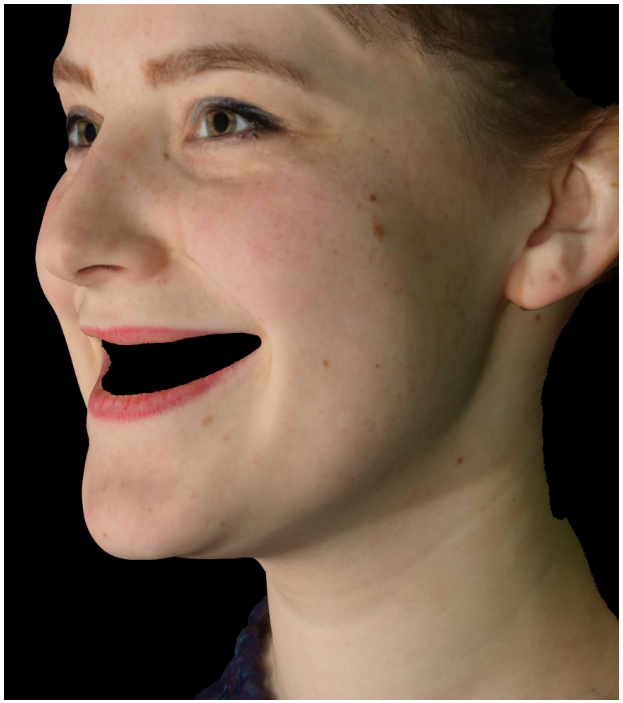

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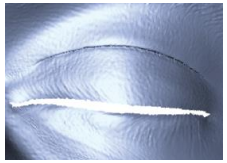

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Beeler12

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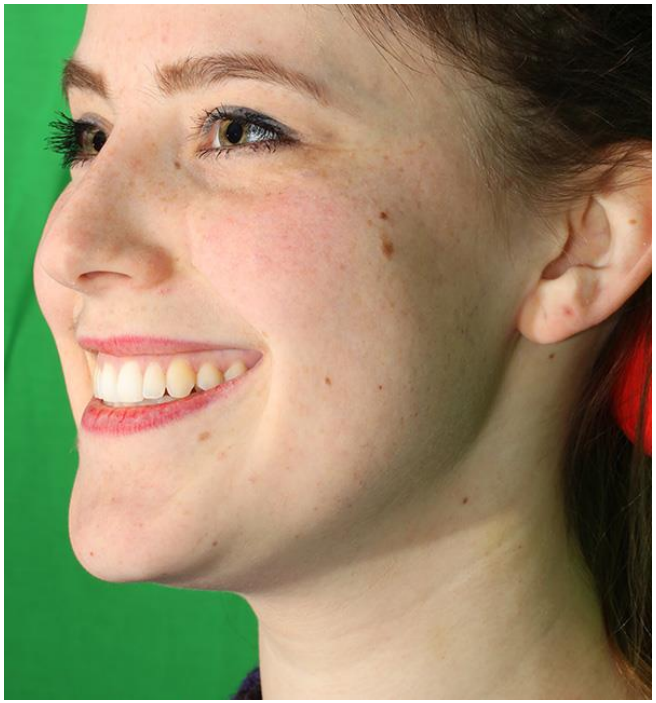

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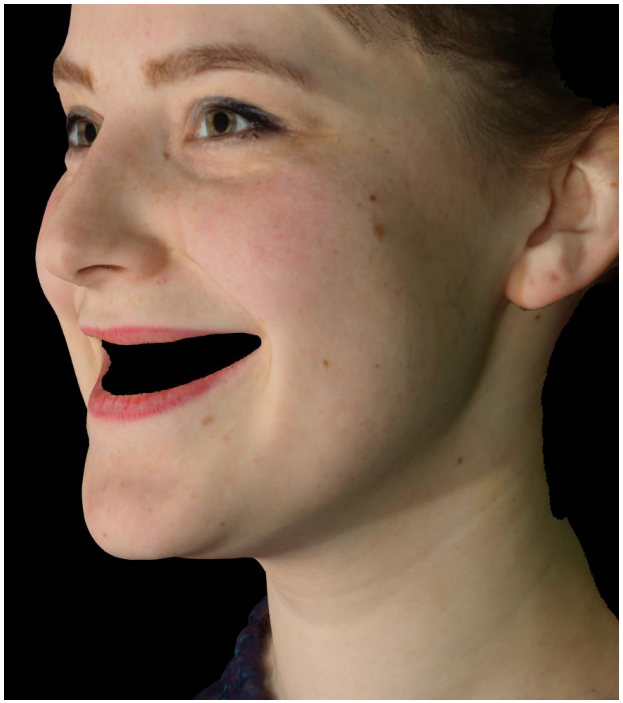

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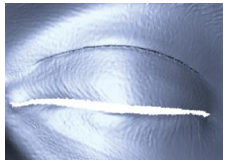

*Bermano*16

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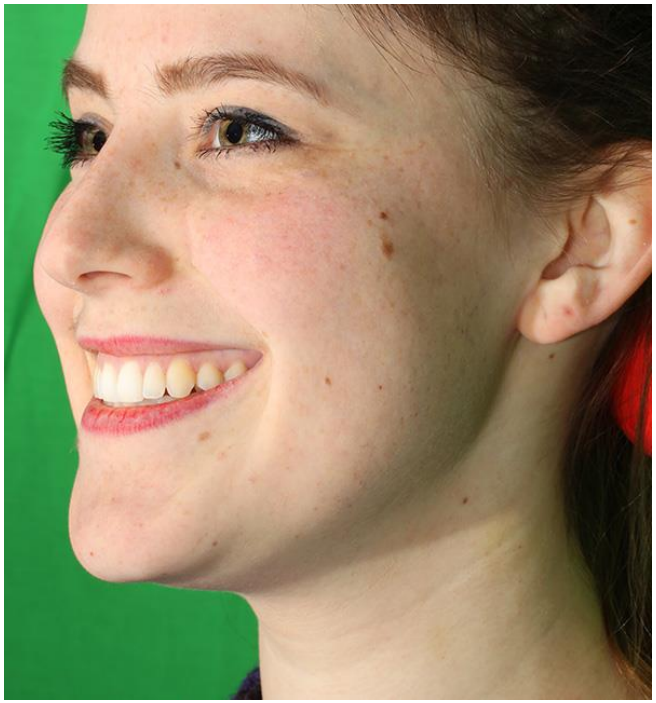

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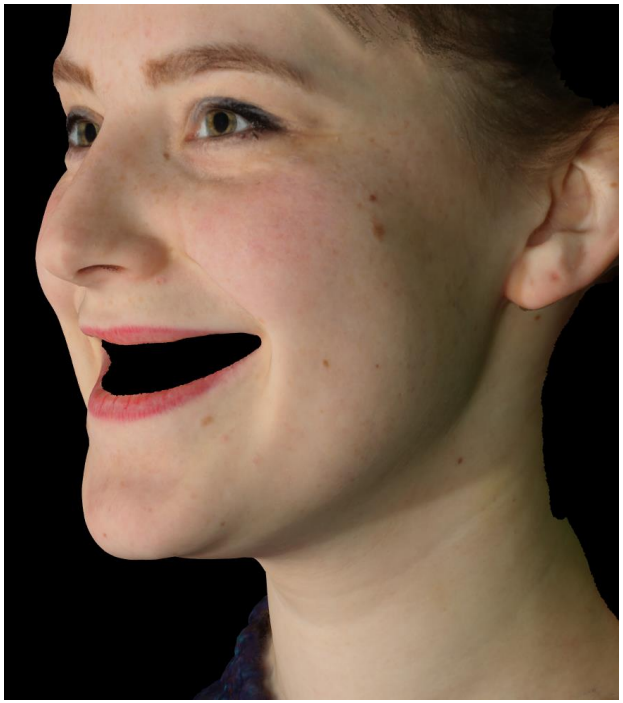
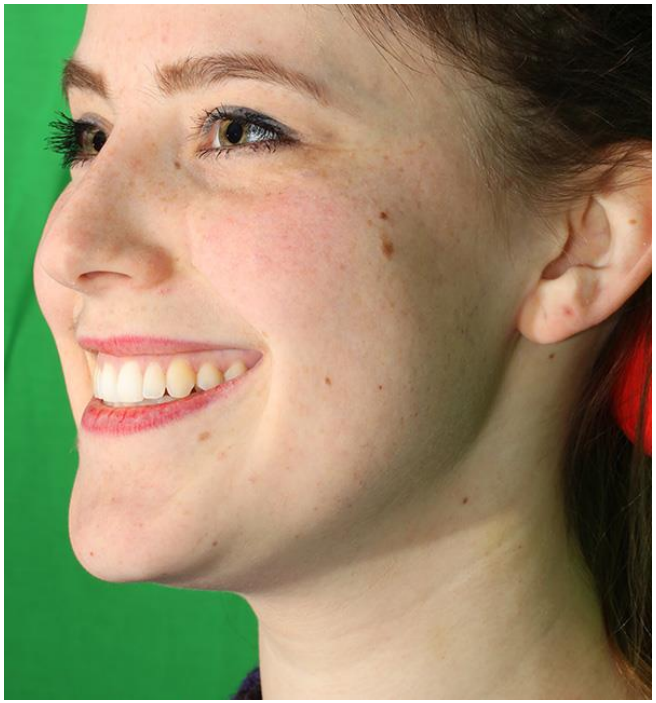


Beeler11

Teeth are missing!

MOTIVATION



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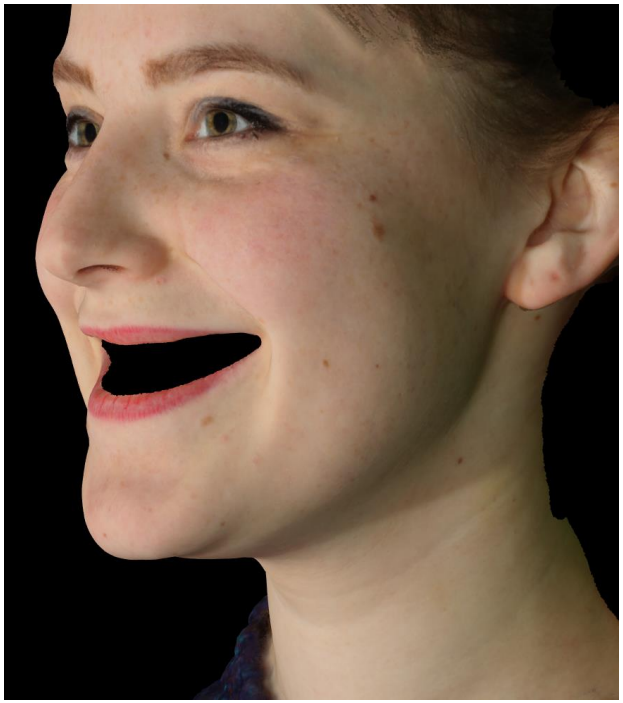

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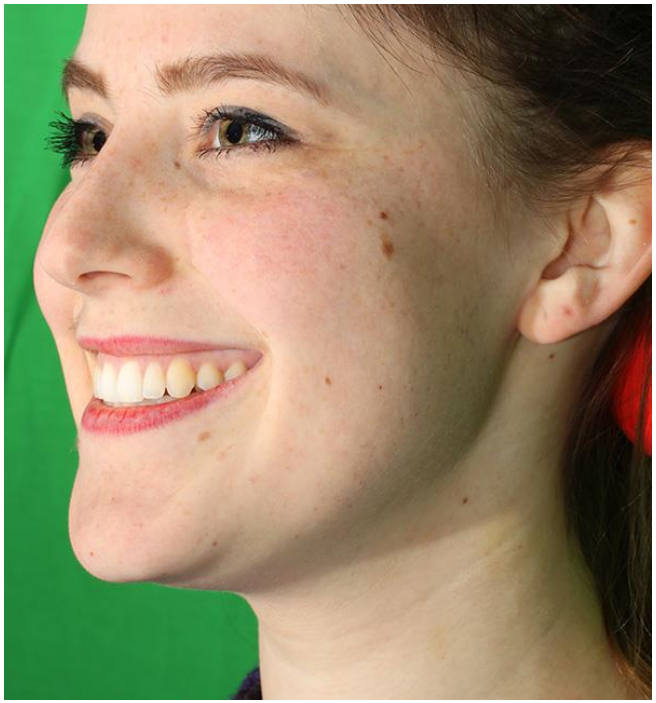

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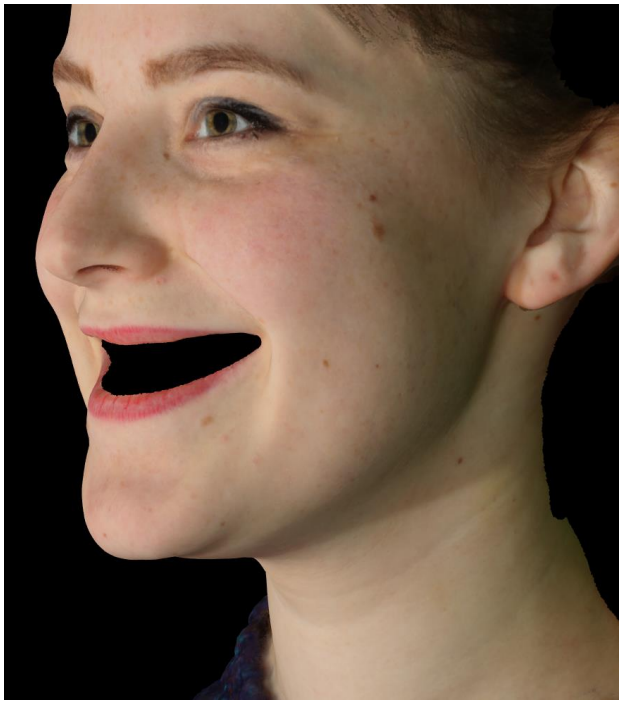
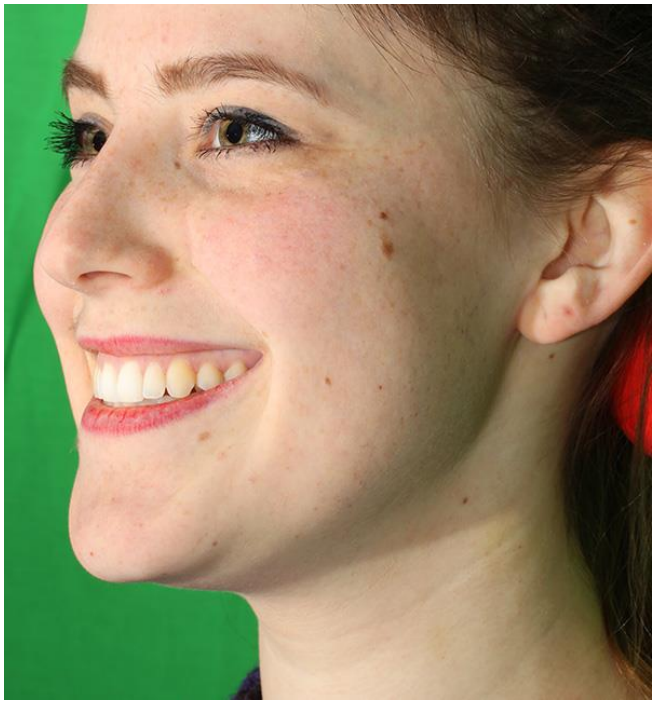


Beeler11

Teeth are missing!

Complex Appearance

MOTIVATION



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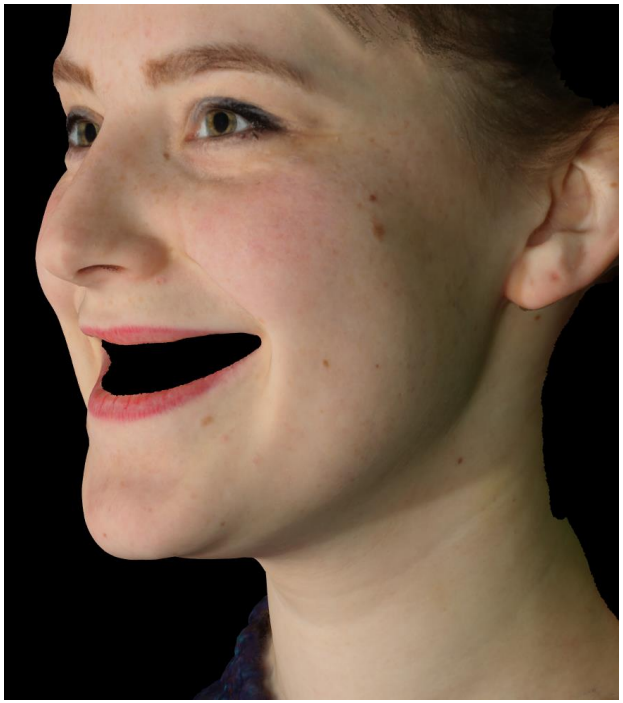


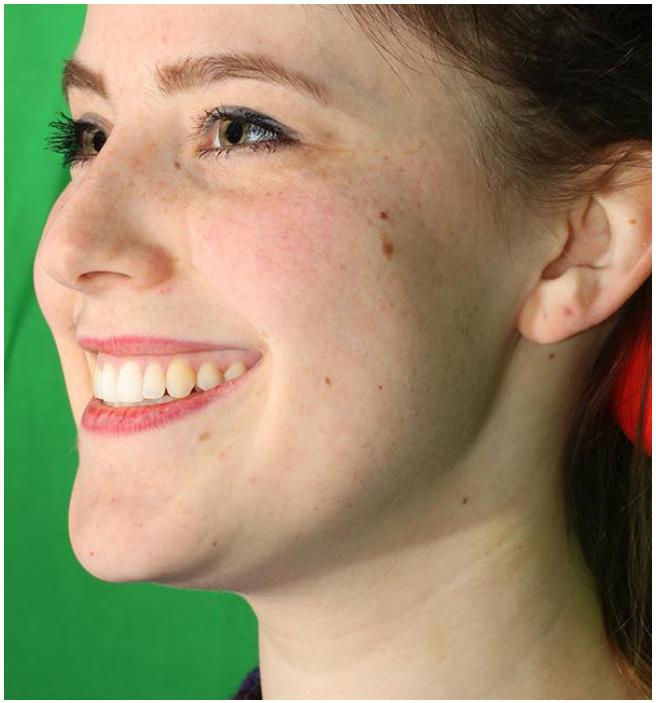
Beeler11

Teeth are missing!

Complex Appearance

Featureless

MOTIVATION



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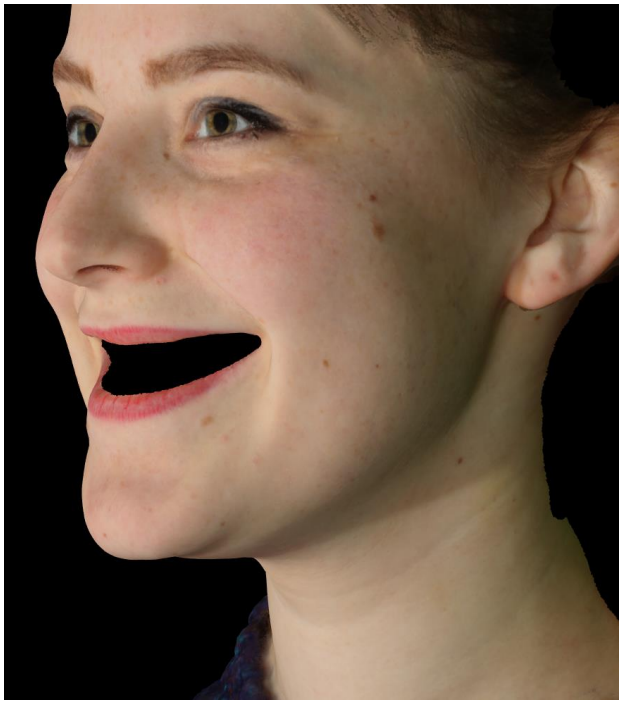
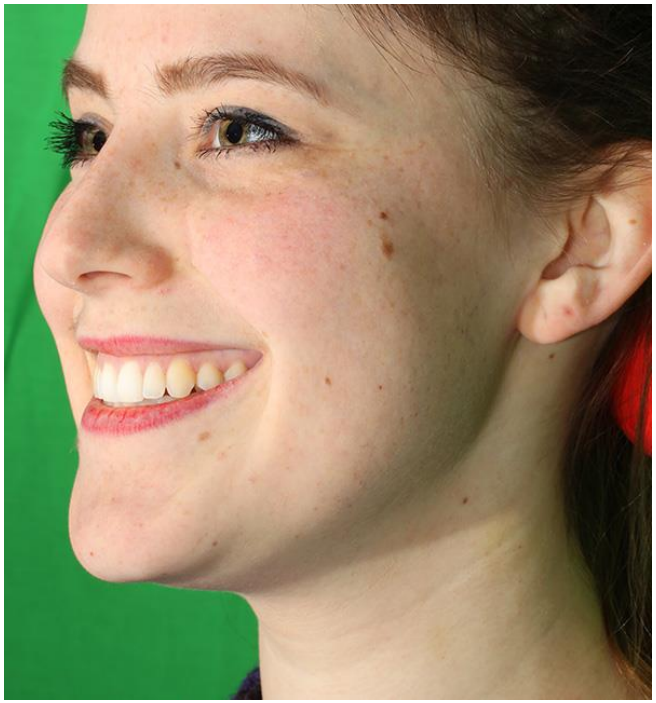


Beeler11

- Teeth are missing!
- Complex Appearance
- Featureless
- Occlusions

MOTIVATION



Input Image

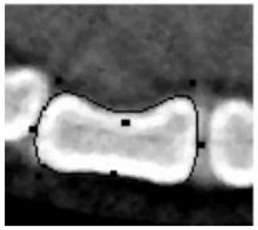
Our Reconstruction

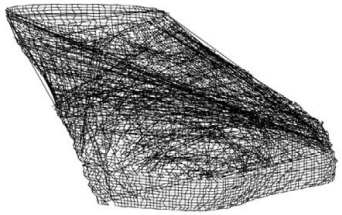
- Teeth are missing!
- Complex Appearance
- Featureless
- Occlusions

RELATED WORK

RELATED WORK

Medical Dentistry

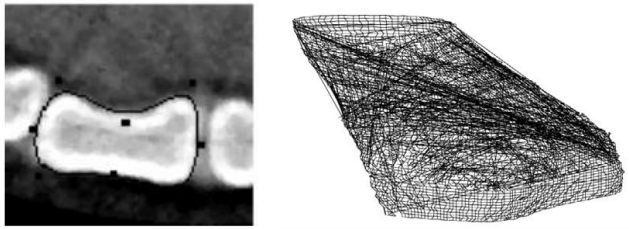




From CT images
[**Omachi07**, Yanagisawa14]

RELATED WORK

Medical Dentistry



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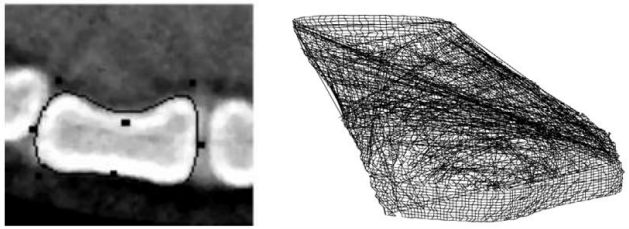
[**Omachi07**, Yanagisawa14]

Intra-Oral Scanners
[3M True Definition, **iTero**, 3Shape TRIOS]

RELATED WORK

Medical Dentistry



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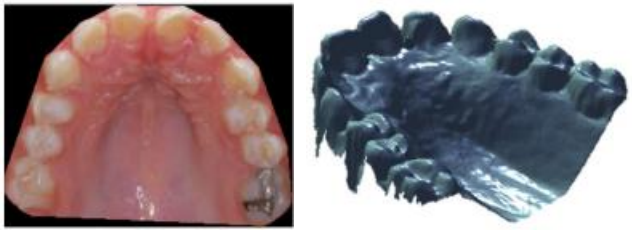
Photogrammetric Reconstruction

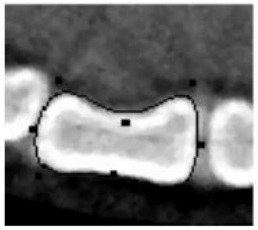
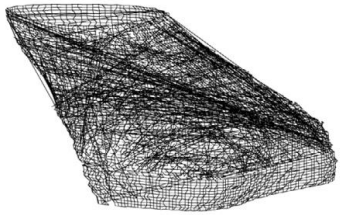


Shape from Shading
[Carter10, **Farag13**, Mostafa14]

Intra-Oral Scanners
[3M True Definition, **iTero**, 3Shape TRIOS]

RELATED WORK

Medical Dentistry

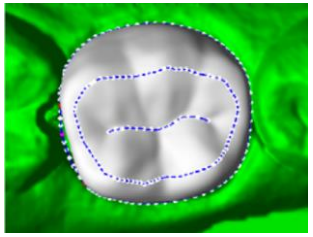



From CT images
[**Omachi07**, Yanagisawa14]

Intra-Oral Scanners
[3M True Definition, **iTero**, 3Shape TRIOS]

Photogrammetric Reconstruction

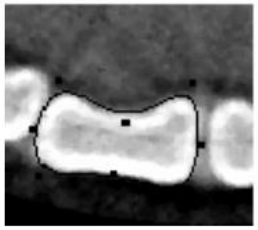

Shape from Shading
[Carter10, **Farag13**, Mostafa14]

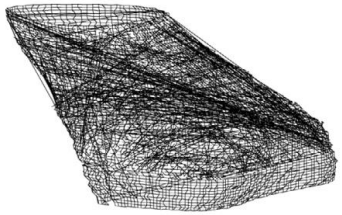


Contours and Feature Points
[**Zheng11**]

RELATED WORK

Medical Dentistry





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Intra-Oral Scanners
[3M True Definition, **iTero**, 3Shape TRIOS]

Photogrammetric Reconstruction

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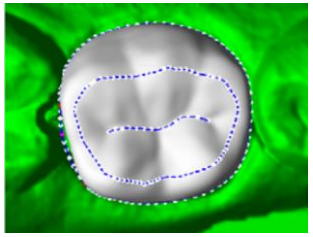

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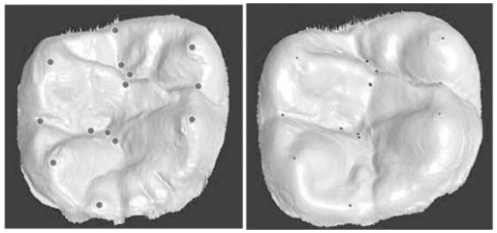
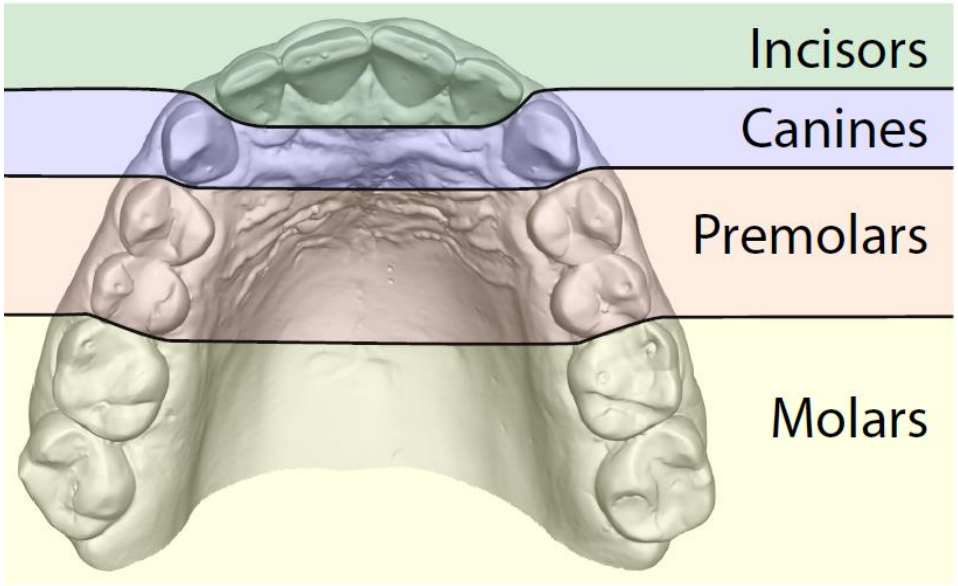


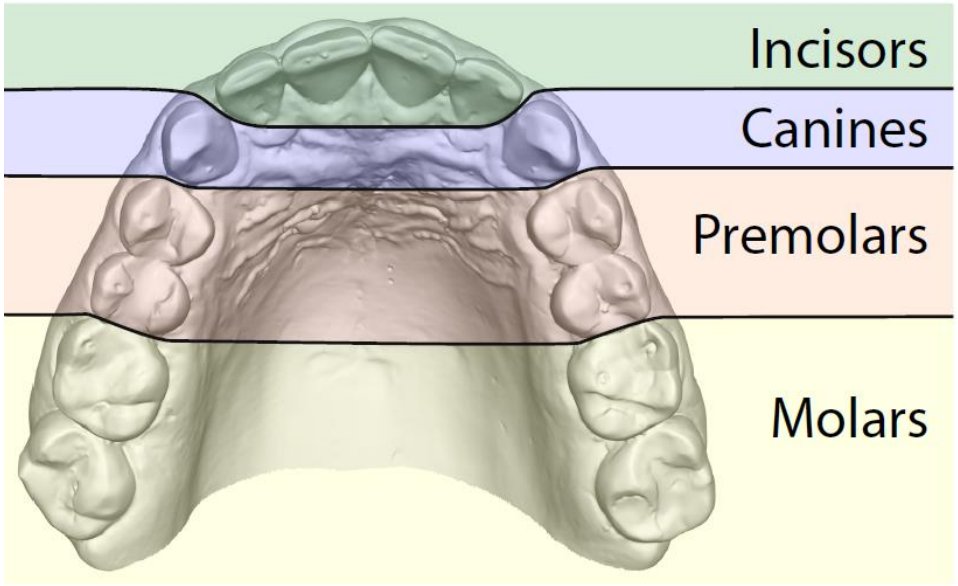
Statistical Models
[**Mehl05**, Buchaillard07]

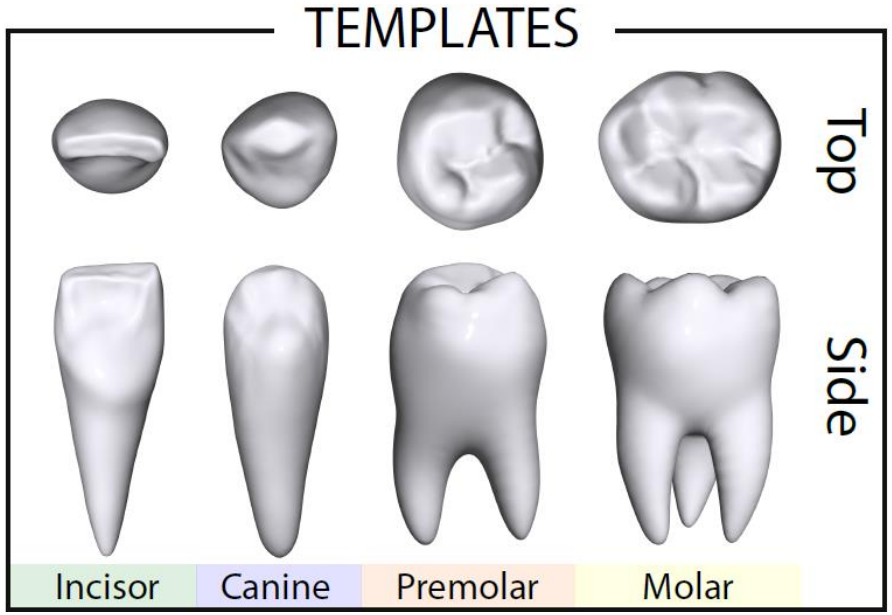
HUMAN TEETH

HUMAN TEETH



HUMAN TEETH

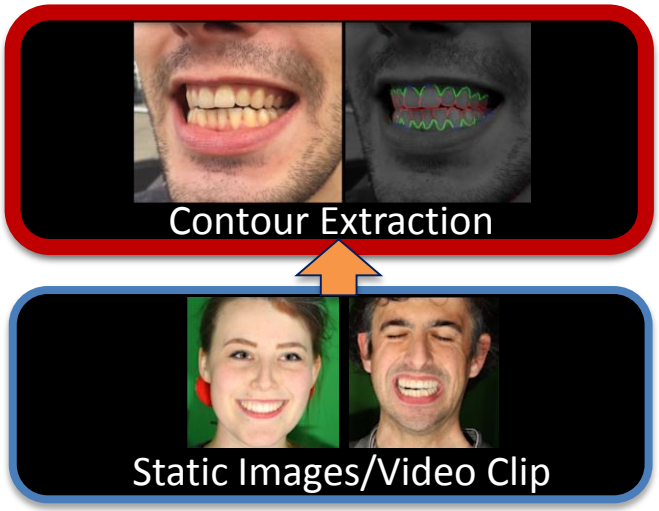

Incisors
Canines
Premolars
Molars


TEMPLATES
Top
Side
Incisor
Canine
Premolar
Molar

OVERVIEW

OVERVIEW

OVERVIEW



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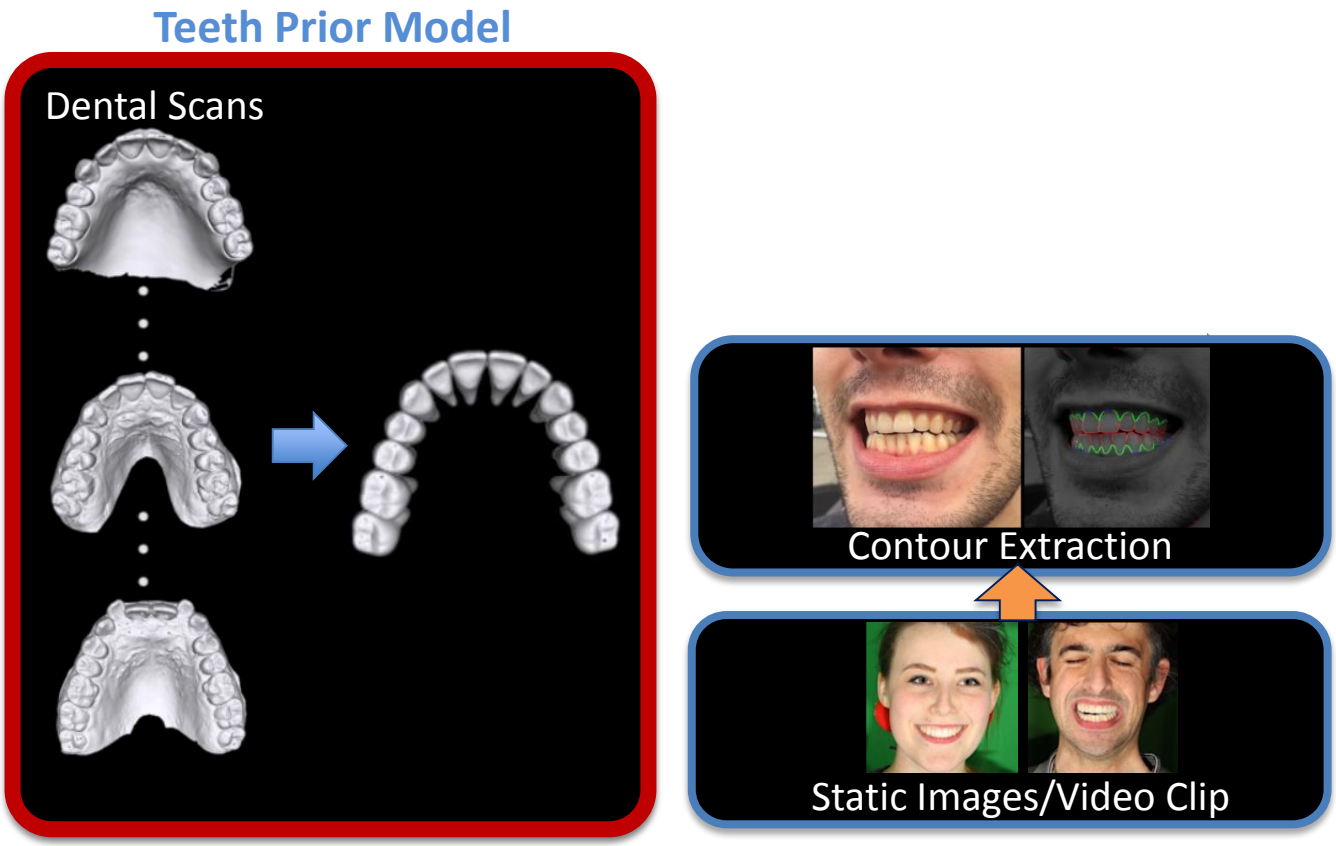
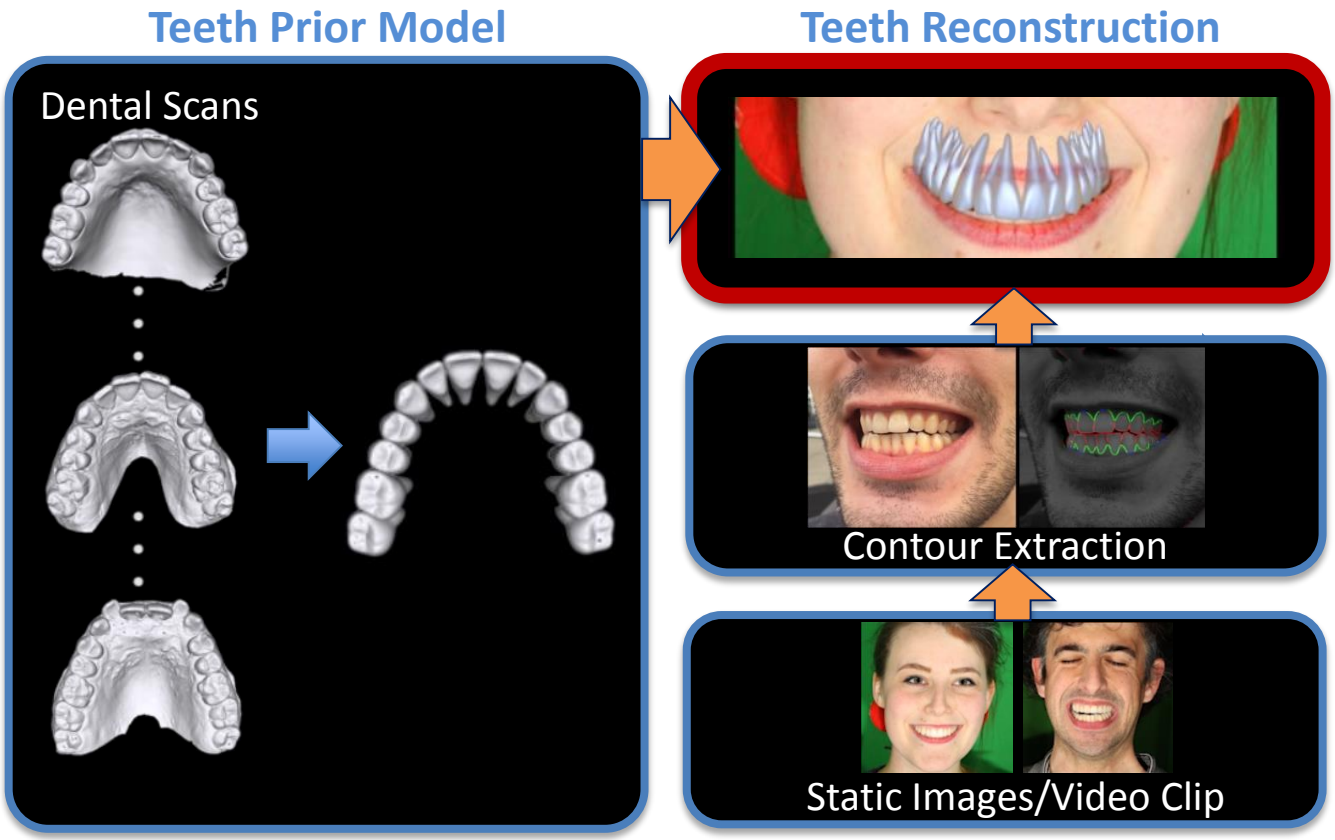

Teeth Prior Model
Dental Scans
Contour Extraction
Static Images/Video Clip

OVERVIEW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Teeth Reconstruction
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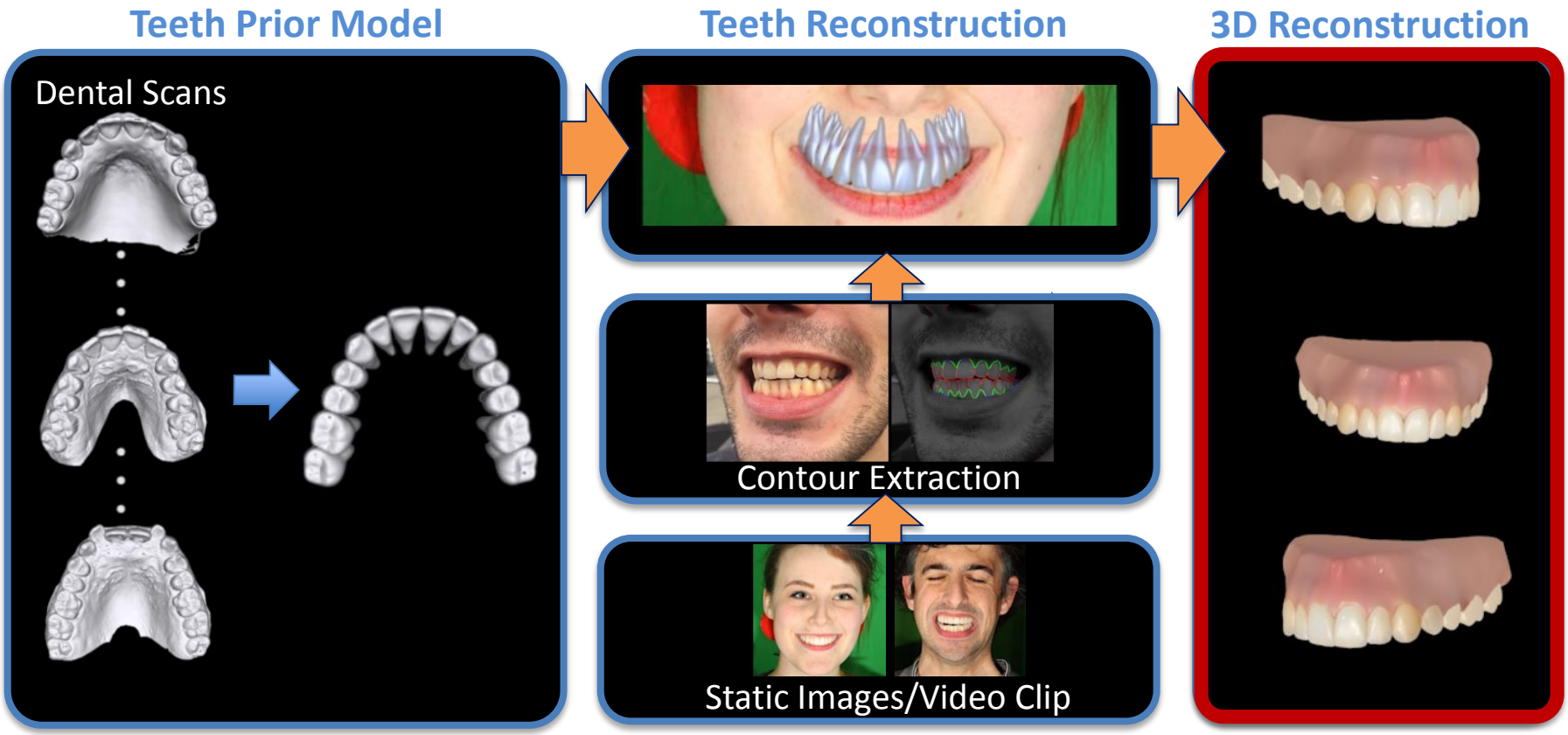
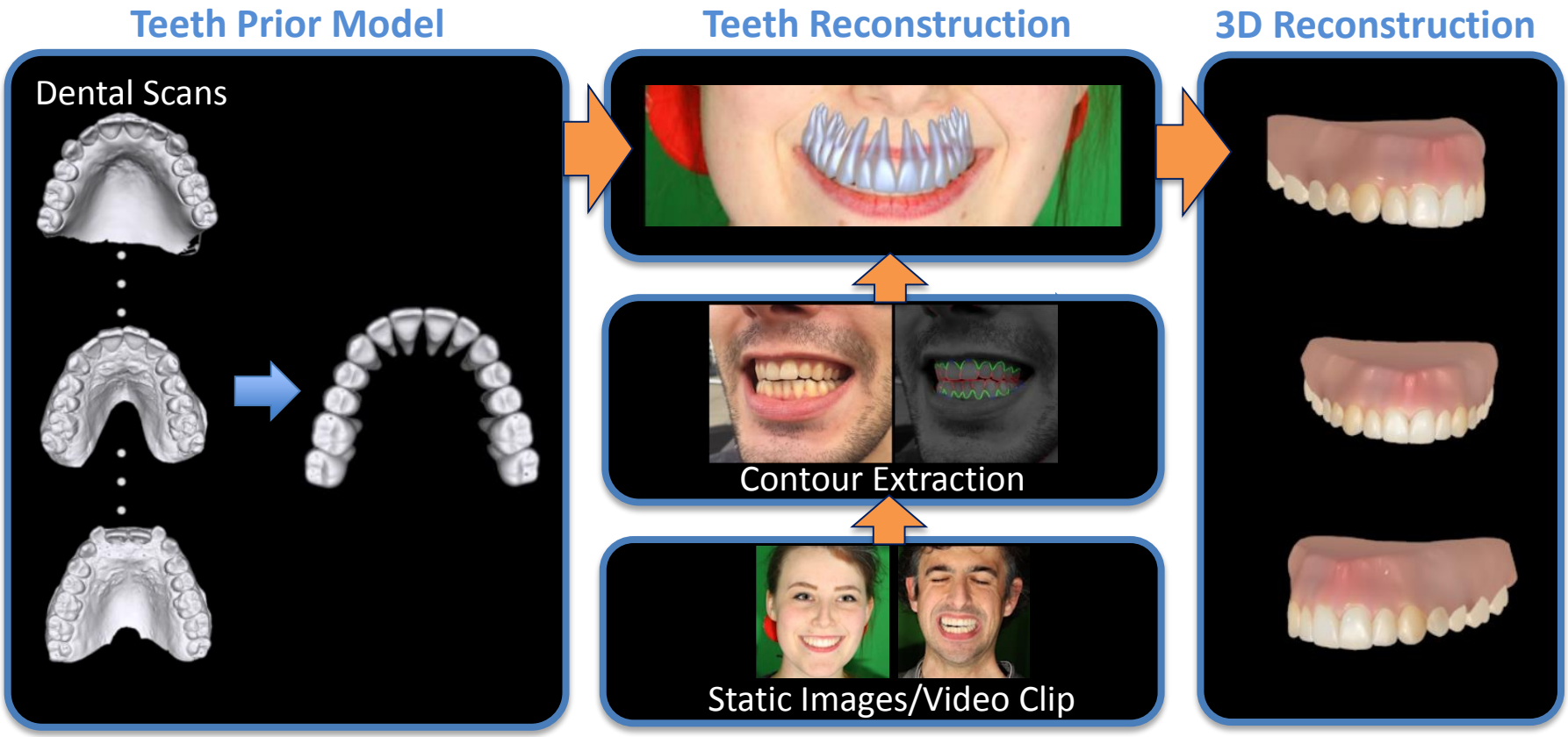
OVERVIEW


Teeth Prior Model
Teeth Reconstruction
3D Reconstruction
Dental Scans
Contour Extraction
Static Images/Video Clip

OVERVIEW


Teeth Prior Model
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3D Reconstruction
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Contour Extraction
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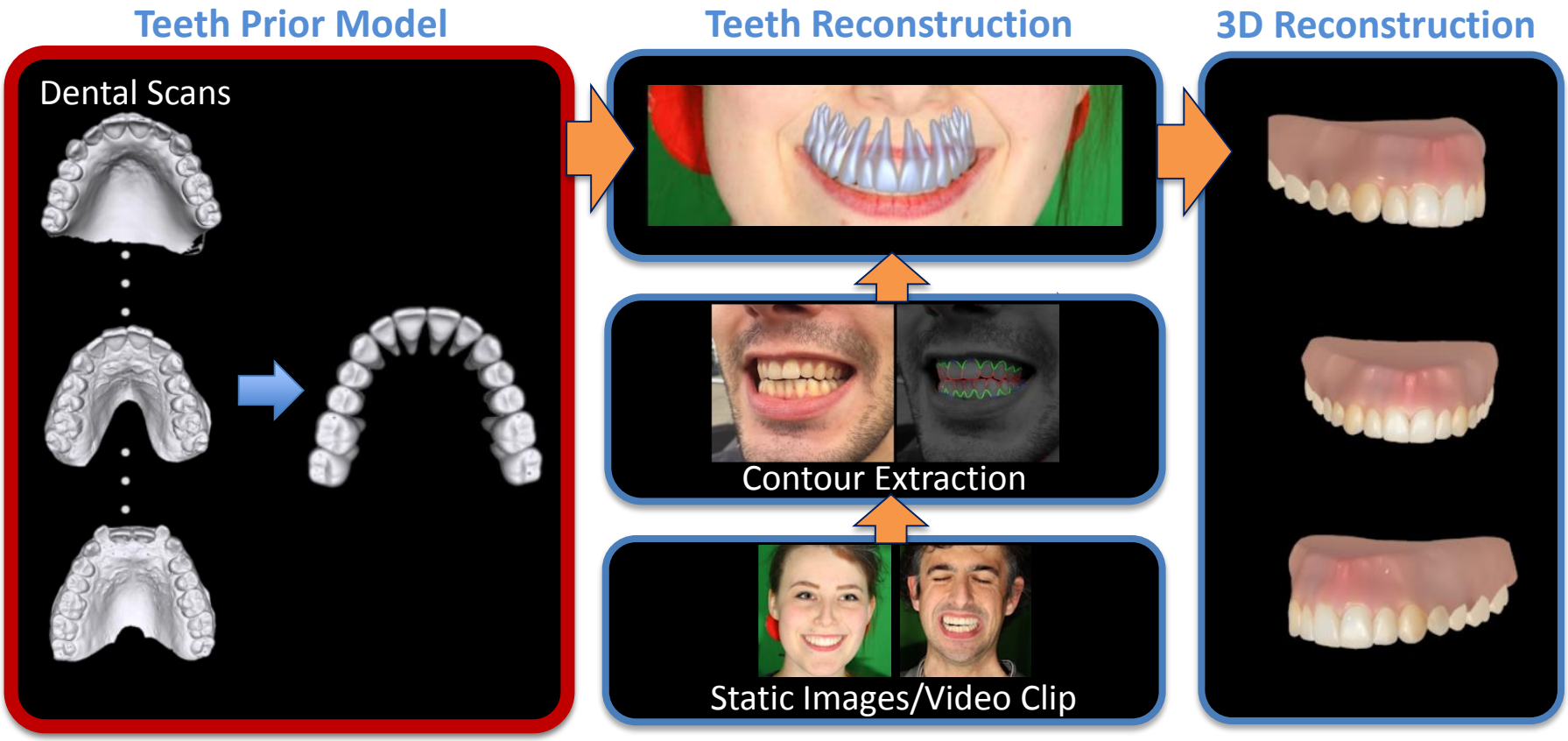
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TEETH MODEL

- 86 high resolution plaster cast scans

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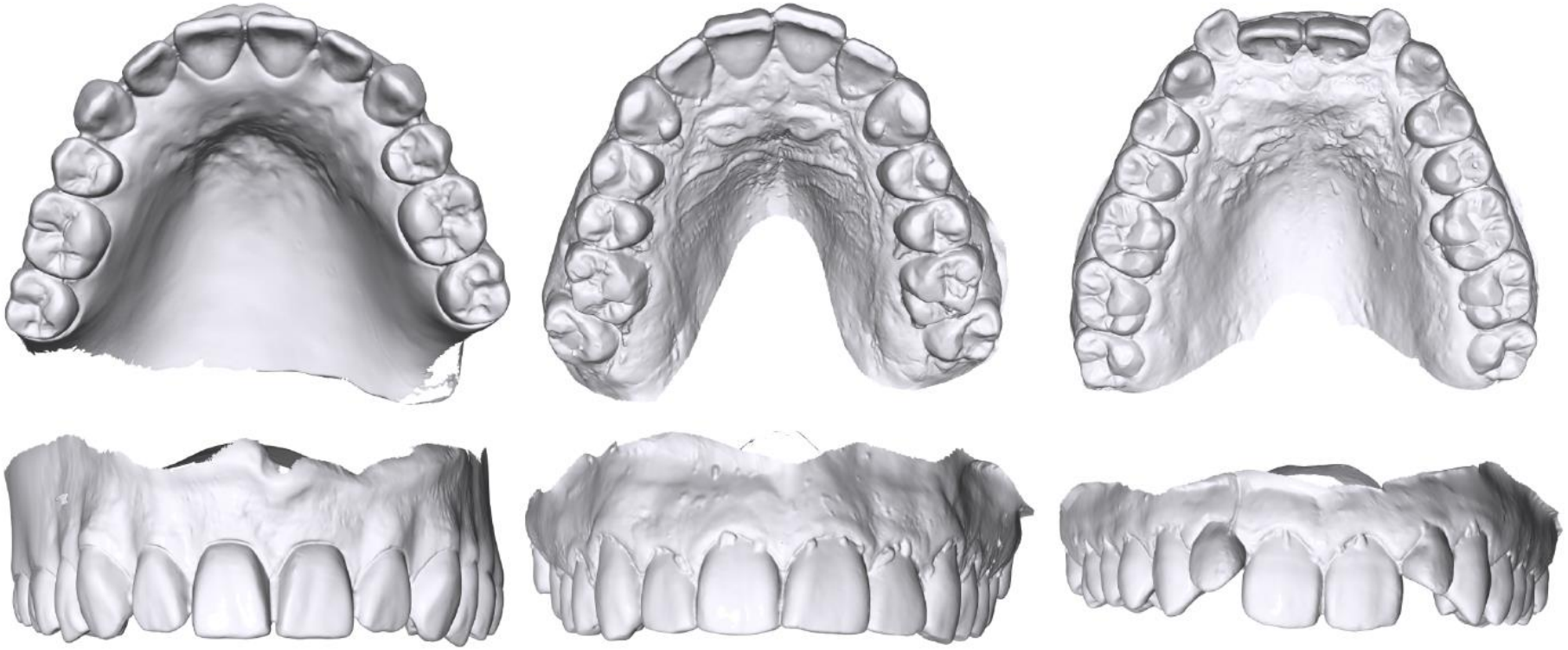
- 86 high resolution plaster cast scans



PREPROCESSING

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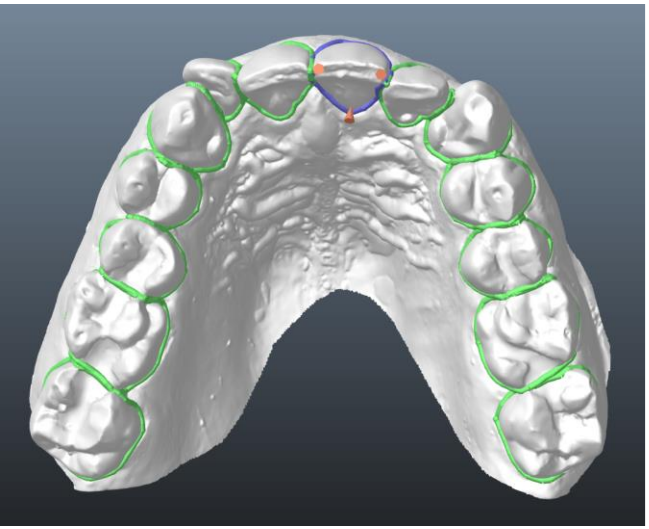
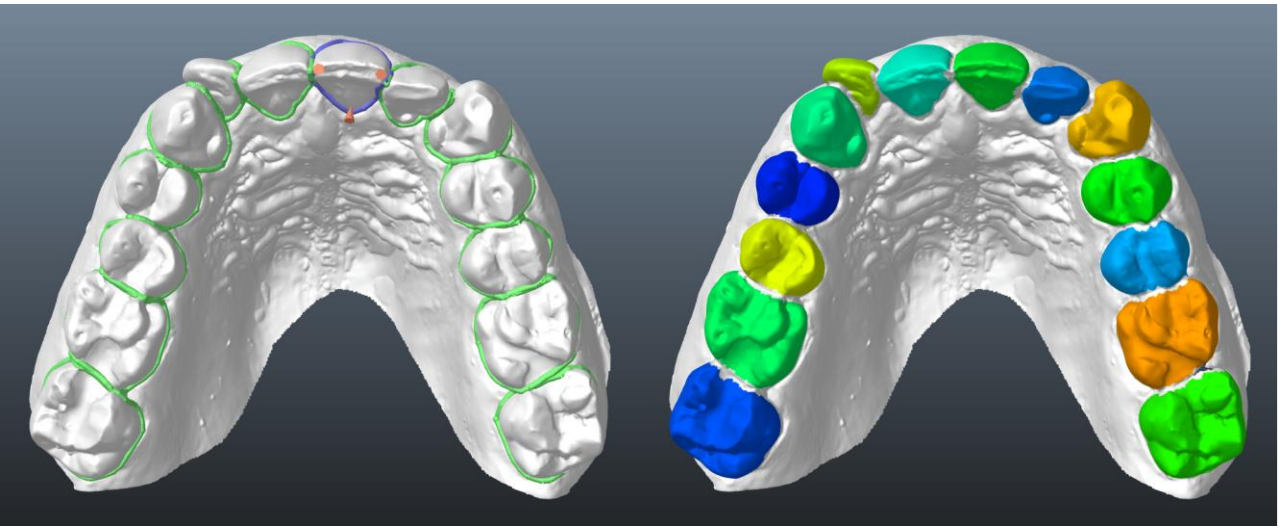


Input Scan

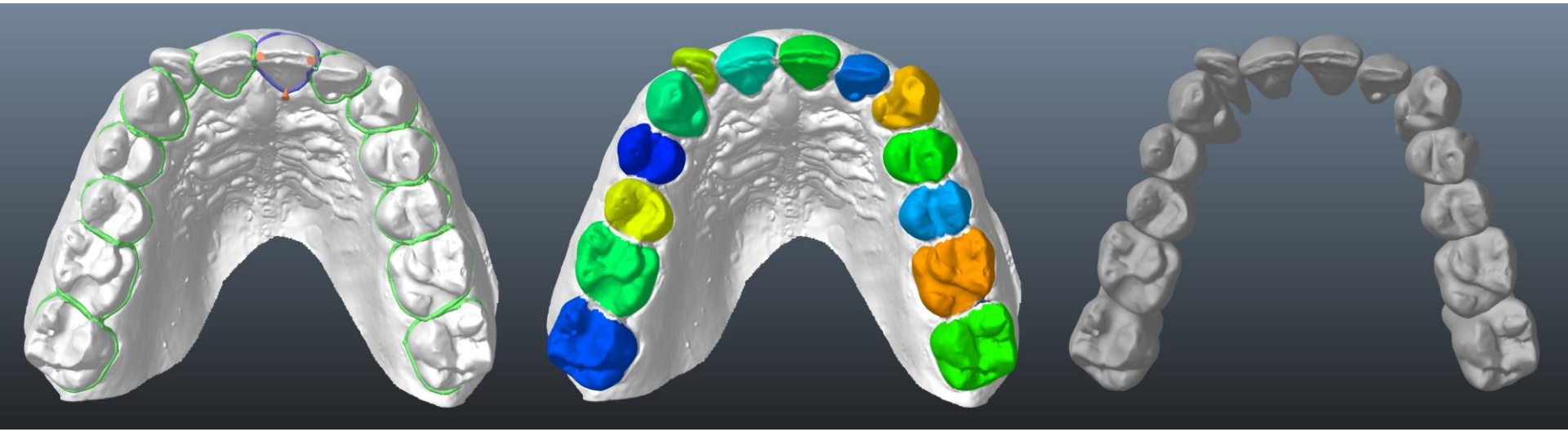
PREPROCESSING



Input Scan

Teeth Segmentation

PREPROCESSING



Input Scan | Teeth Segmentation | Fitted Template

PARAMETRIC TEETH MODEL

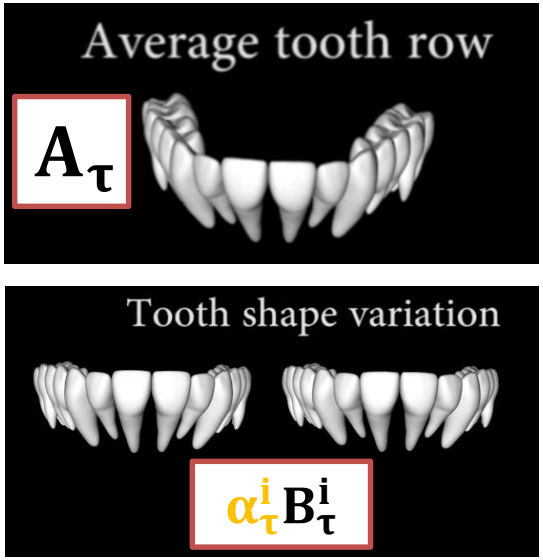
$$\mathbf{Z_\tau} = \boldsymbol{S}\, \boldsymbol{T}_\tau \left(\mathbf{A_\tau} + \sum_{\mathbf{i}} \boldsymbol{\alpha}_\tau^{\mathbf{i}} \mathbf{B}_\tau^{\mathbf{i}} \right)$$

PARAMETRIC TEETH MODEL

$$\mathbf{Z_\tau} = S\,T_\tau\left(\mathbf{A_\tau} + \sum_i \alpha_\tau^i \mathbf{B}_\tau^i\right)$$

PARAMETRIC TEETH MODEL

$$\mathbf{Z}_\tau = S\,T_\tau\left(\mathbf{A}_\tau + \sum_i \alpha_\tau^i \mathbf{B}_\tau^i\right)$$



shape of tooth τ

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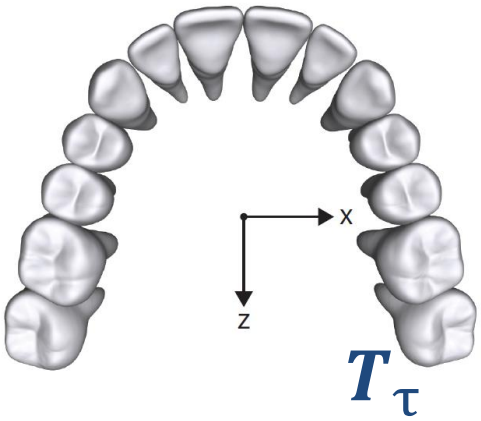

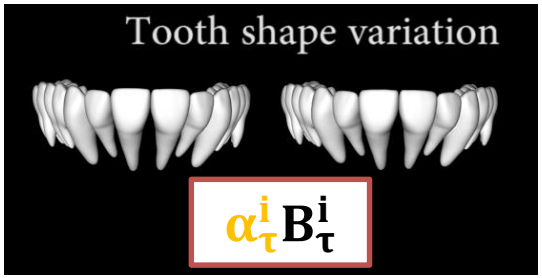

position of tooth τ

shape of tooth τ

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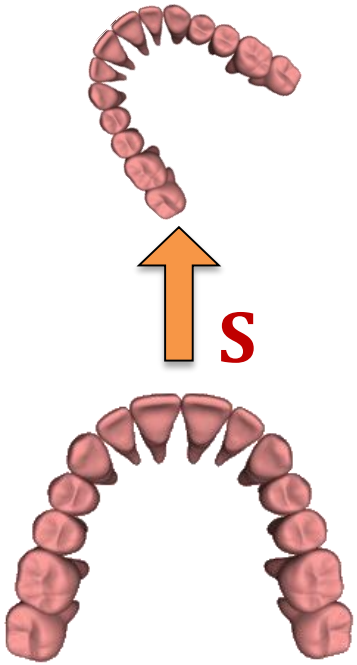

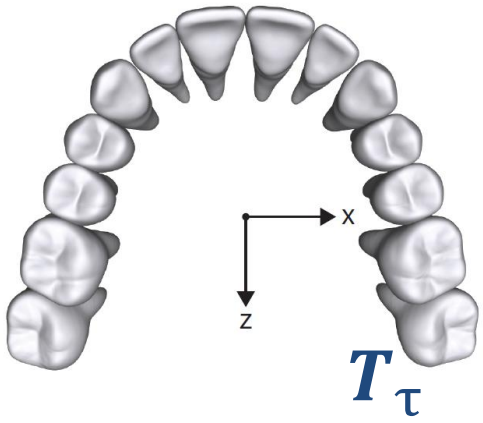

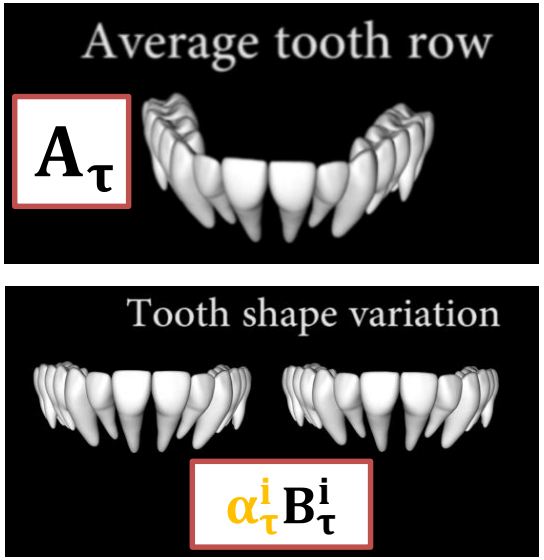

Scale and position

position of tooth τ

shape of tooth τ

GAUSSIAN DISTRIBUTION

$$X = (S, T_\tau, \{\alpha_\tau^i\})$$

GAUSSIAN DISTRIBUTION

- All dimensions modeled via multivariate Gaussians

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GAUSSIAN DISTRIBUTION

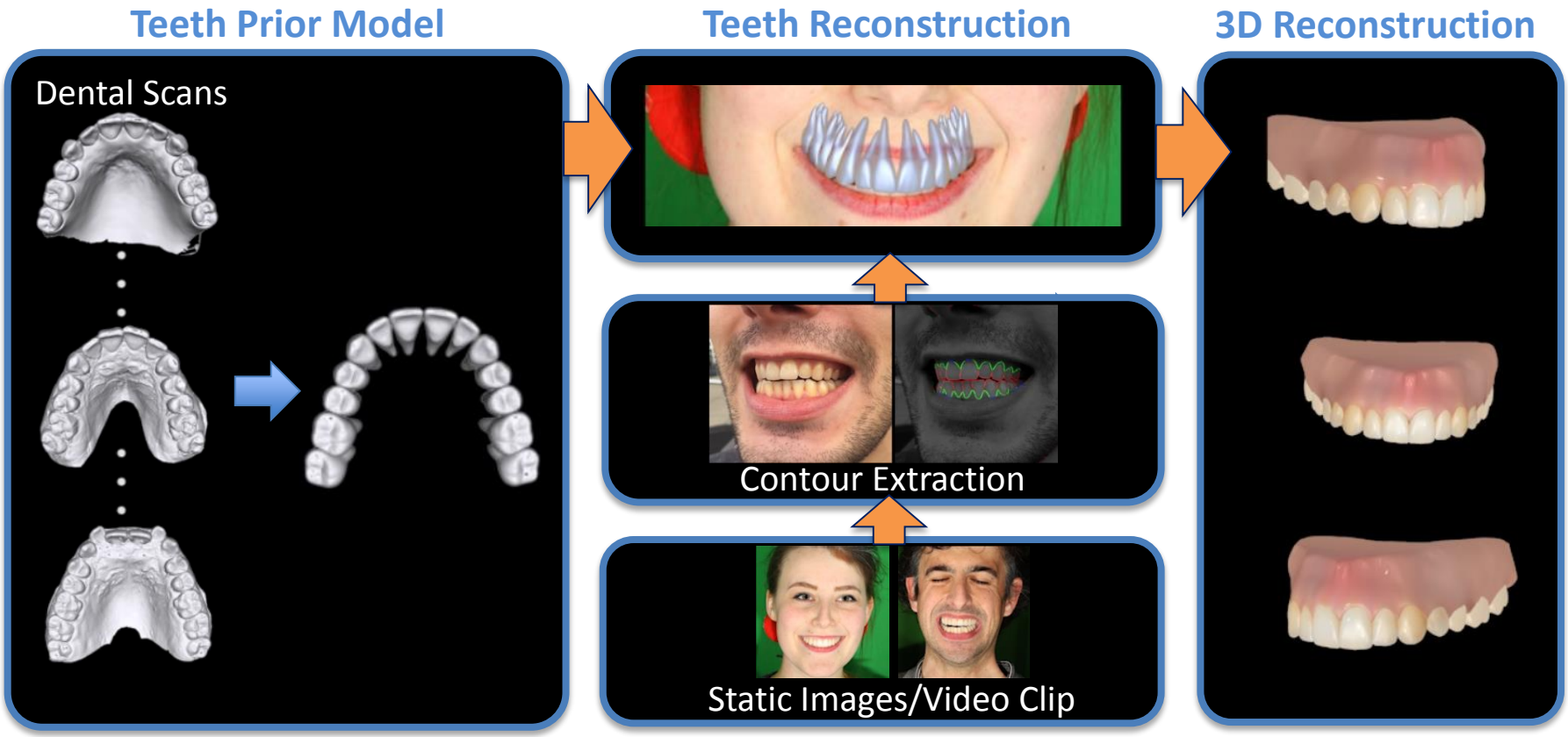
- All dimensions modeled via multivariate Gaussians

$$\boldsymbol{X} = (\boldsymbol{S}, \boldsymbol{T}_{\tau}, \{\boldsymbol{\alpha}_{\tau}^{\mathbf{i}}\})$$

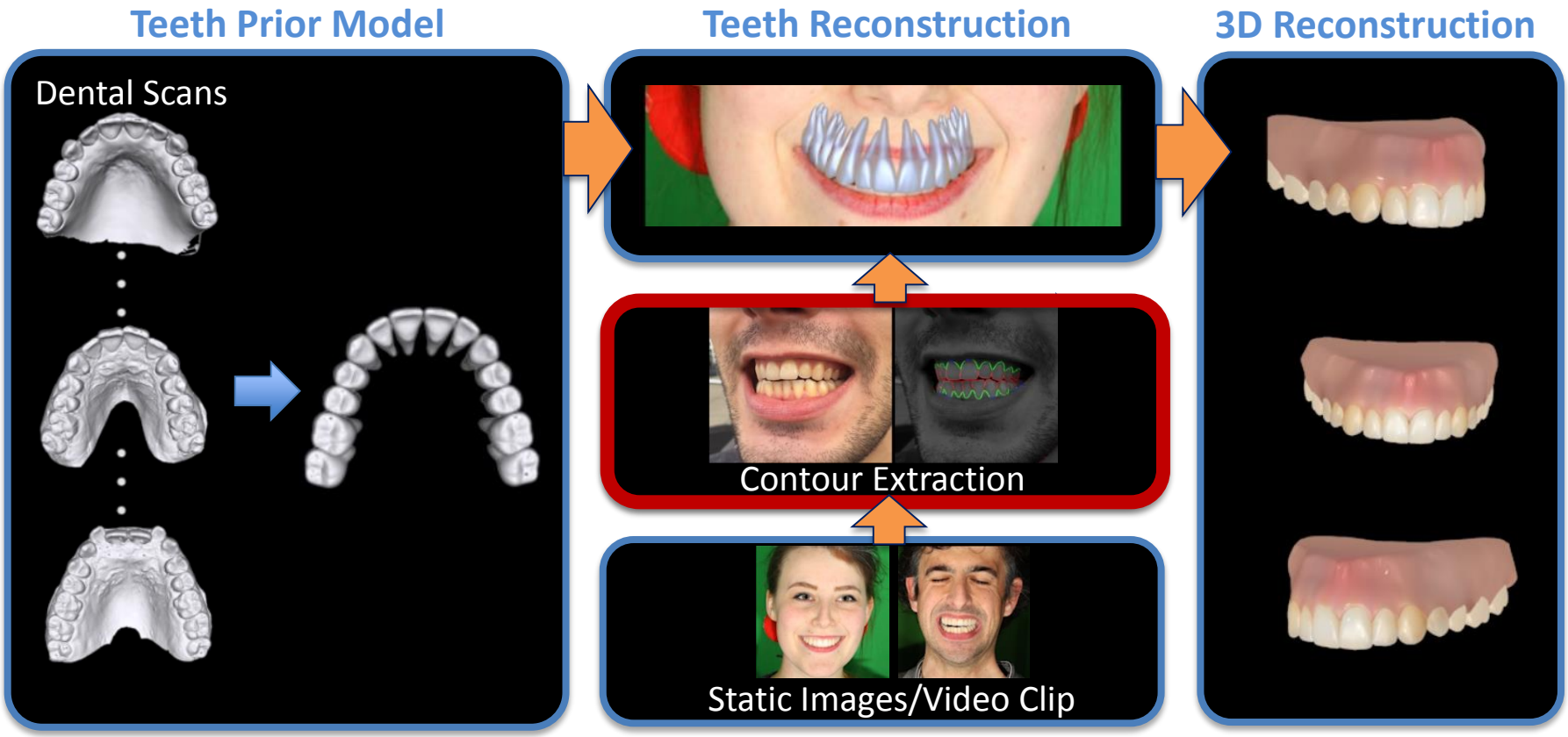
$\boldsymbol{p(X)}$

Teeth Prior

OVERVIEW


Teeth Prior Model
Teeth Reconstruction
3D Reconstruction
Dental Scans
Contour Extraction
Static Images/Video Clip

OVERVIEW


Teeth Prior Model
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3D Reconstruction
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Static Images/Video Clip

CONTOUR EXTRACTION

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- Teeth are featureless

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  - Except the silhouette

CONTOUR EXTRACTION

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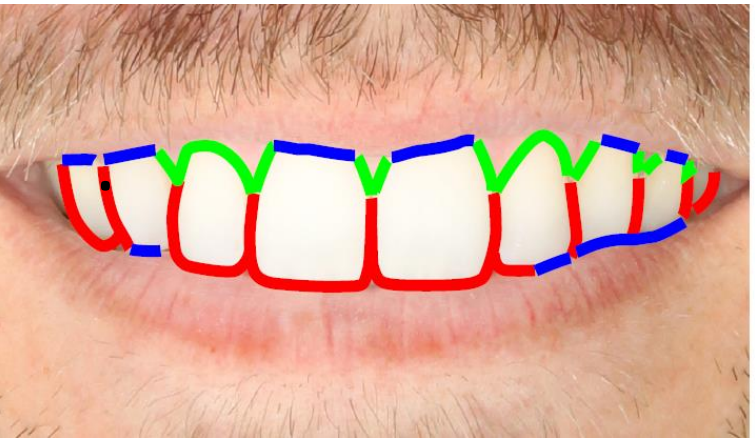
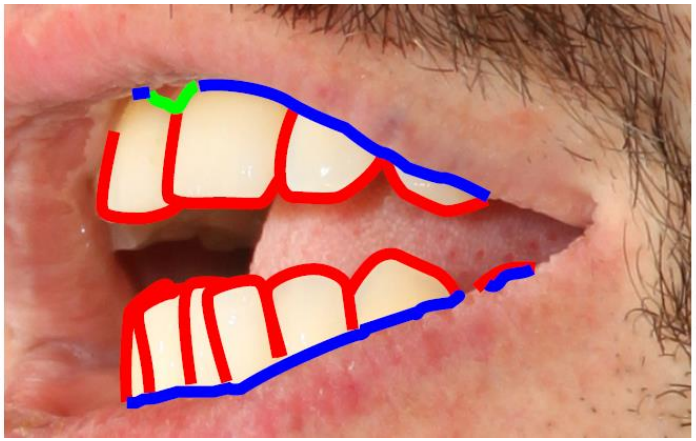
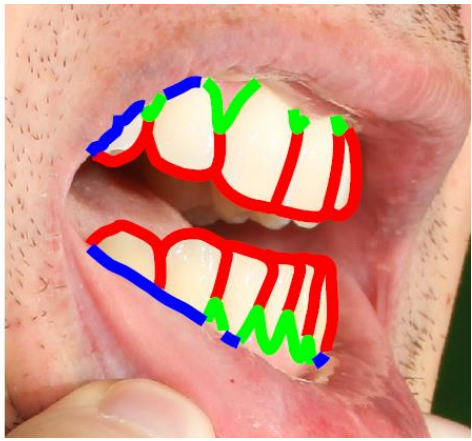

CONTOUR EXTRACTION

- Teeth are featureless
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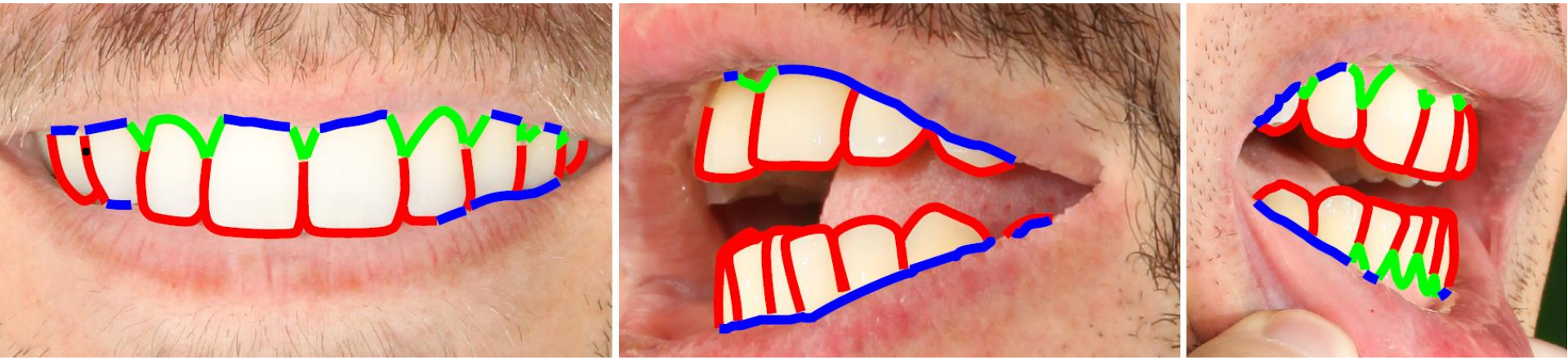


➢ Boosted Edge Learning (BEL)

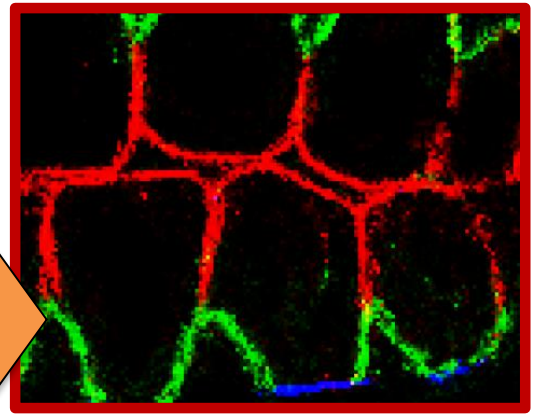
FEATURE FUSION

FEATURE FUSION

Input

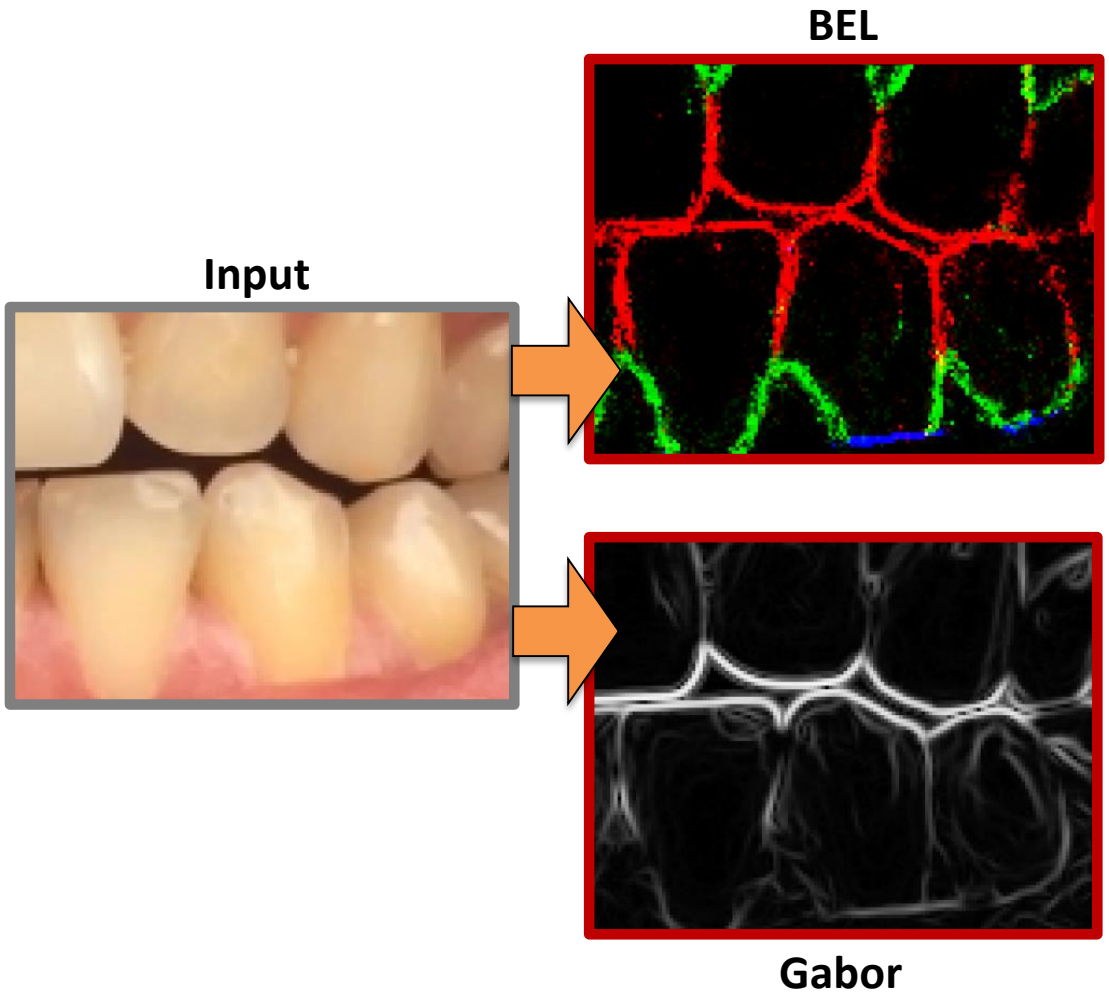
FEATURE FUSION

BEL

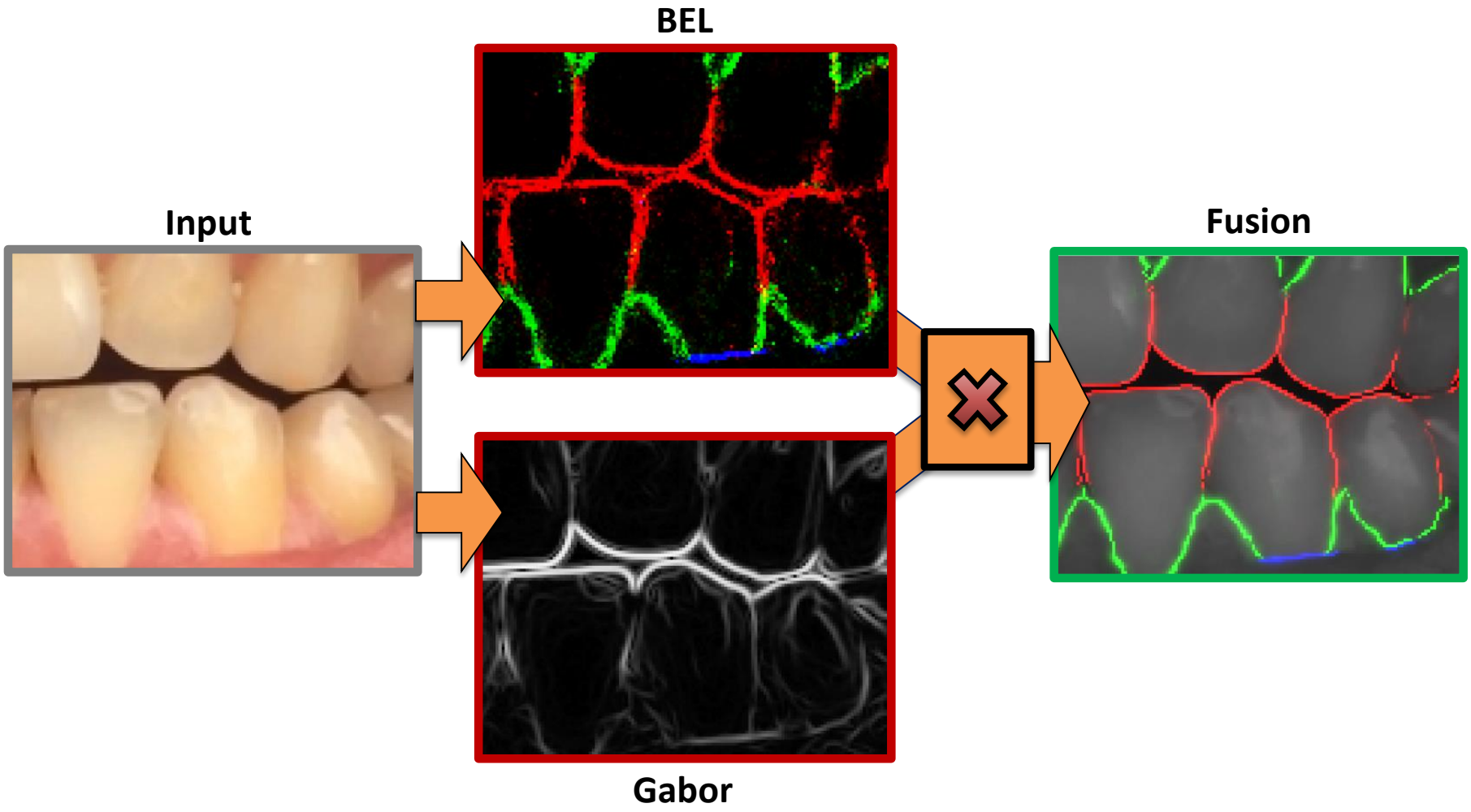


Input

FEATURE FUSION

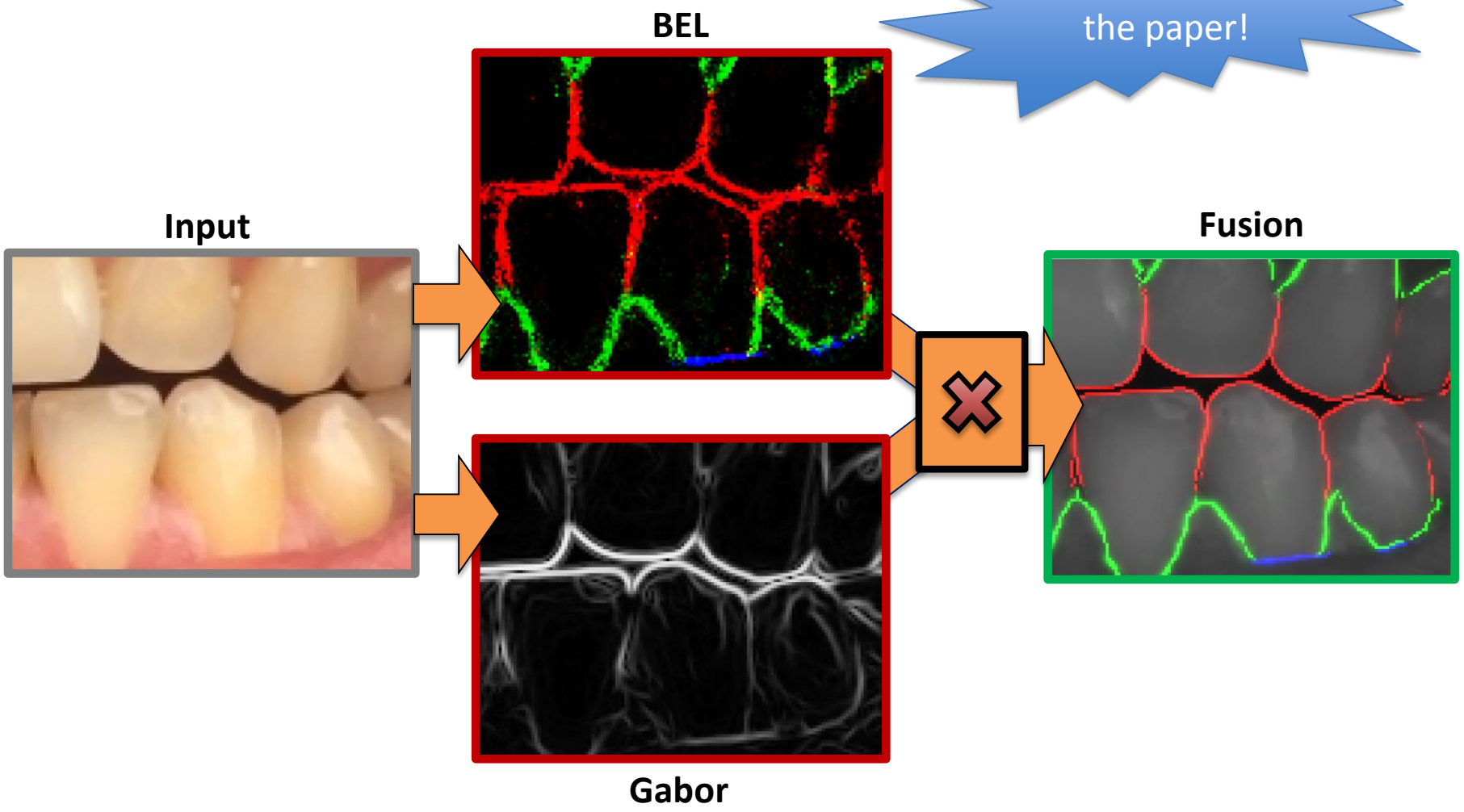


FEATURE FUSION

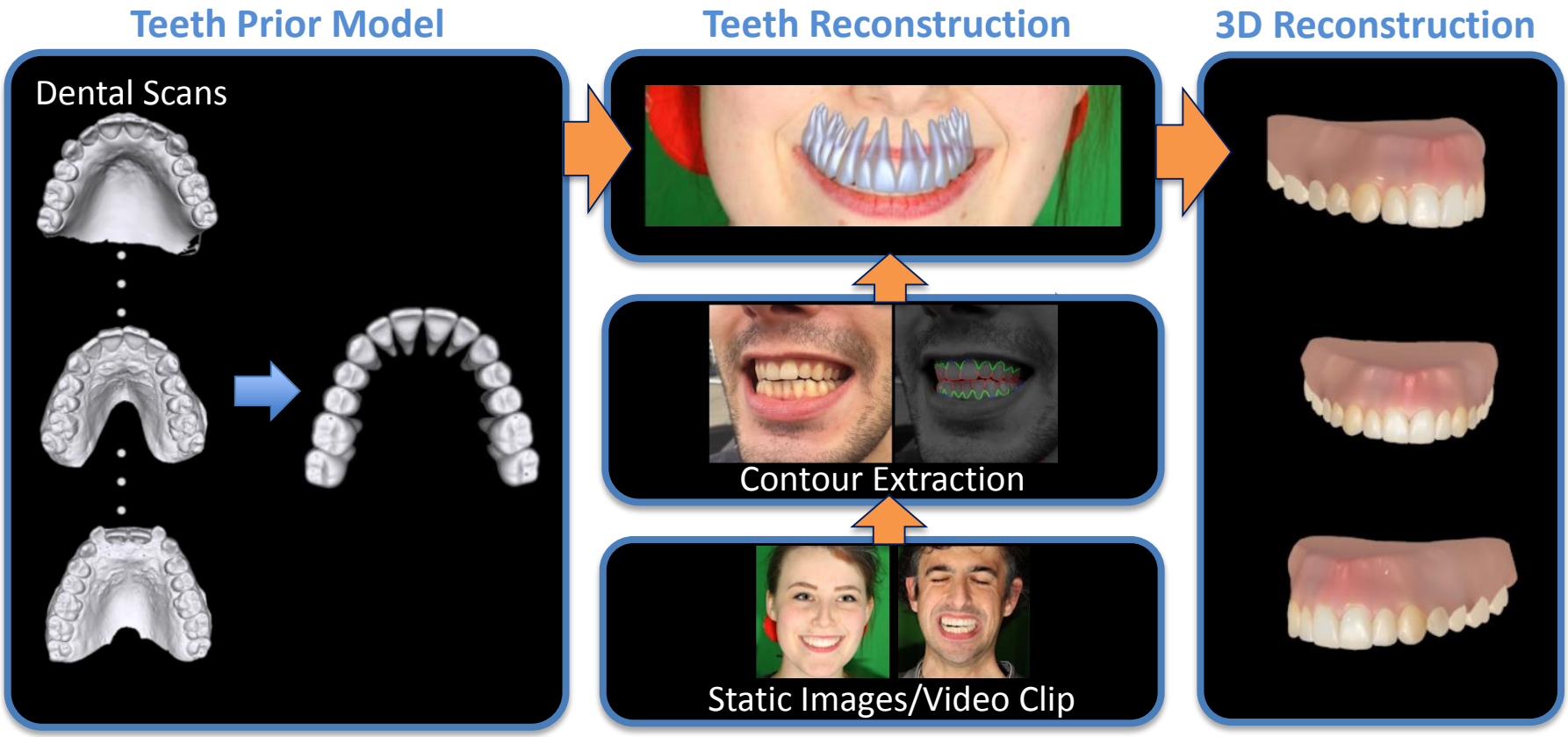


FEATURE FUSION

Formulas in the paper!



OVERVIEW


Teeth Prior Model
Teeth Reconstruction
3D Reconstruction
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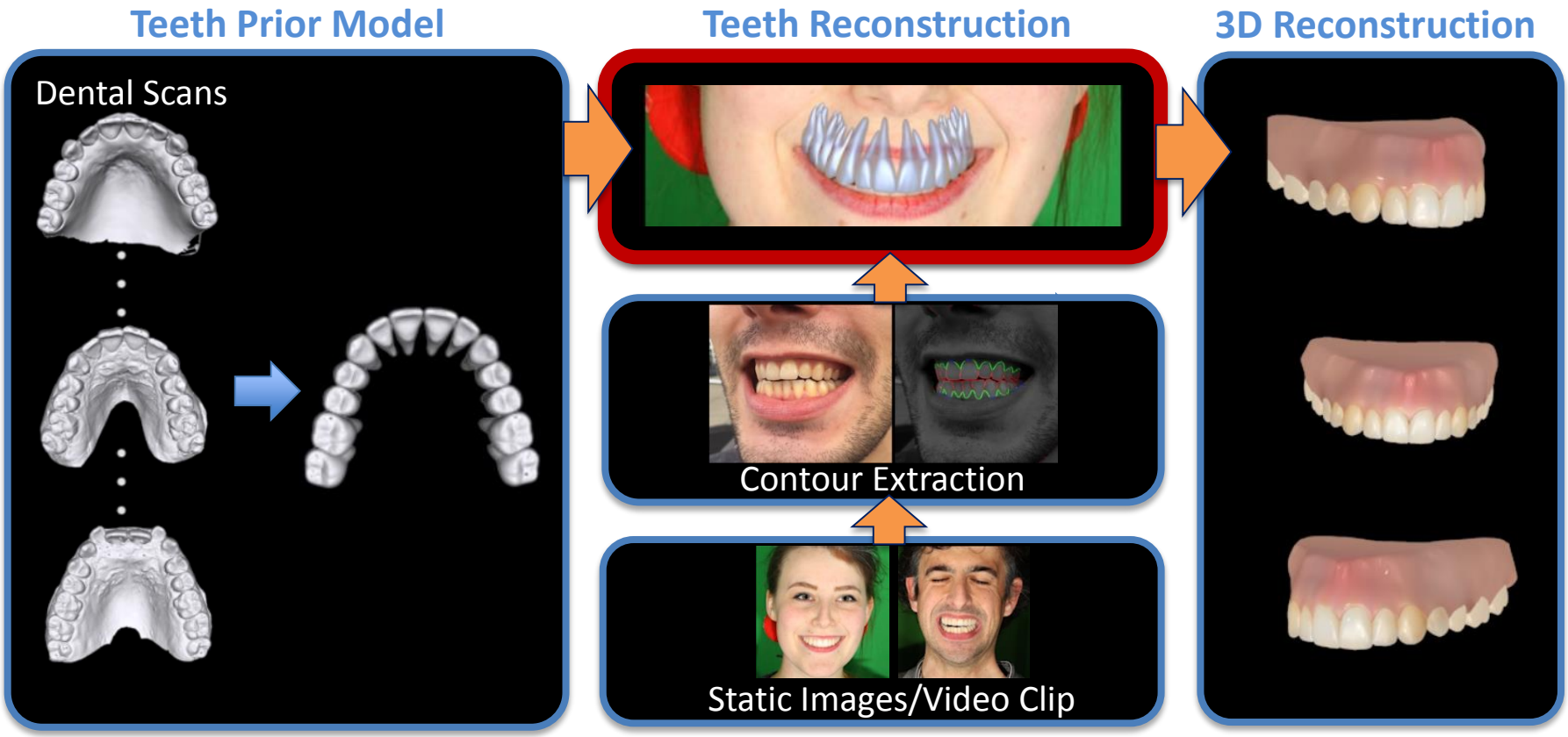
OVERVIEW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TEETH FITTING

- Given detected contours $\boldsymbol{C}$

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MAXIMUM A POSTERIORI (MAP) PROBLEM

- Given detected contours $\boldsymbol{C}$
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$$\boldsymbol{X^*} = \boldsymbol{arg}\max_{\boldsymbol{X}} \boldsymbol{p(X|C)}$$
$$= \boldsymbol{arg}\max_{\boldsymbol{X}} [\, \boldsymbol{p(C|X)} \cdot \boldsymbol{p(X)} \,]$$

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Teeth Edge Likelihood

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Teeth Edge Likelihood	Teeth Prior

MAXIMUM A POSTERIORI (MAP) PROBLEM

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$$\boldsymbol{= arg\max_X [\, p(C|X) \cdot p(X) \,]}$$

Solve with EM-Algorithm

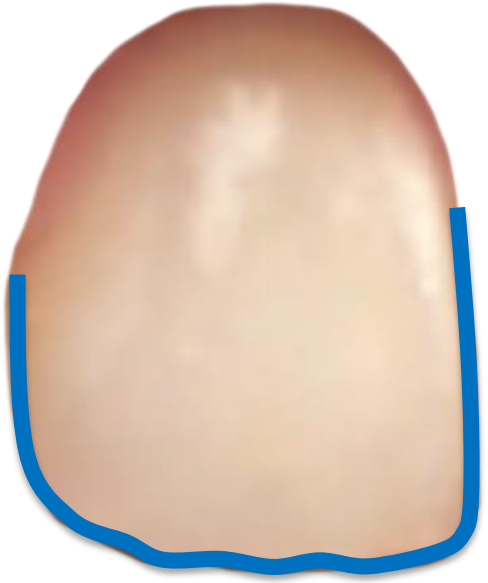
Teeth Edge Likelihood	Teeth Prior

EM ALGORITHM

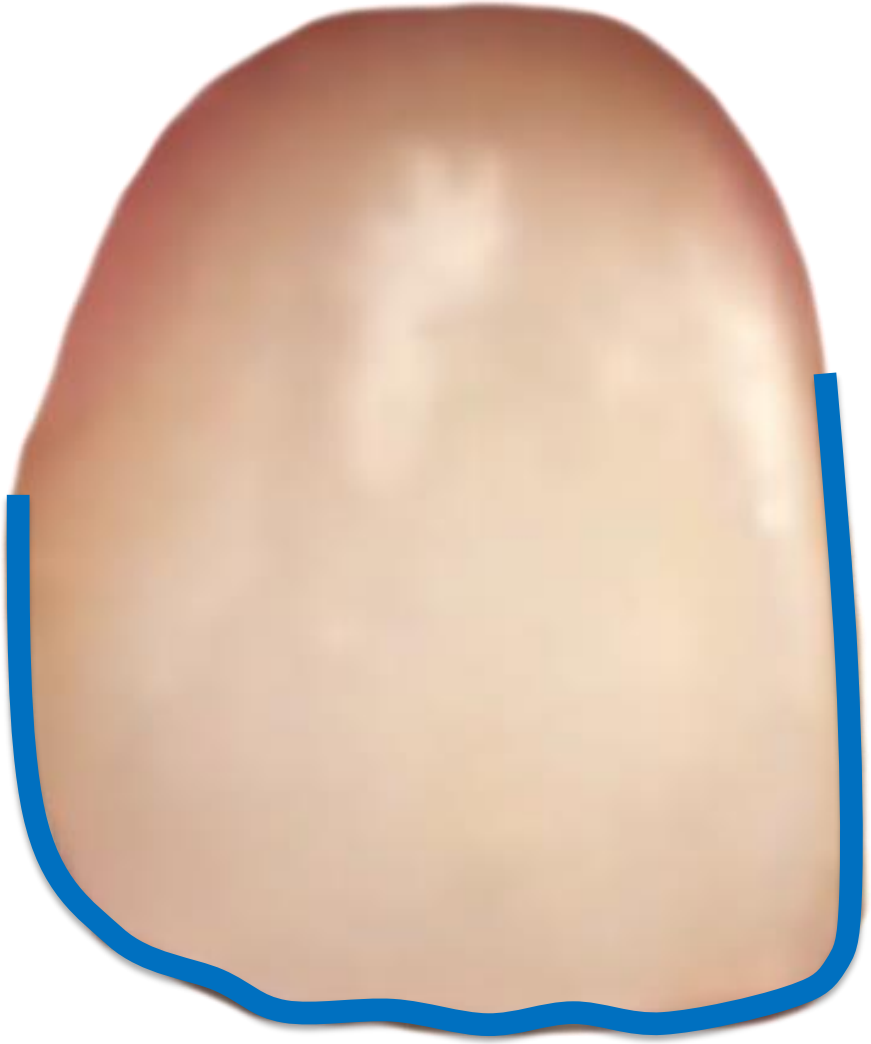
EM ALGORITHM

EM ALGORITHM

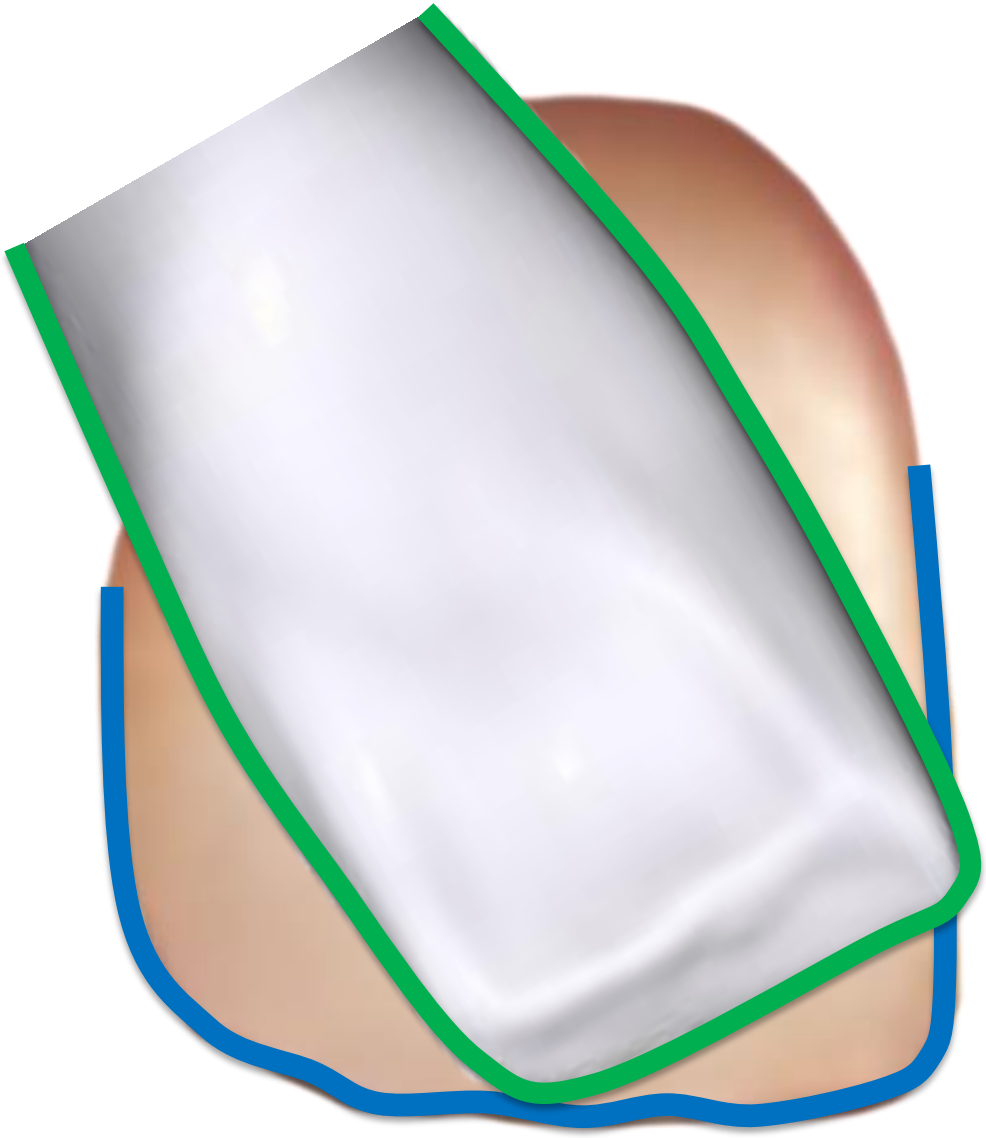
EM ALGORITHM



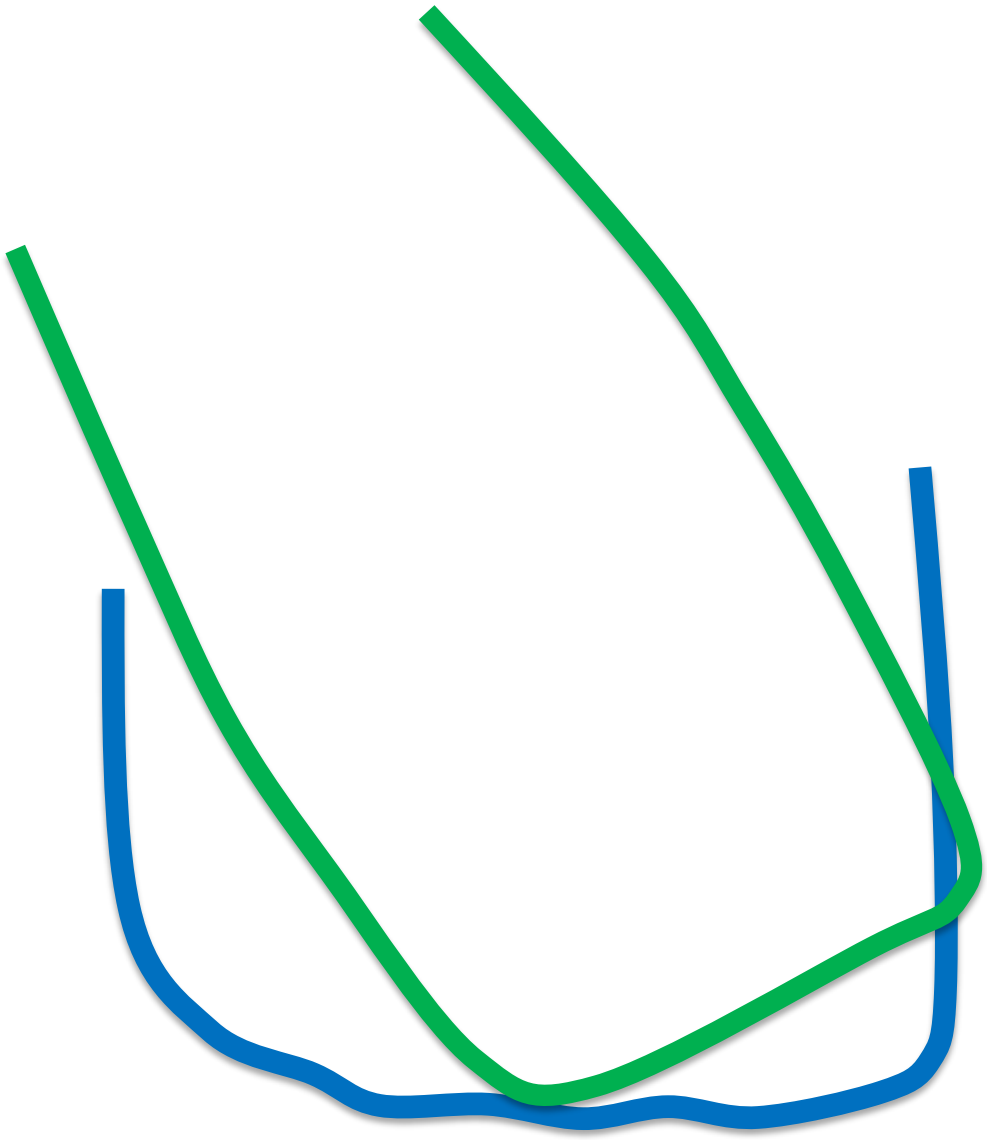
EM ALGORITHM



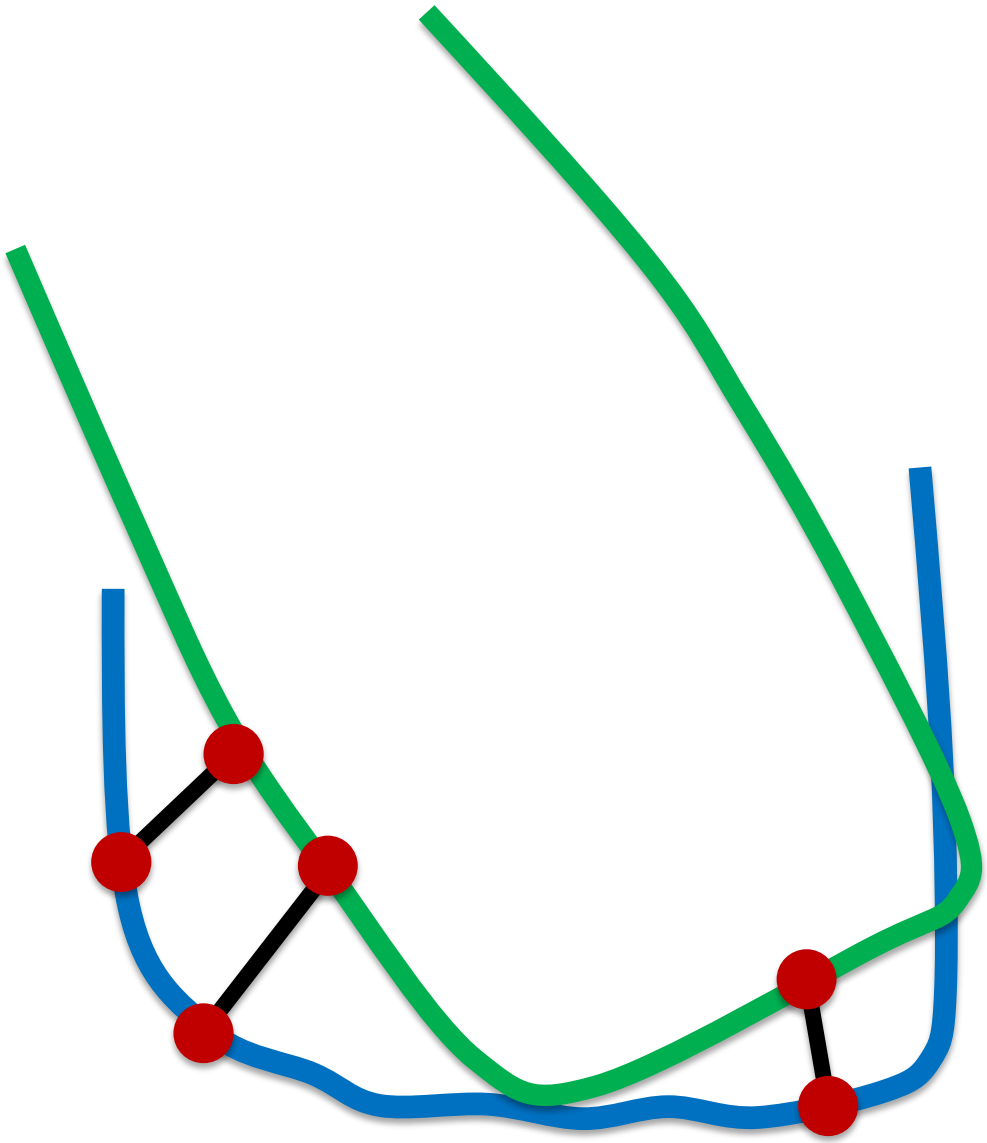
EM ALGORITHM



EM ALGORITHM



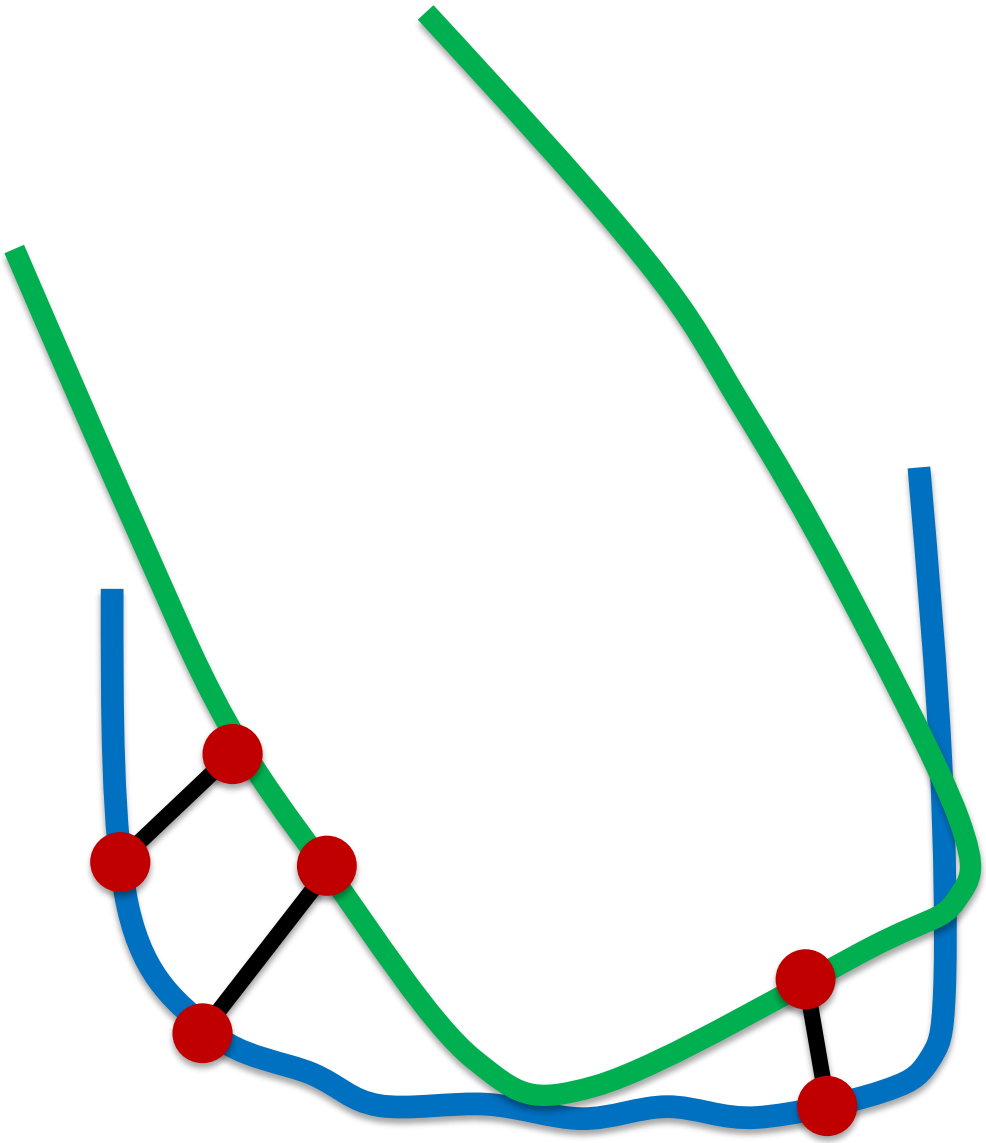
E-STEP



TEETH EDGE LIKELIHOOD

Teeth Edge Likelihood

$$p(C|X)$$



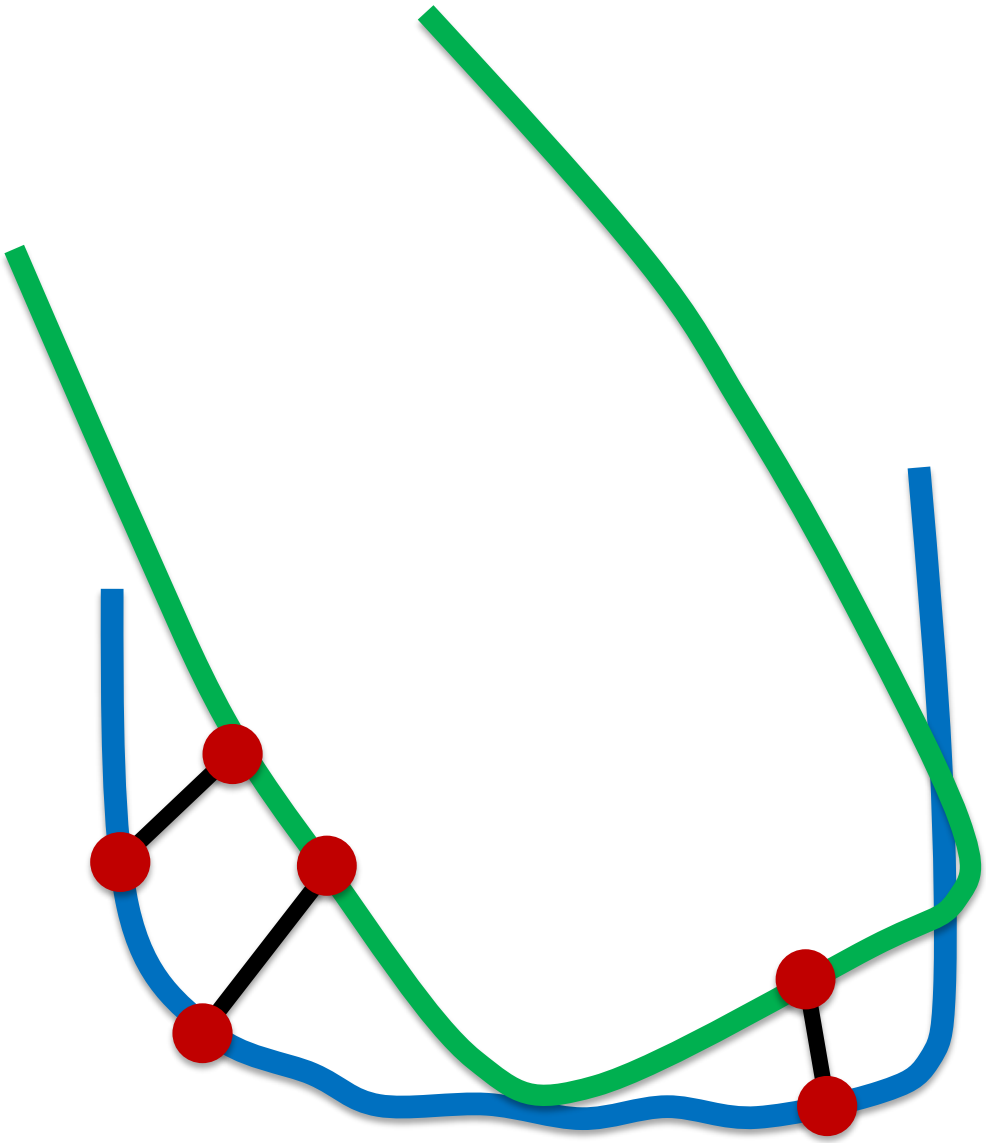
TEETH EDGE LIKELIHOOD

Teeth Edge Likelihood

$$p(C|X)$$

$$=$$

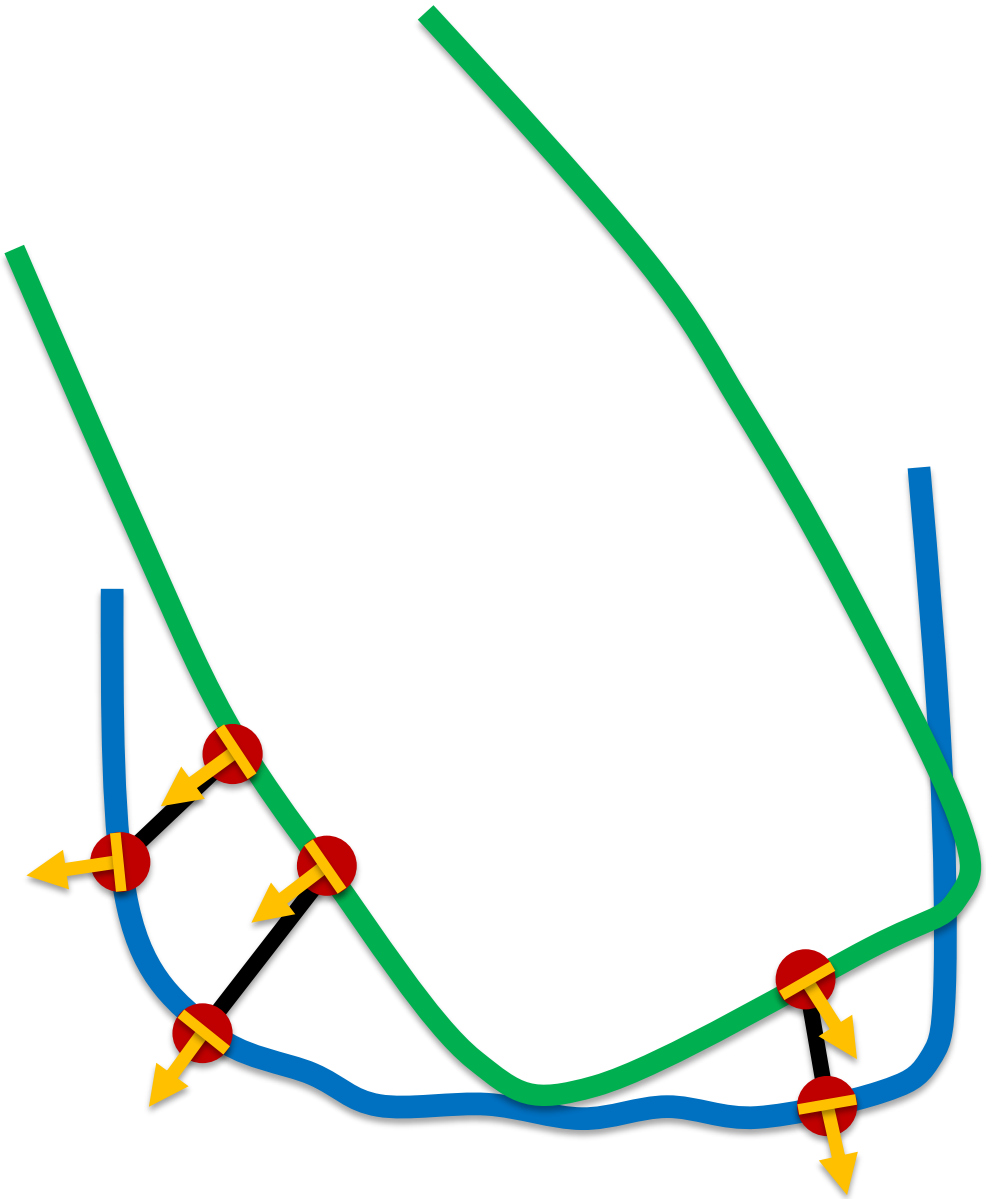
$$p_p(C|X)$$



TEETH EDGE LIKELIHOOD

Teeth Edge Likelihood

$$p(C|X) = p_p(C|X) \cdot p_n(C|X)$$



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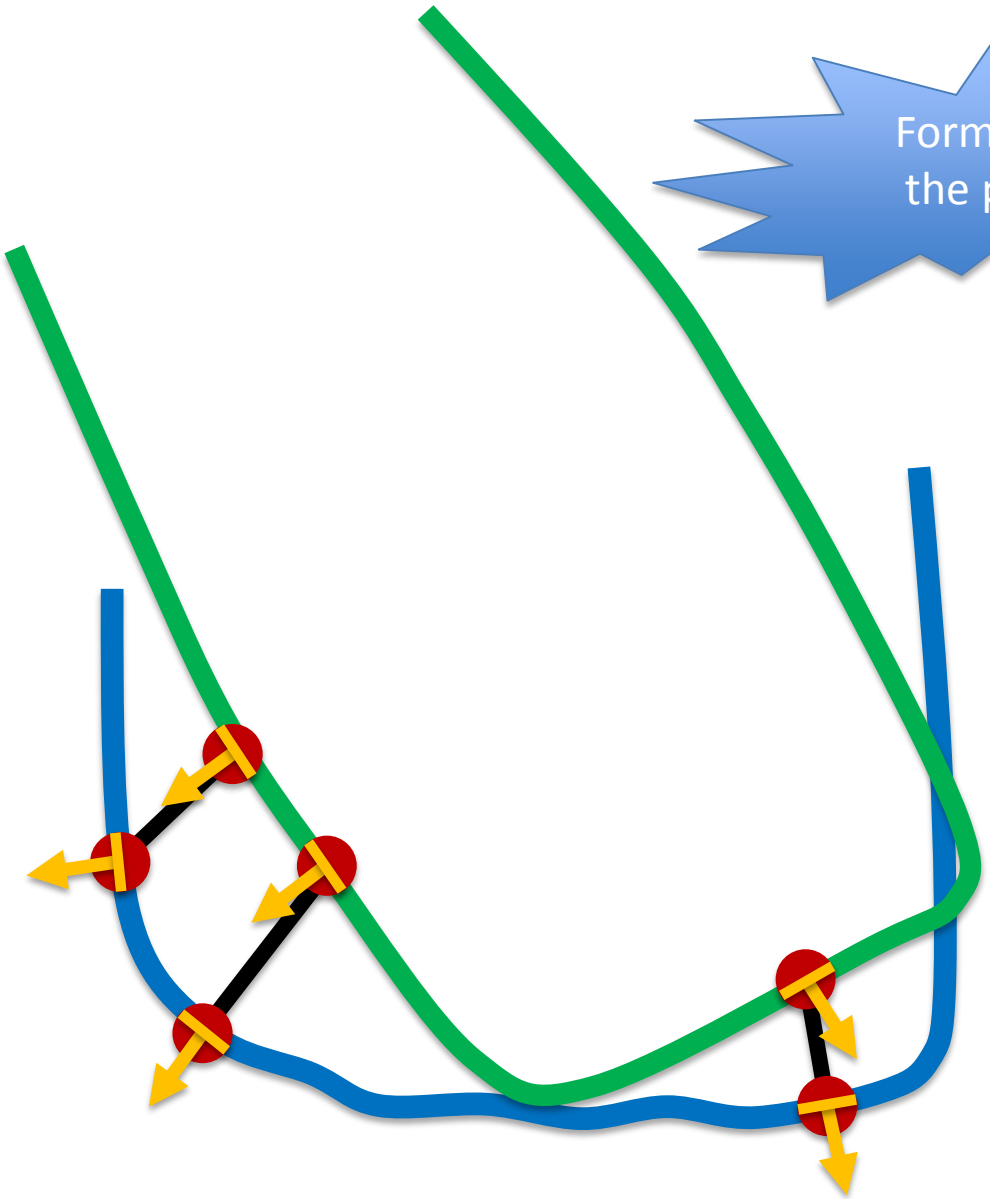
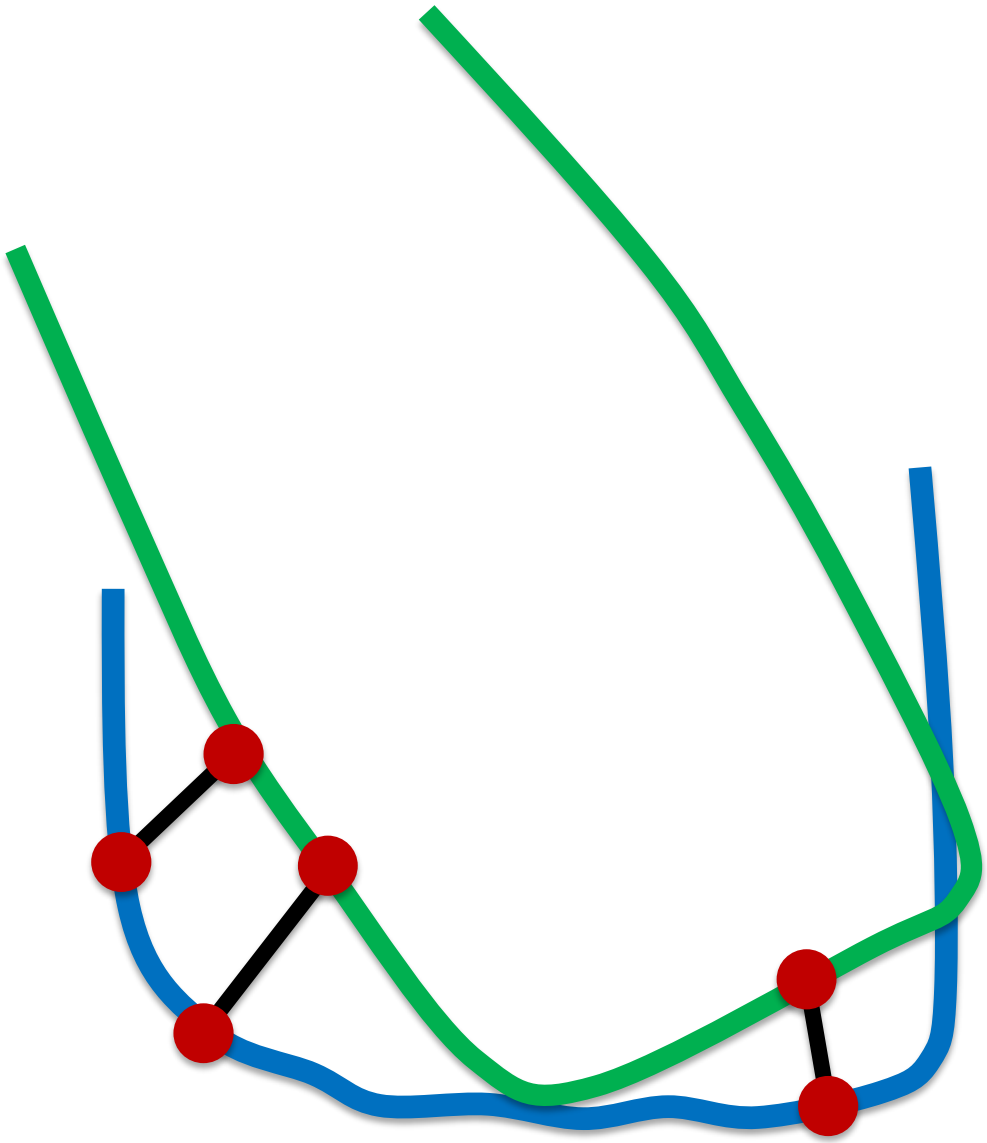


Formulas in the paper!

M-STEP



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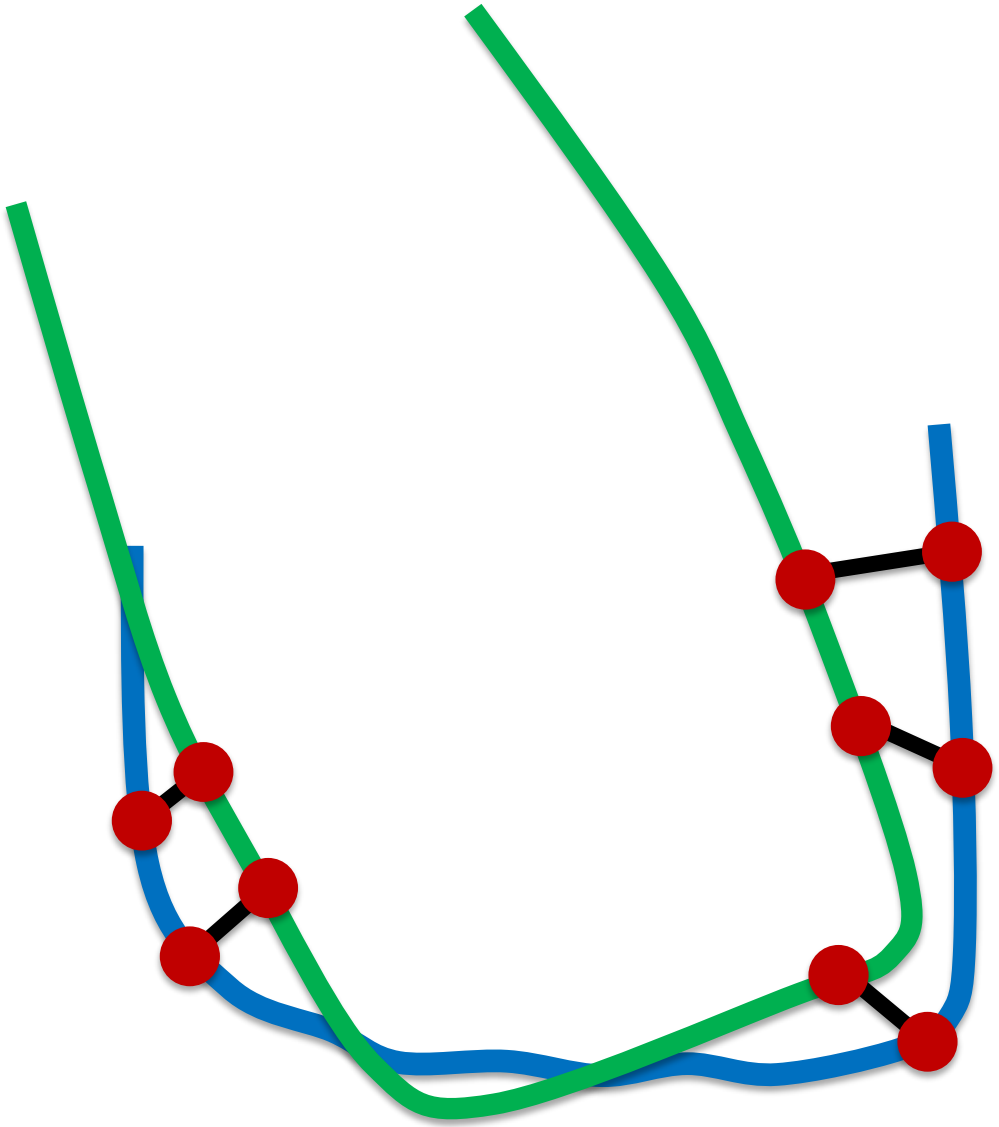
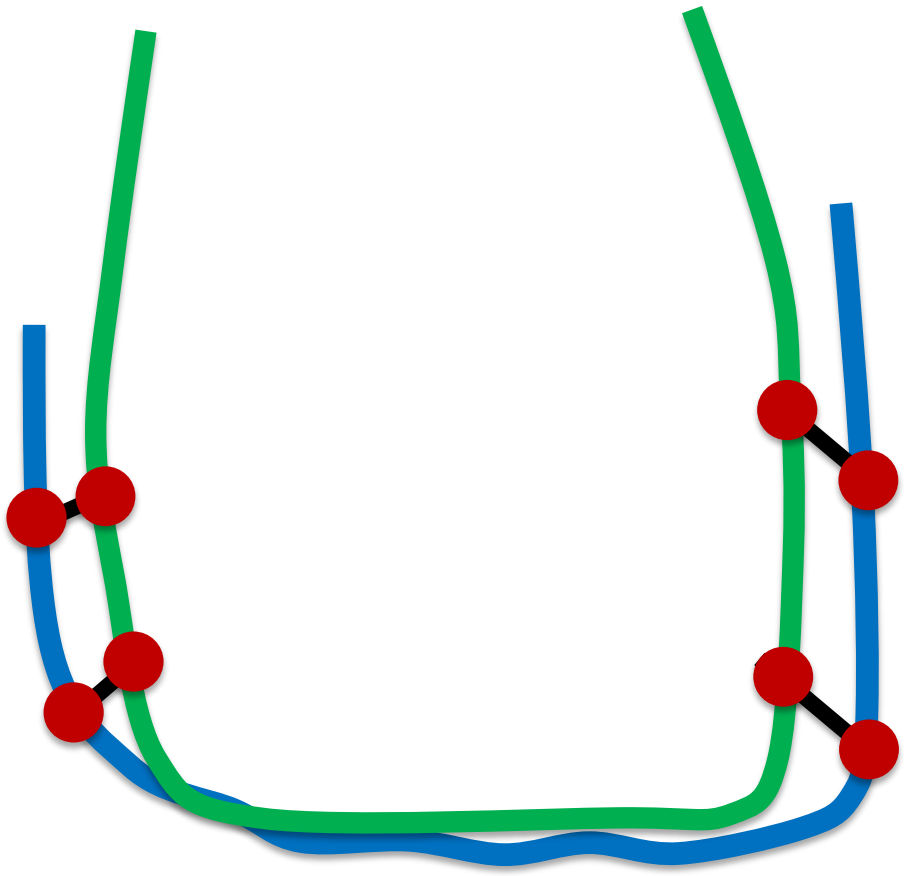
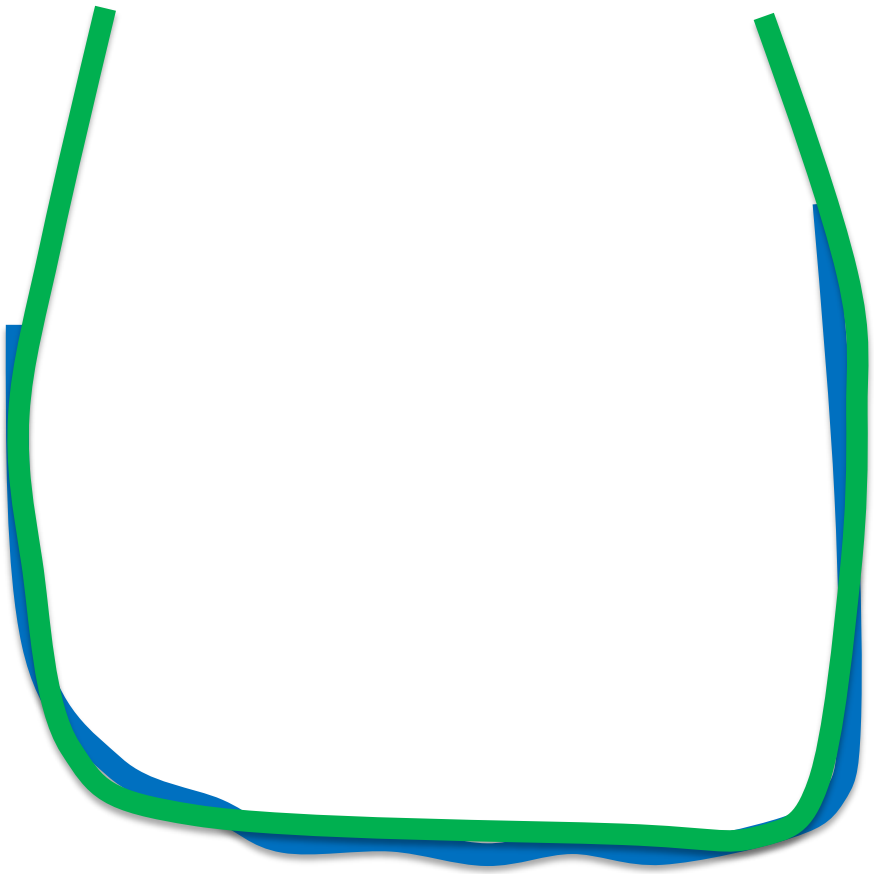


ITERATE



DONE



COLOR AND GUMS

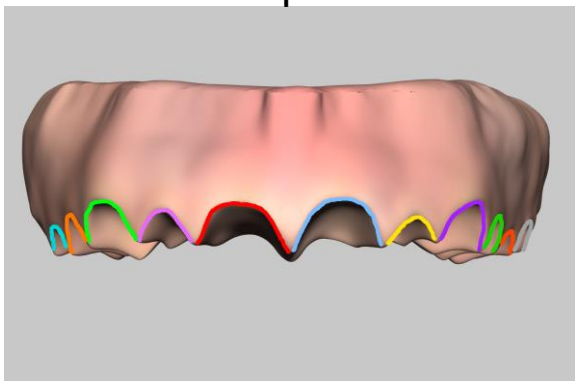
COLOR AND GUMS

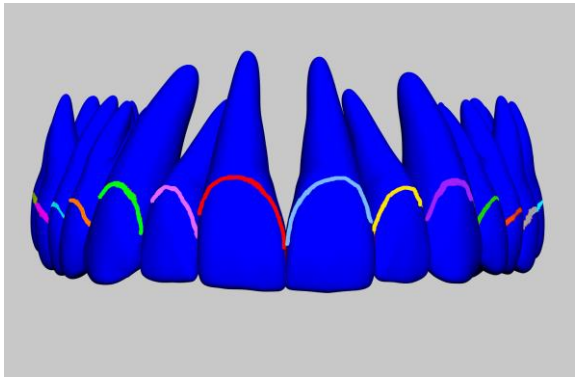
- Projective Texturing

COLOR AND GUMS

- Projective Texturing
- Fit 3D gum template via Laplacian deformation

Template

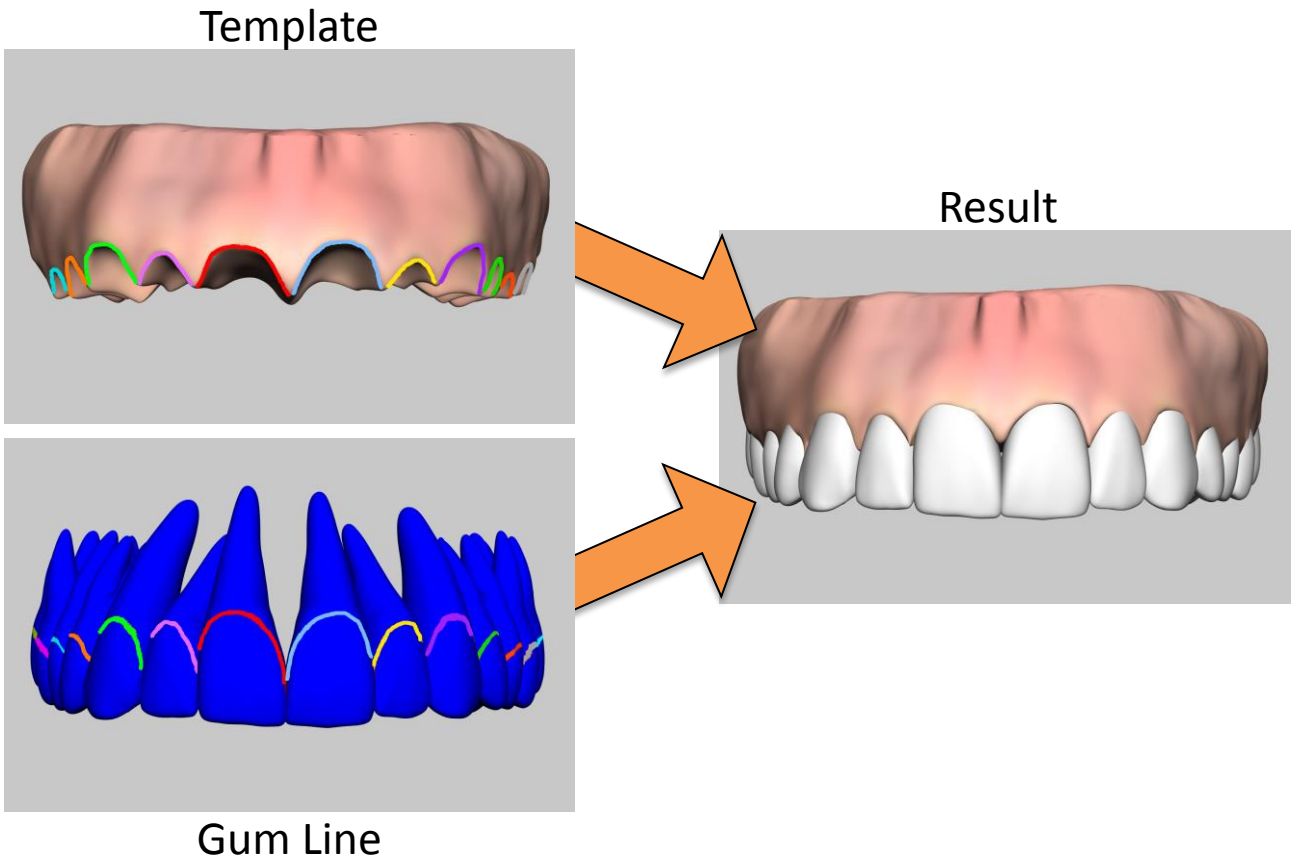




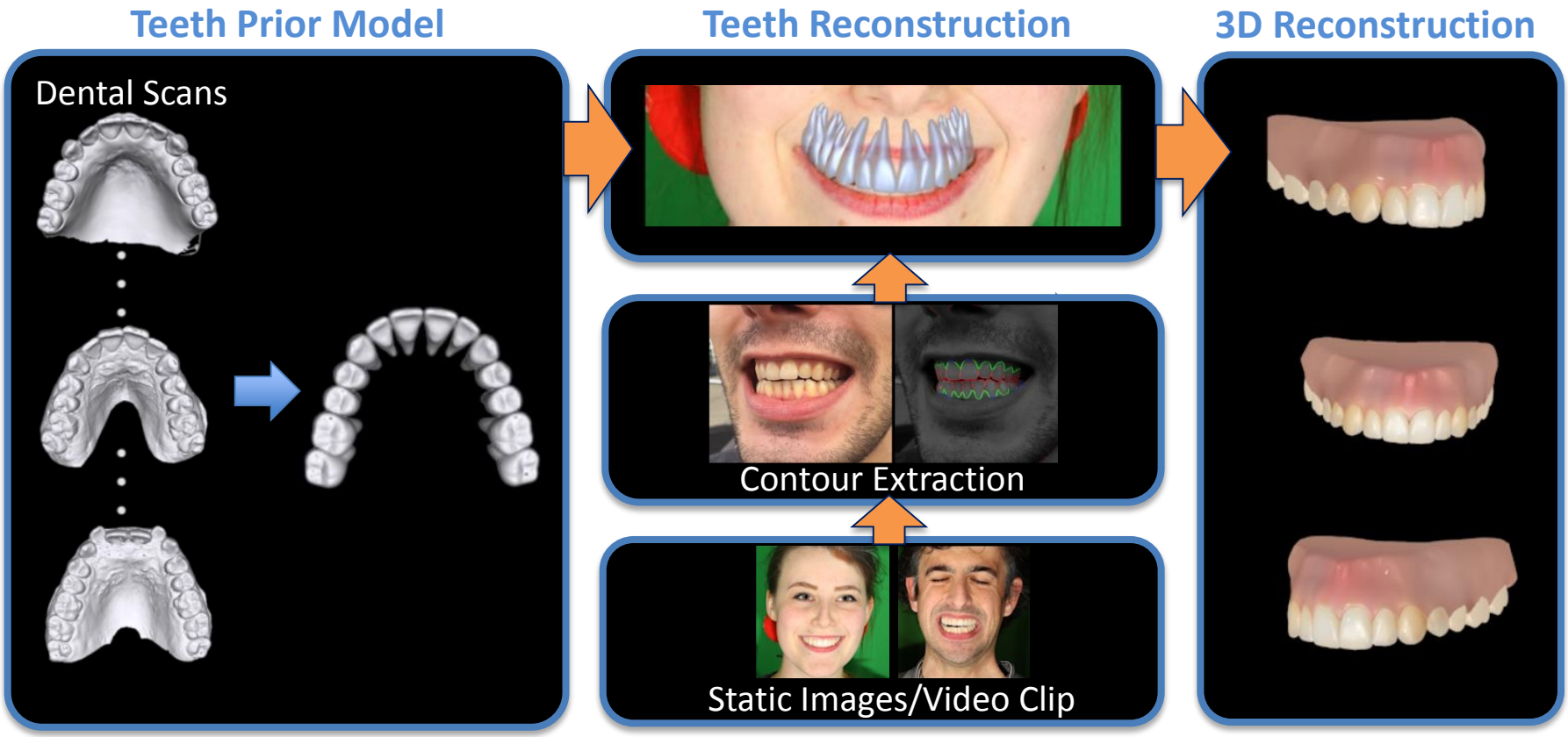
Gum Line

COLOR AND GUMS

- Projective Texturing
- Fit 3D gum template via Laplacian deformation



OVERVIEW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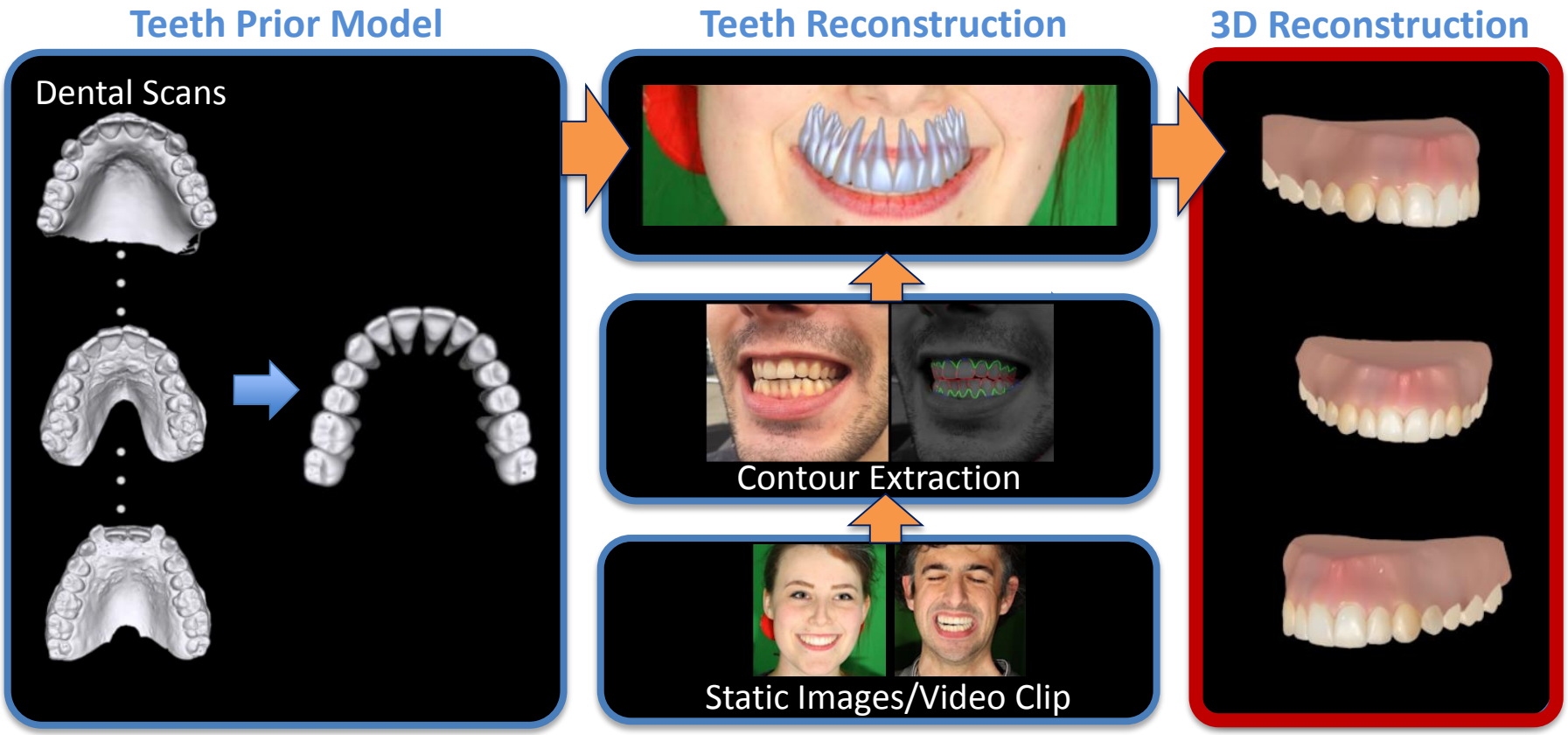
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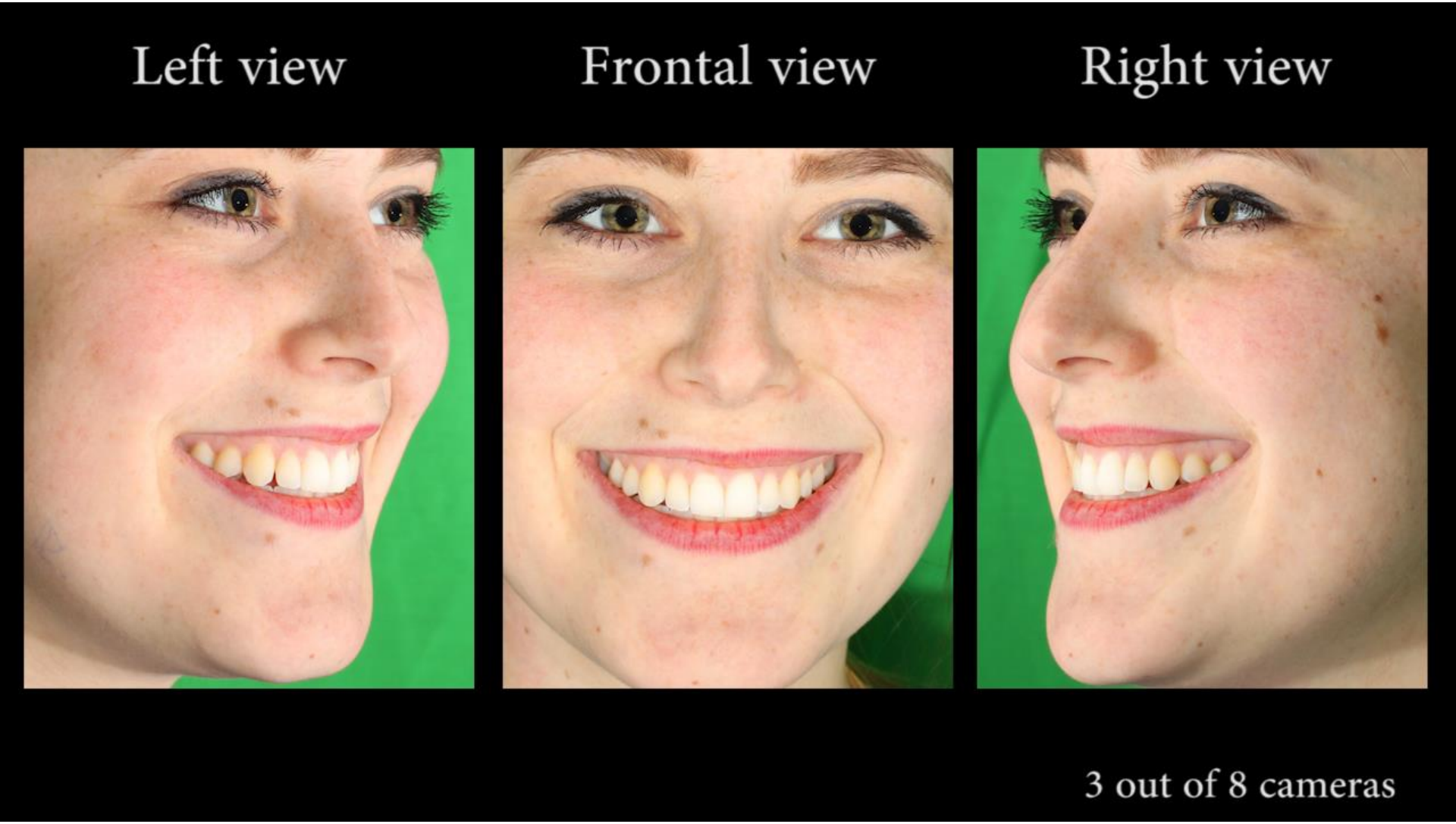
MULTI-VIEW IMAGES



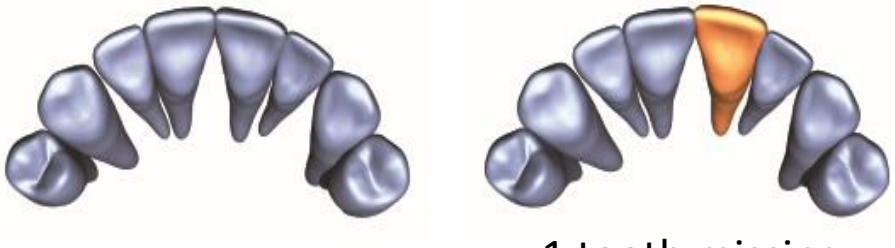
MONOCULAR VIDEO

Input video

Rendered 3D results

APPLICATION: TOOTH RESTORATION

APPLICATION: TOOTH RESTORATION



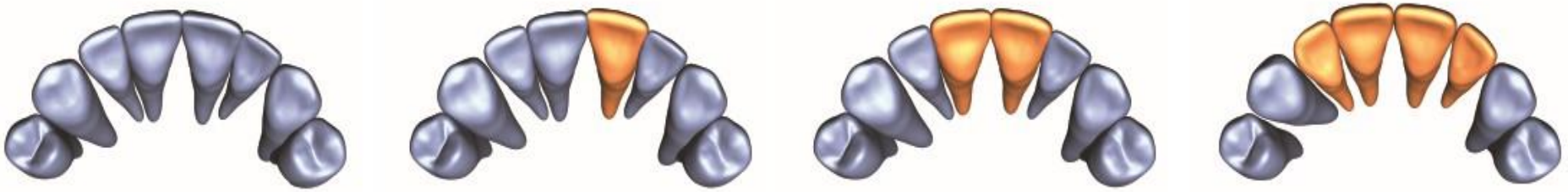
1 tooth missing

APPLICATION: TOOTH RESTORATION

1 tooth missing

2 teeth missing

APPLICATION: TOOTH RESTORATION



1 tooth missing

2 teeth missing

4 teeth missing

CONCLUSION

First non-invasive teeth reconstruction approach

CONCLUSION

First non-invasive teeth reconstruction approach

Content creation (i.e. digital actor)

CONCLUSION

First non-invasive teeth reconstruction approach

Content creation (i.e. digital actor)

Dentistry (i.e tooth restoration)

THANK YOU!

C. Wu

D. Bradley

P. Garrido

M. Zollhöfer

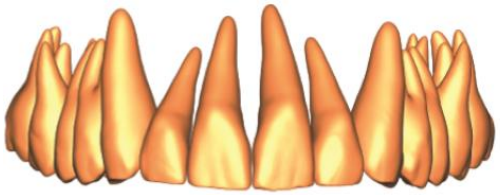
C. Theobalt

M. Gross

T. Beeler

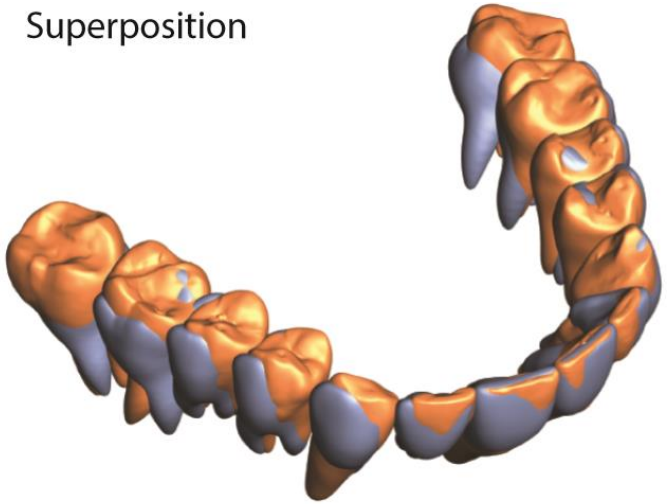
APPENDIX

Ground-Truth



Reconstructed

Superposition



Alignment Error