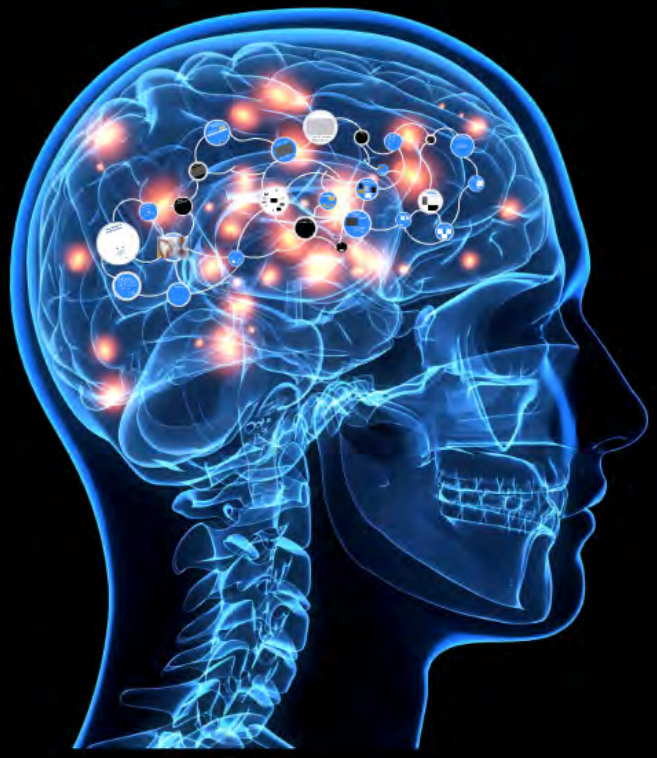
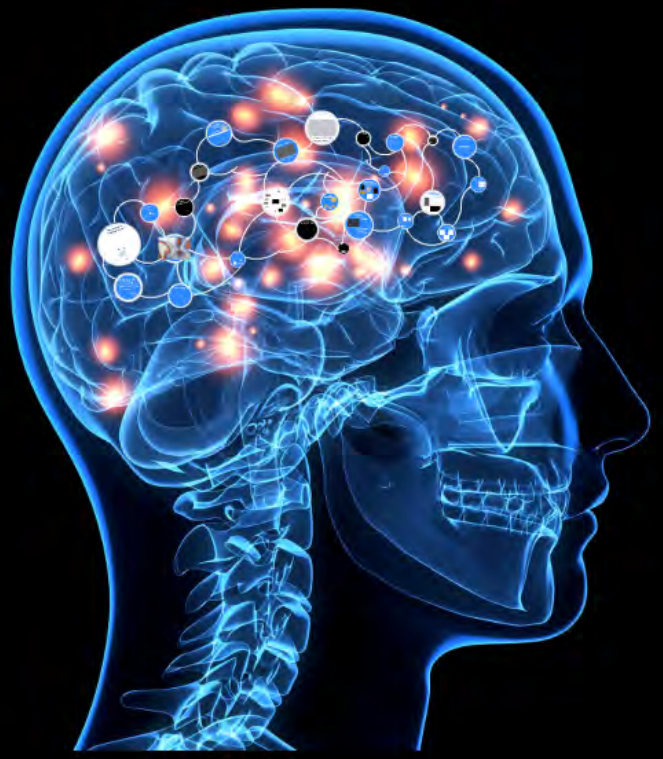
Generative Approach to Mass Customization of Patient Specific Products



Sergei Azernikov
ML Team Lead @ Glidewell Dental

Generative Approach to Mass Customization of Patient Specific Products



Sergei Azernikov
ML Team Lead @ Glidewell Dental

The World is Getting Older

2015

Percentage aged 60 years or older:
- 30% or more
- 10 to <30%
- <10%

2050

The World is Getting Older

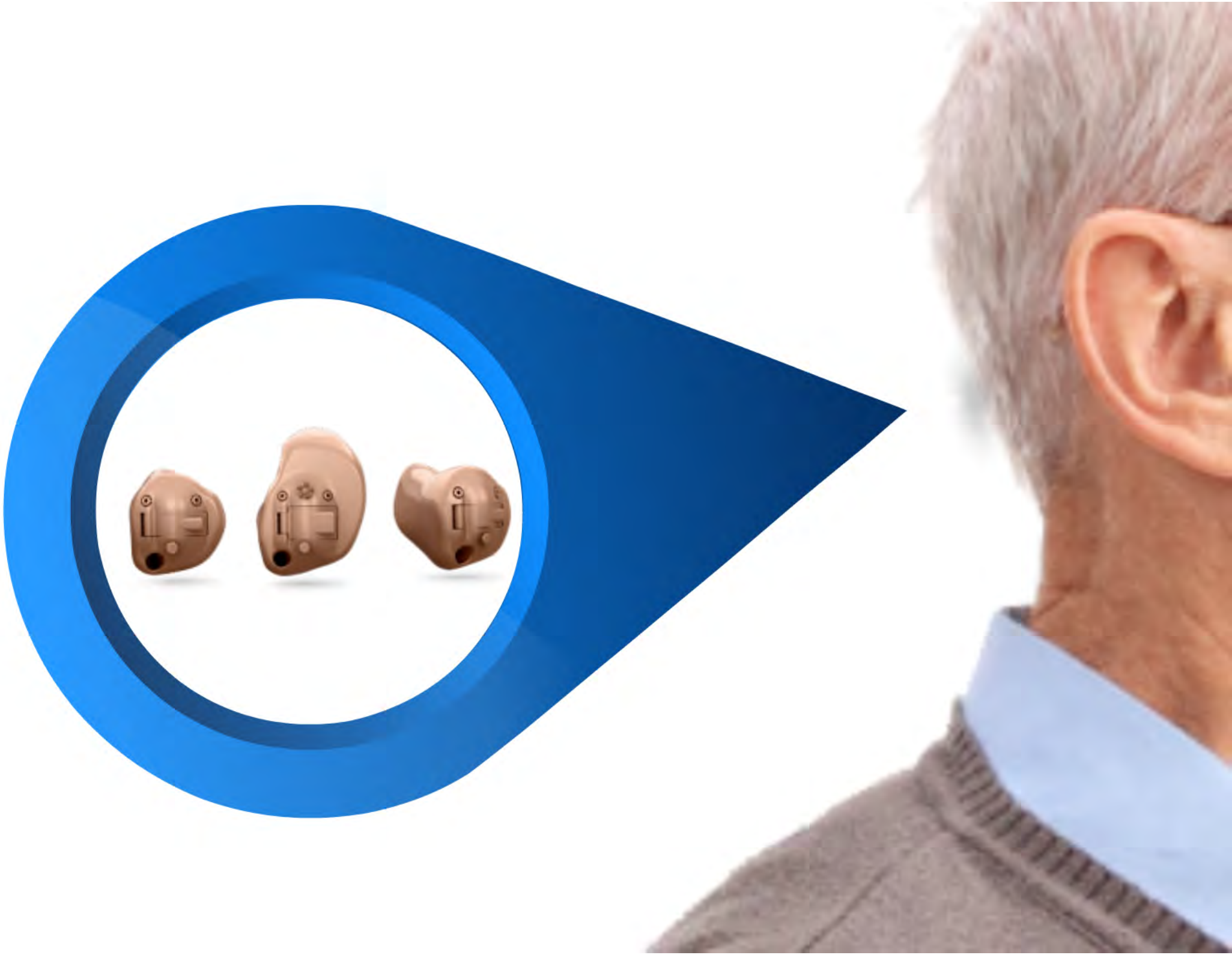
2015

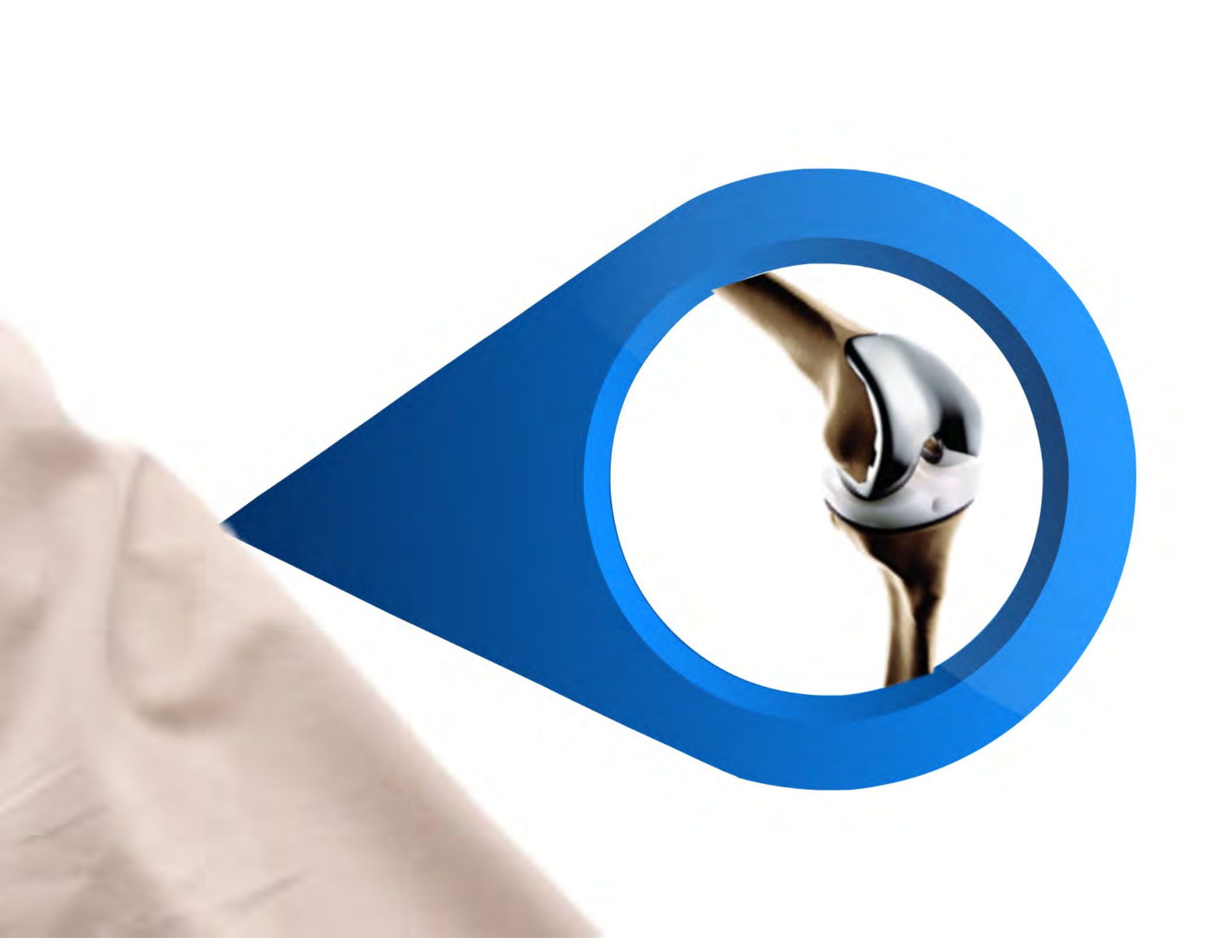
2050

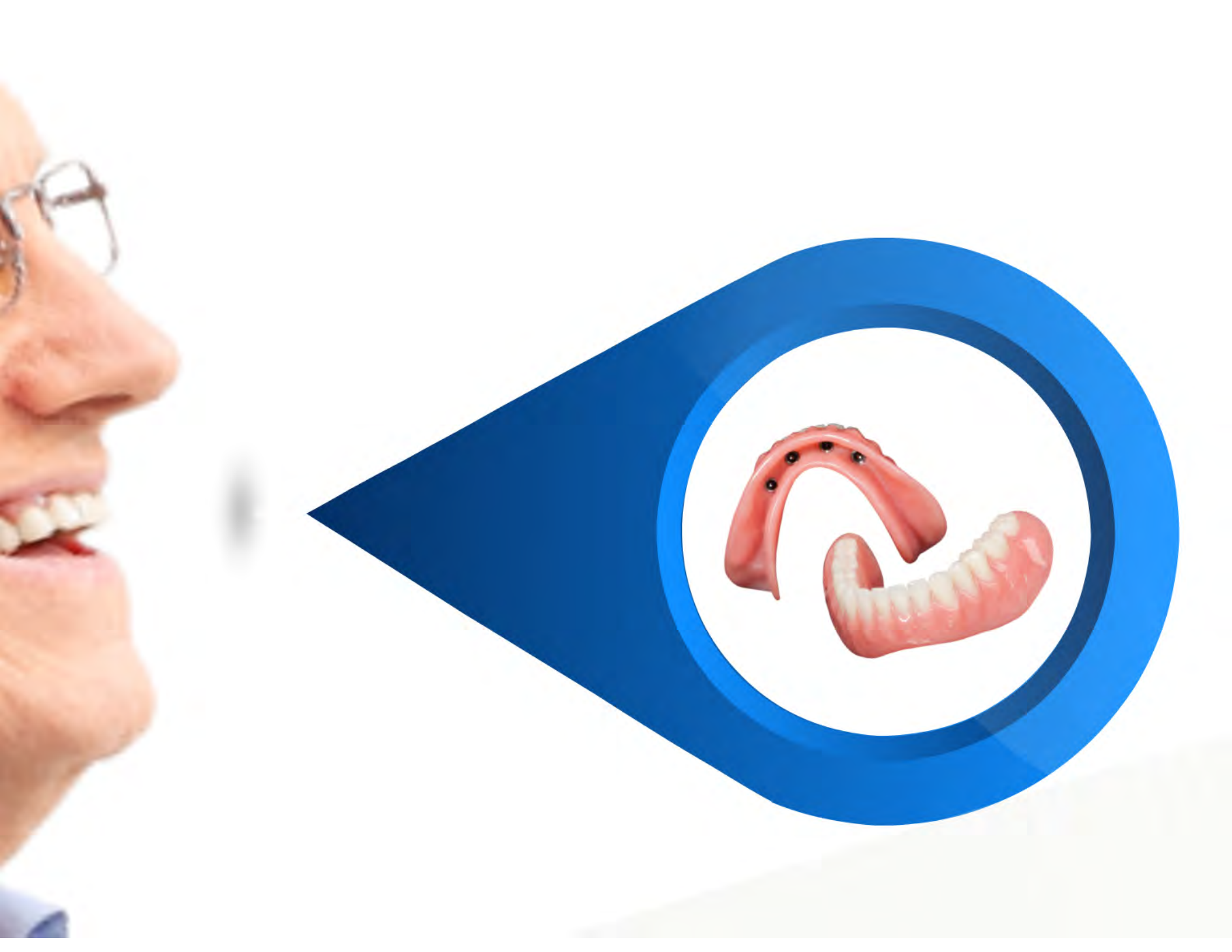
Percentage aged 60 years or older:

- 30% or more
- 10 to <30%
- <10%


1. Lead time
2. Quality
3. Cost








1. Lead time
2. Quality
3. Cost

Who we are?

Affordable

Fast

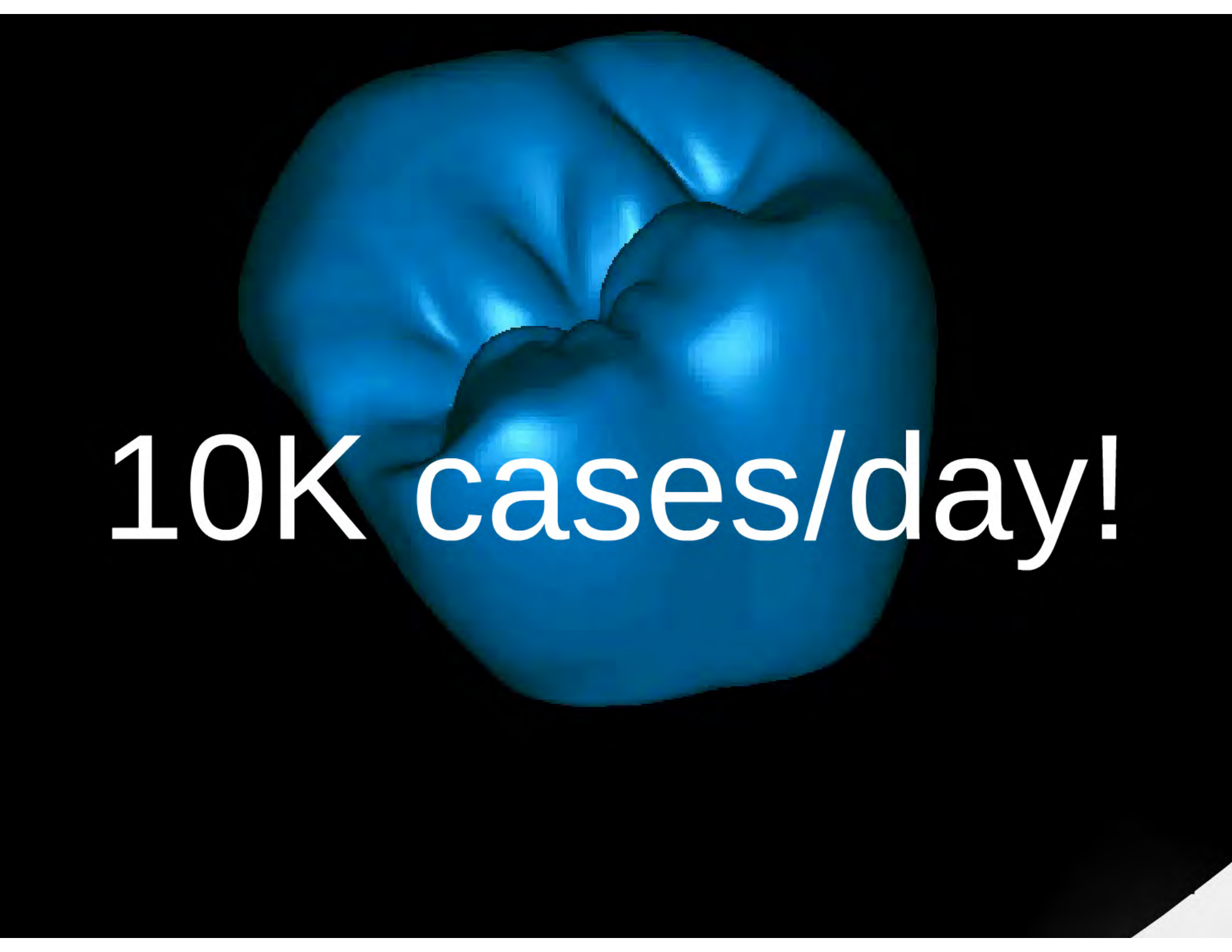
High Quality

- Headquarters in Newport Beach, CA
- 4500 employees in 5 countries
- 60% of US dentists

Mass Customization

10K cases/day!


10K cases/day!


10K cases/day!

CAD/CAM Revolution

10 years ago...

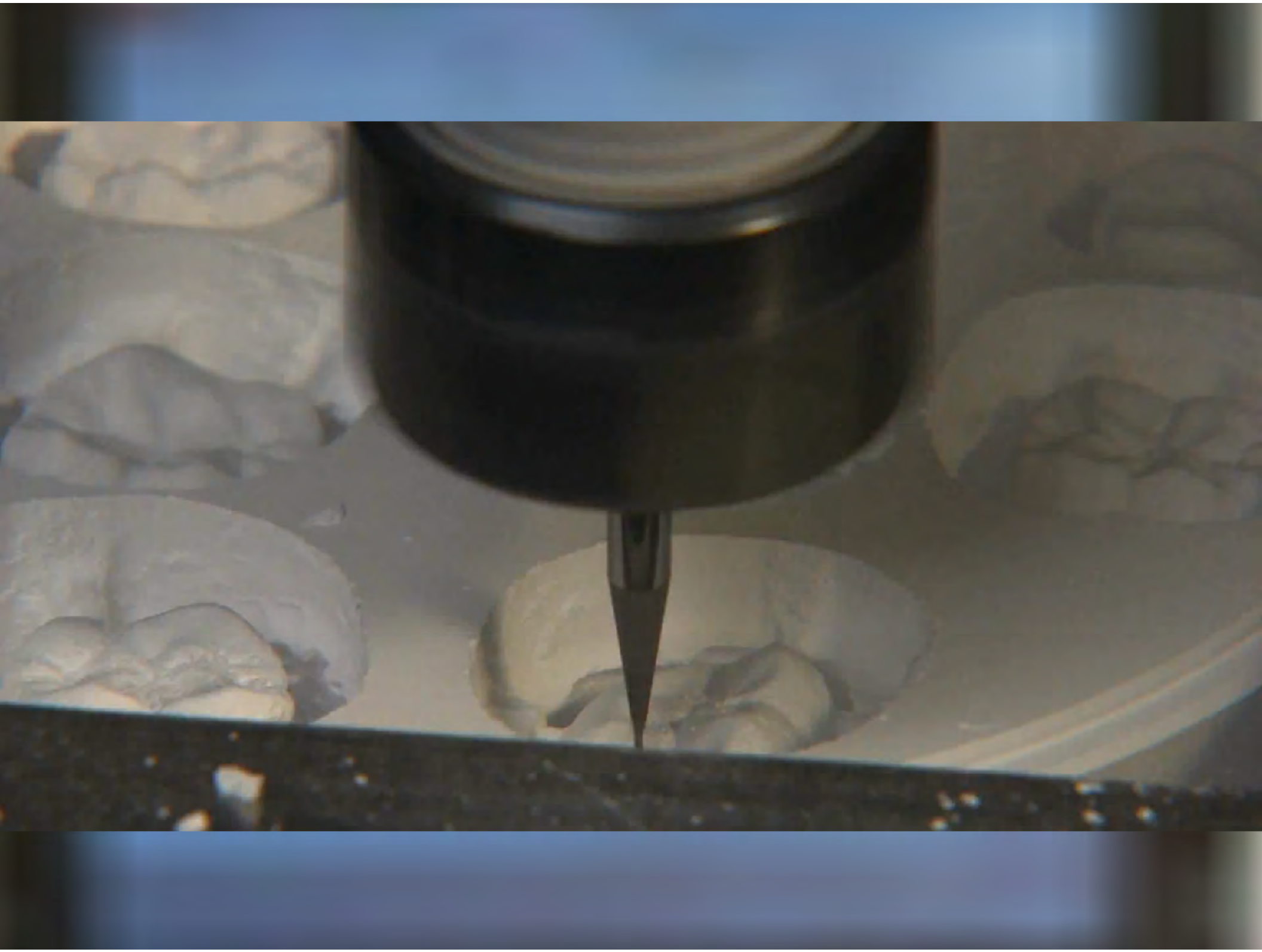
3D Scanning

CAD

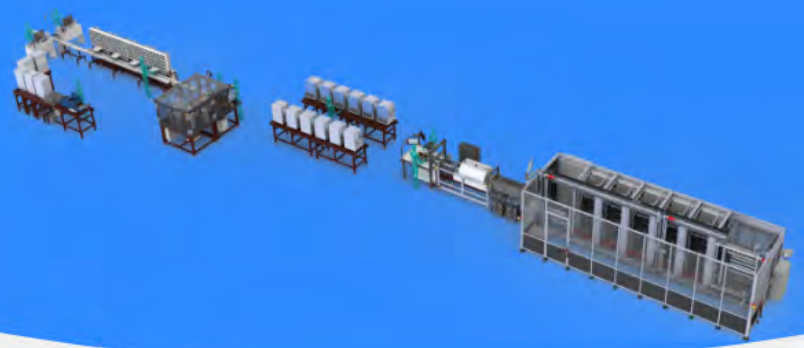
CAM

Today

In the near future...

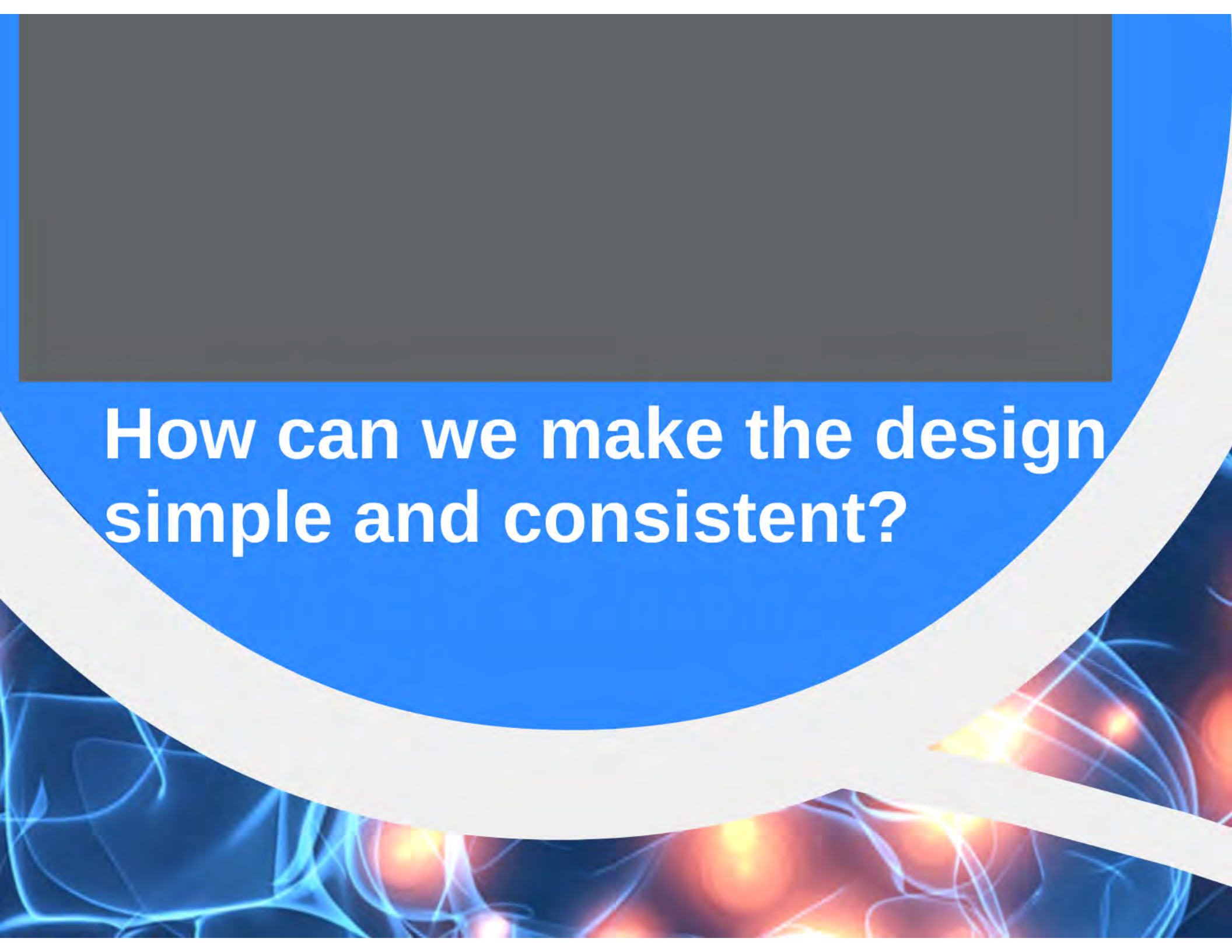


In the near future...

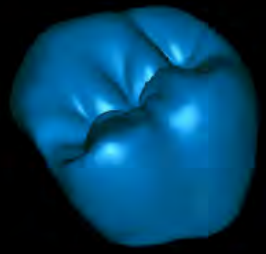


glidewell.io™
IN-OFFICE SOLUTION

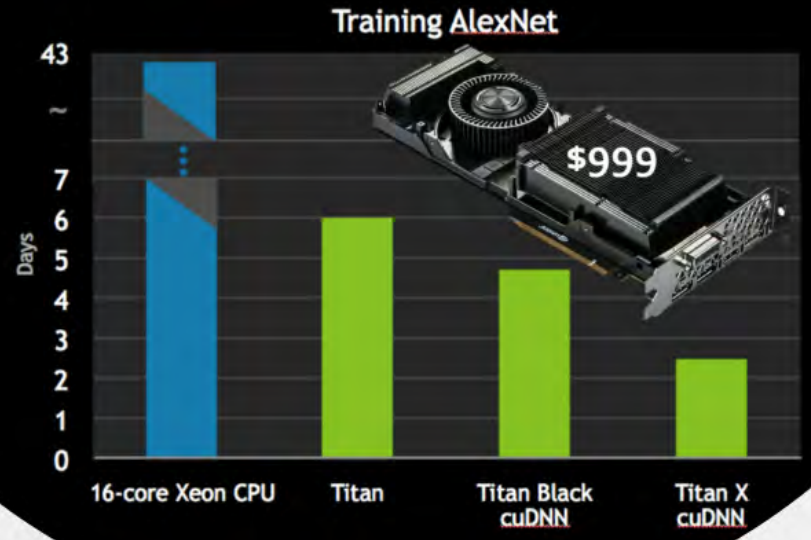
How can we make the design

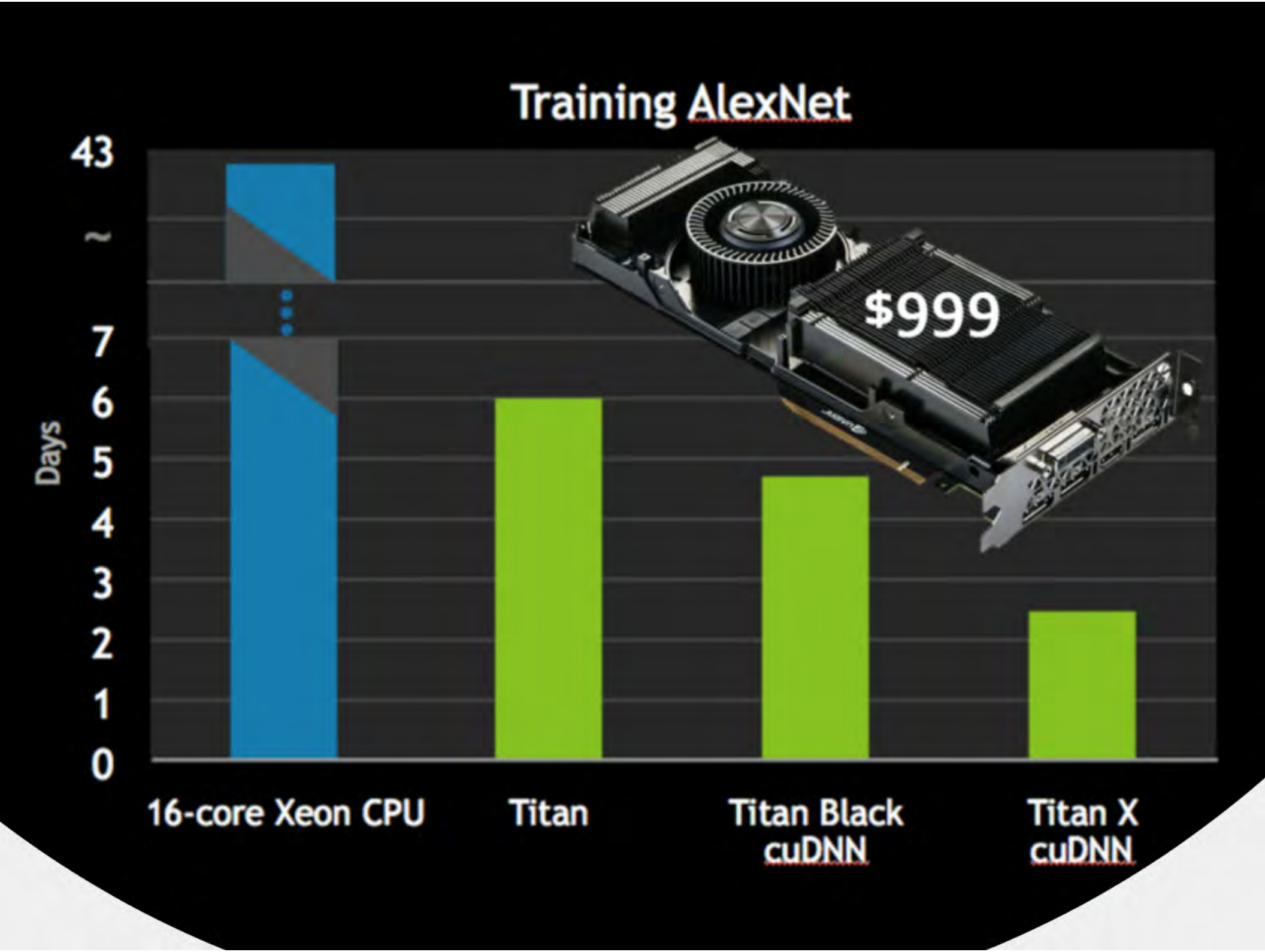

How can we make the design simple and consistent?

Where we started...



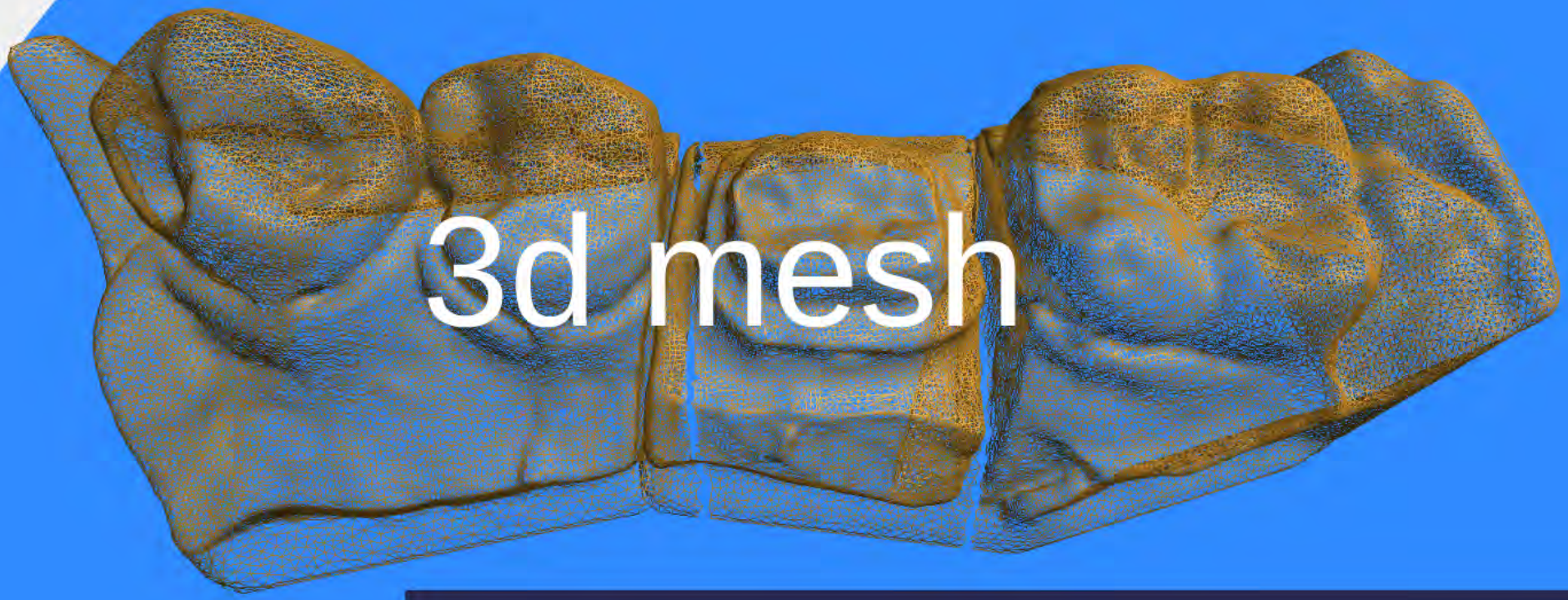
Tooth # ?

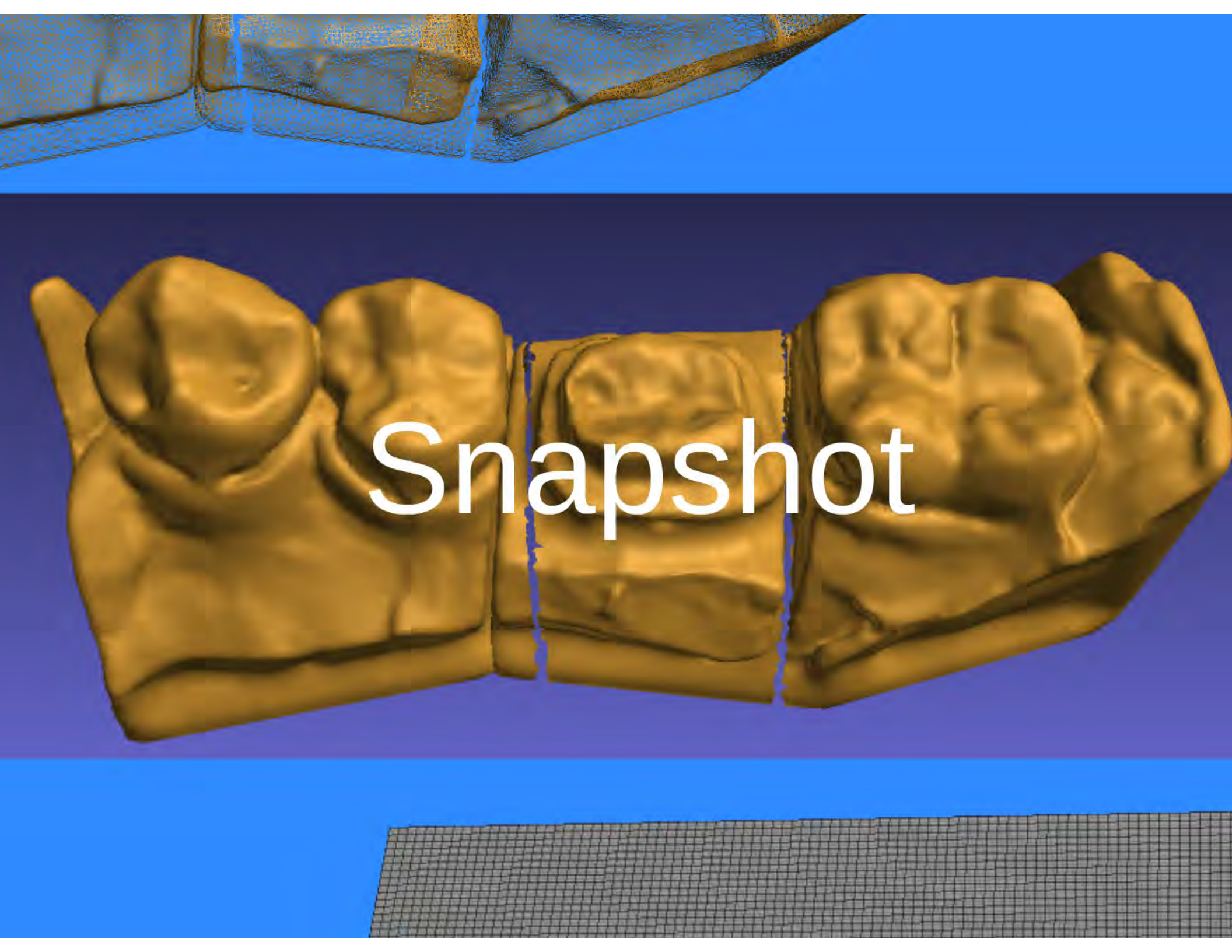



Training AlexNet
43
~
7
6
5
4
3
2
1
0
Days
$999
16-core Xeon CPU
Titan
Titan Black cuDNN
Titan X cuDNN

Representation

Represen



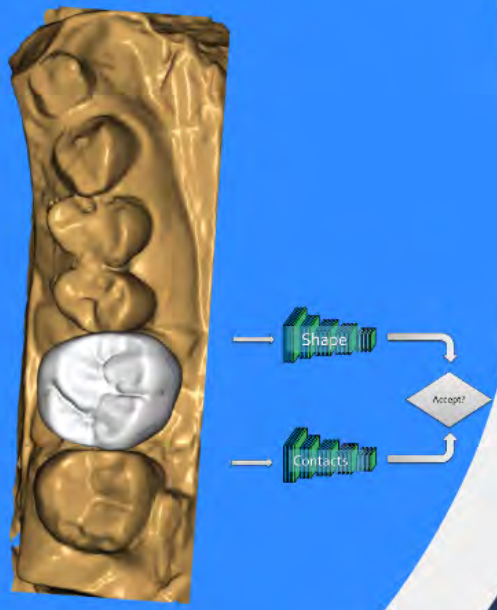

Snapshot

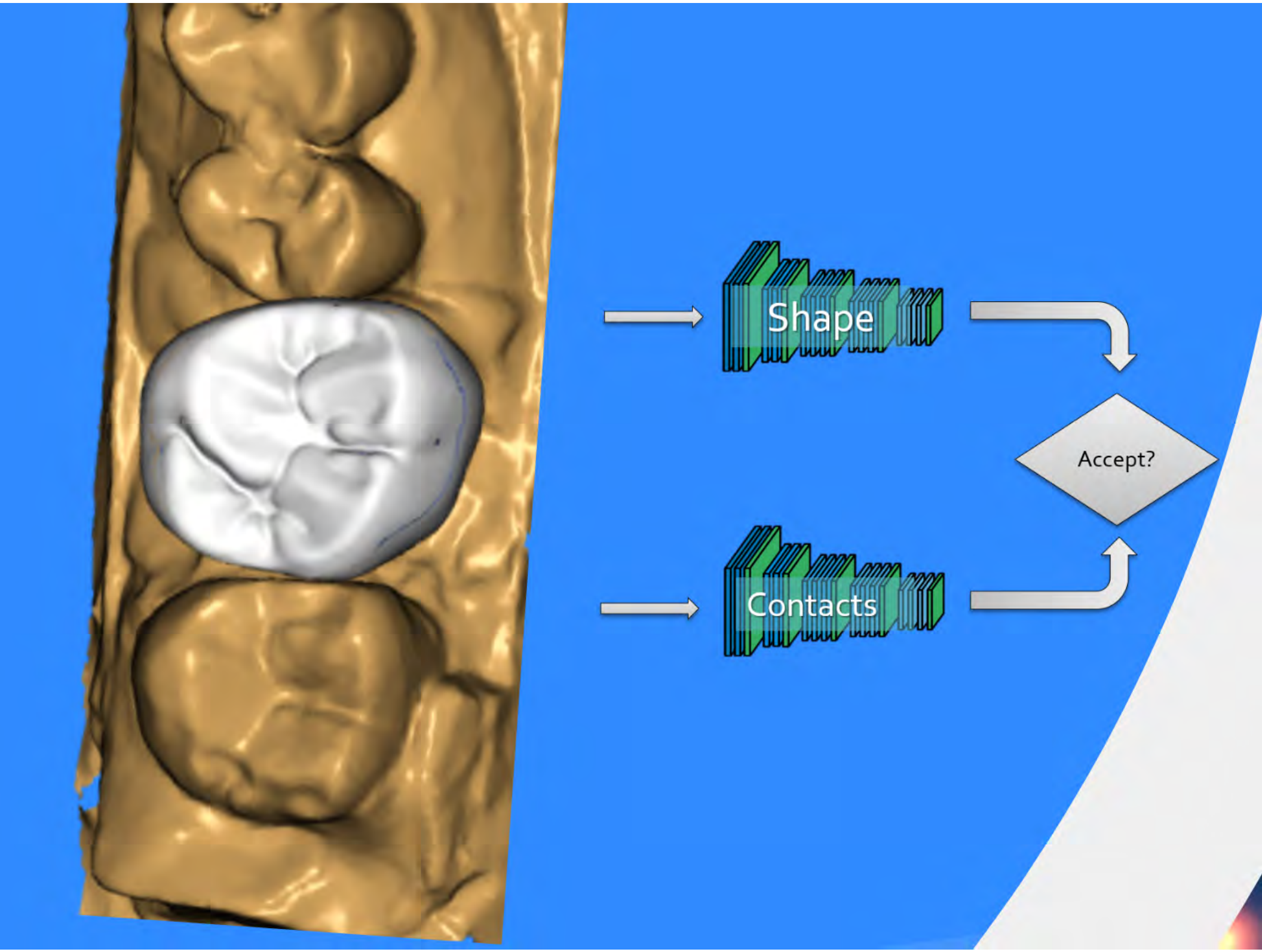

Voxelization


Voxelization
Depthmap

What Can We Do Today?

- Upper/Lower Jaw
- Prepared Tooth
- Adjacent Teeth
- Design QC




Shape
Accept?
Contacts

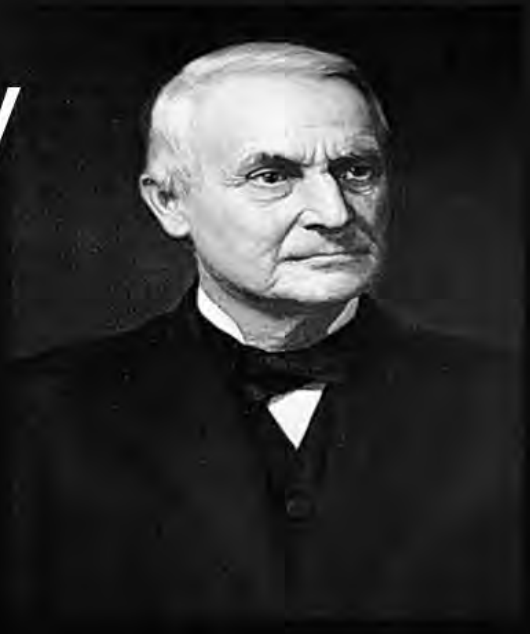
Inconsistent Data

Inconsistency is the only thing in which men are consistent.

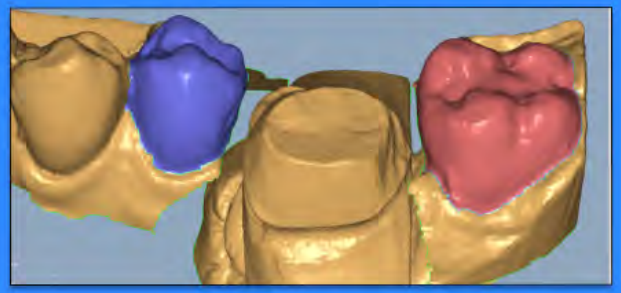
-- Horace Smith

Inconsistency is the only thing in which men are consistent.

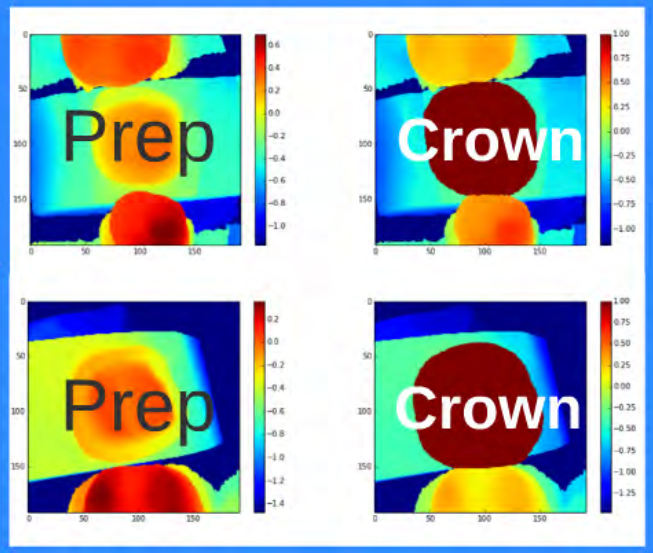
-- Horace Smith



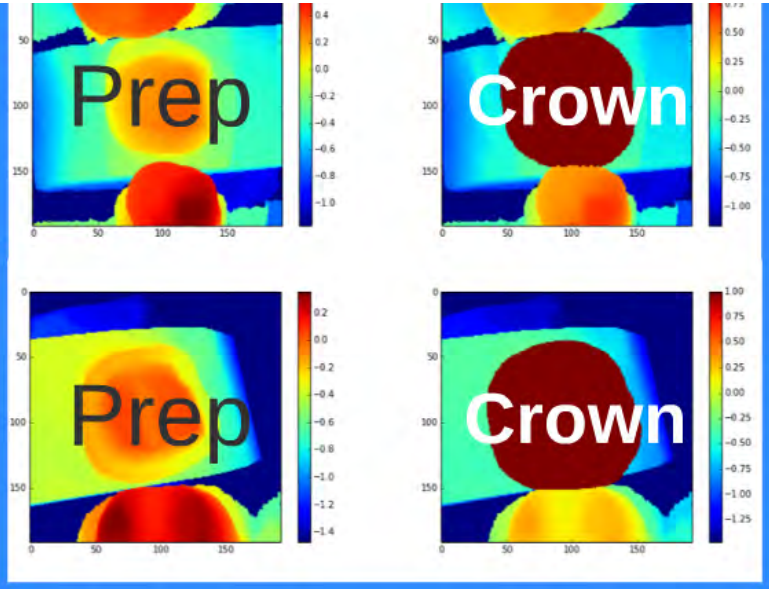
Our First Generative Model



Contour Generation



Can we generate a **complete** crown?



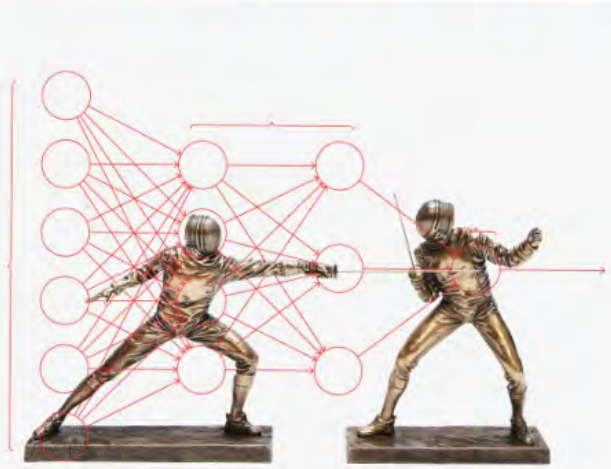
Can we generate a **complete** crown?

Inpainting Problem

Pathak et. al, 2016


How?

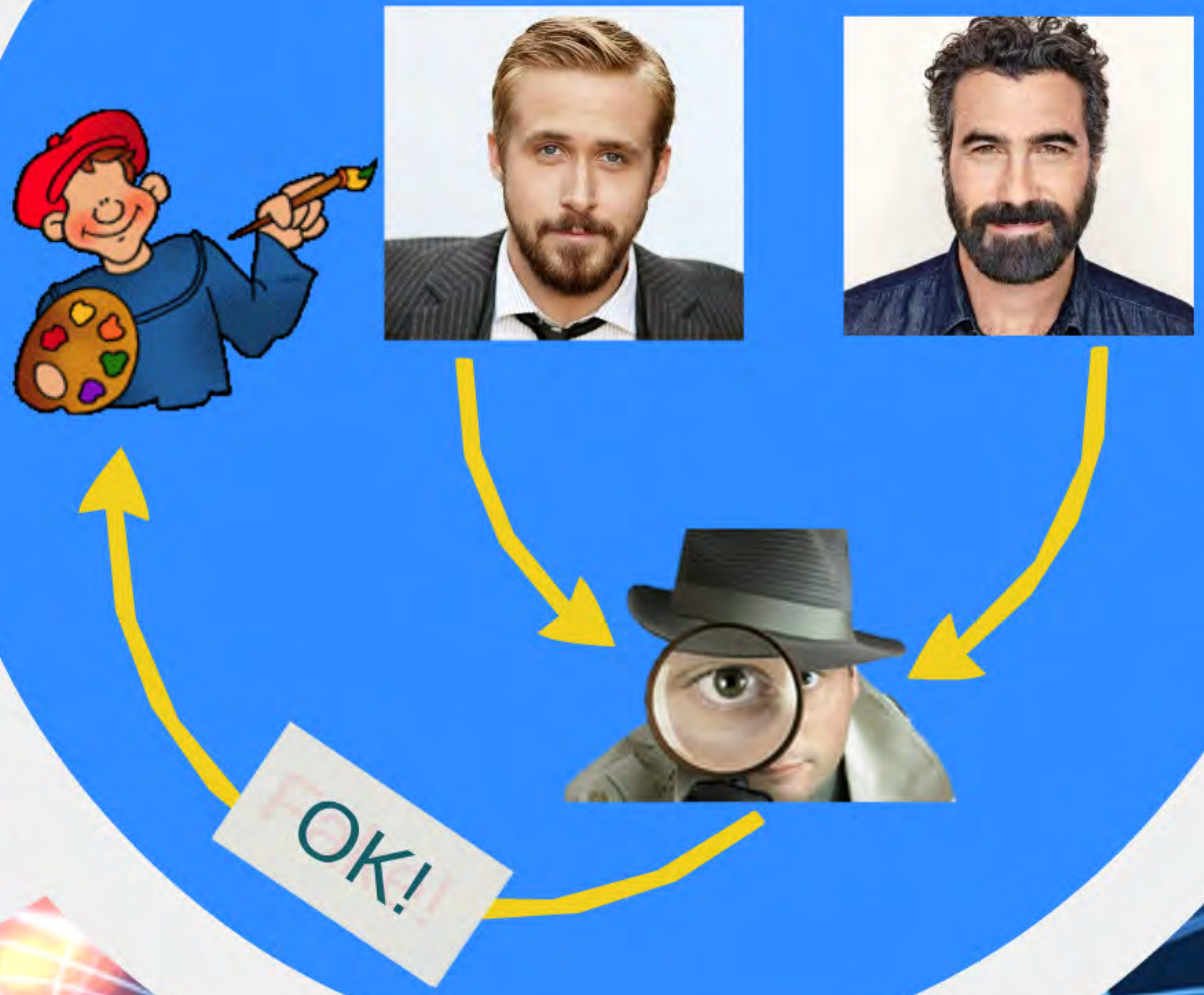
Generative Adversarial Networks



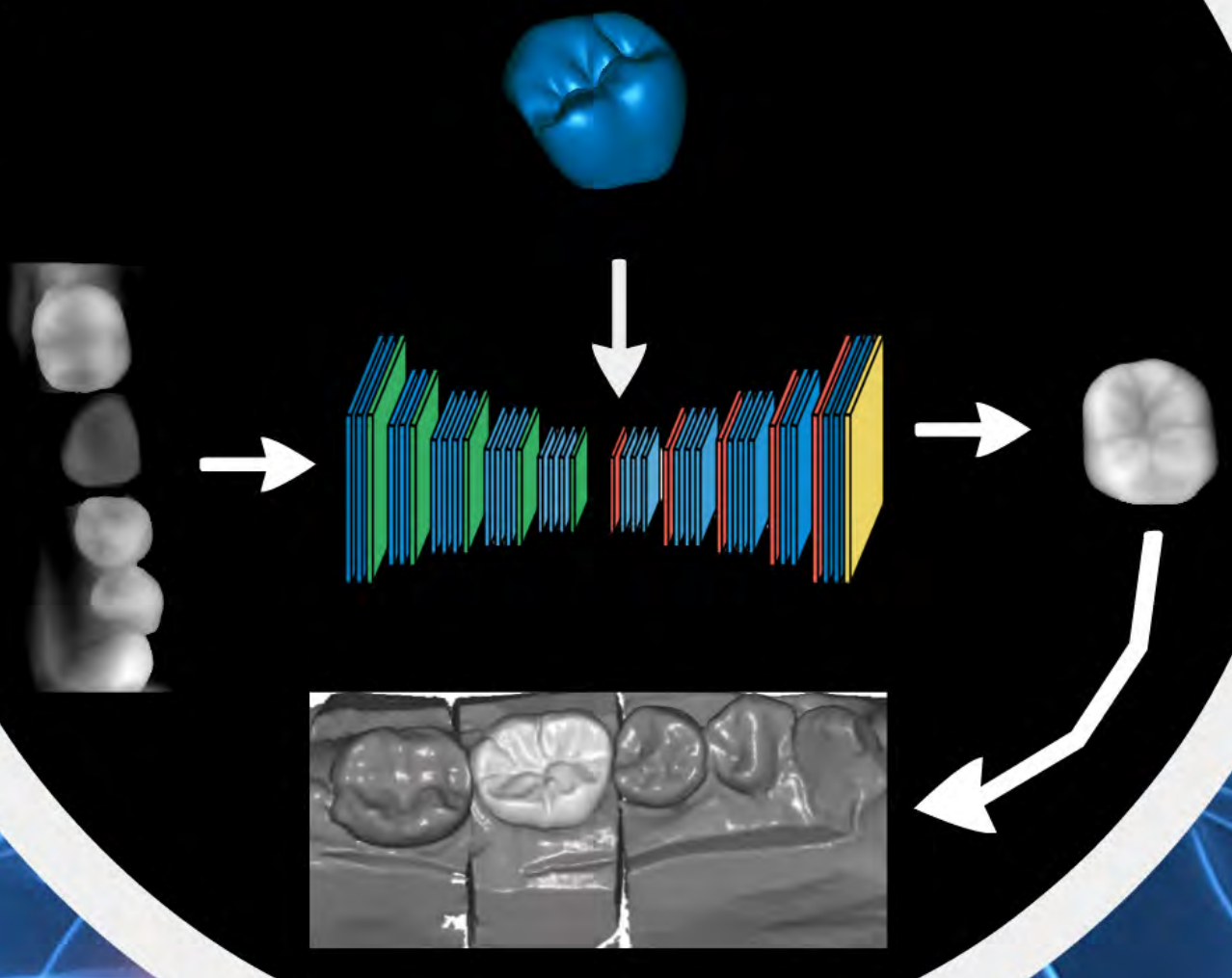
MIT Technology Review

10 BREAKTHROUGH TECHNOLOGIES 2018

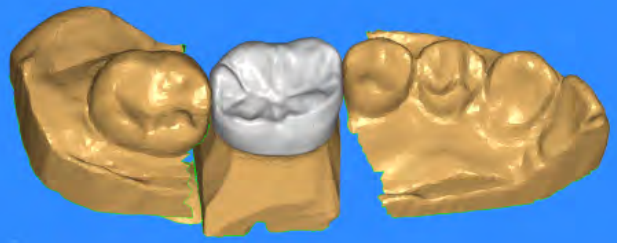
How GANs Work?

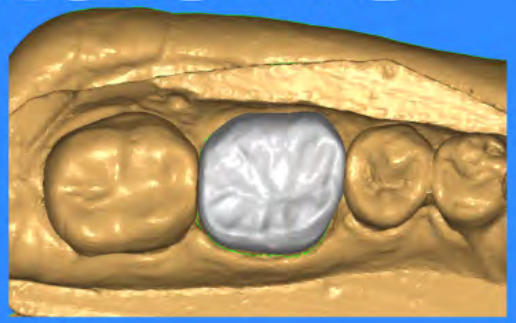


Training GANs on Crowns

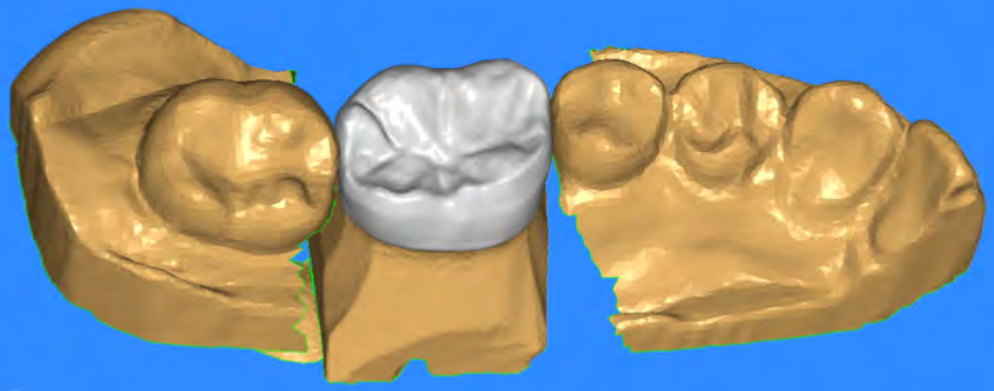


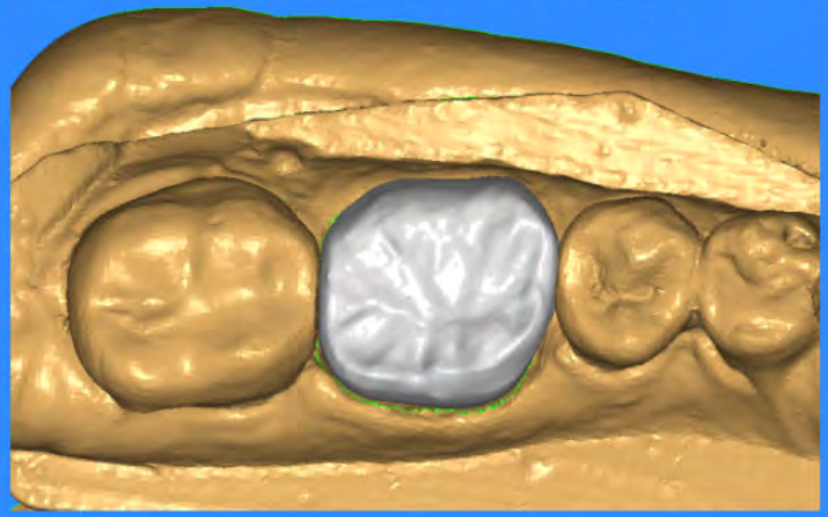
GAN Restorations



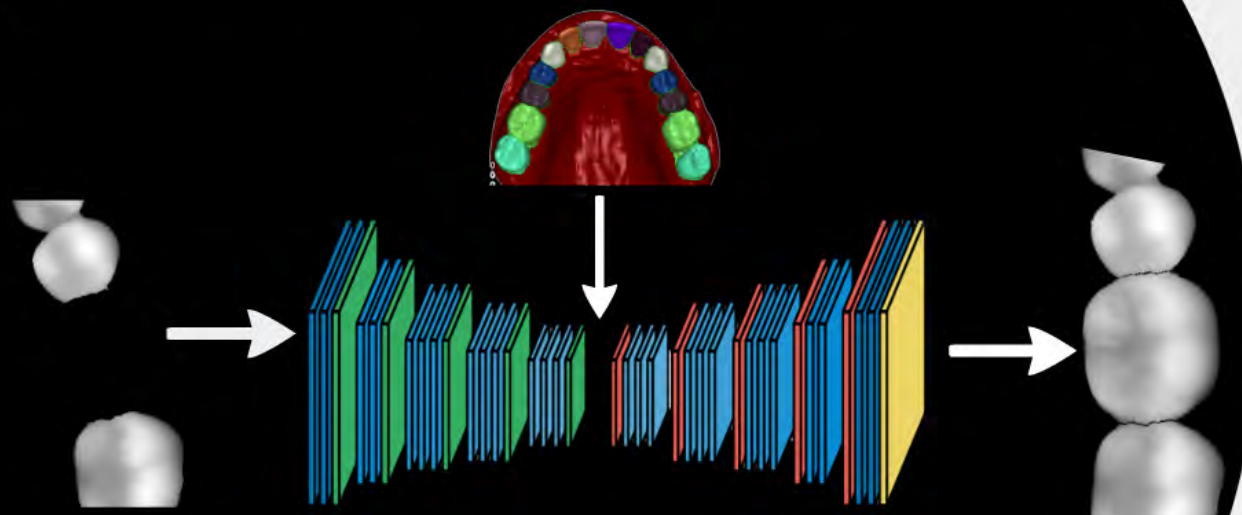


GAN Restorations





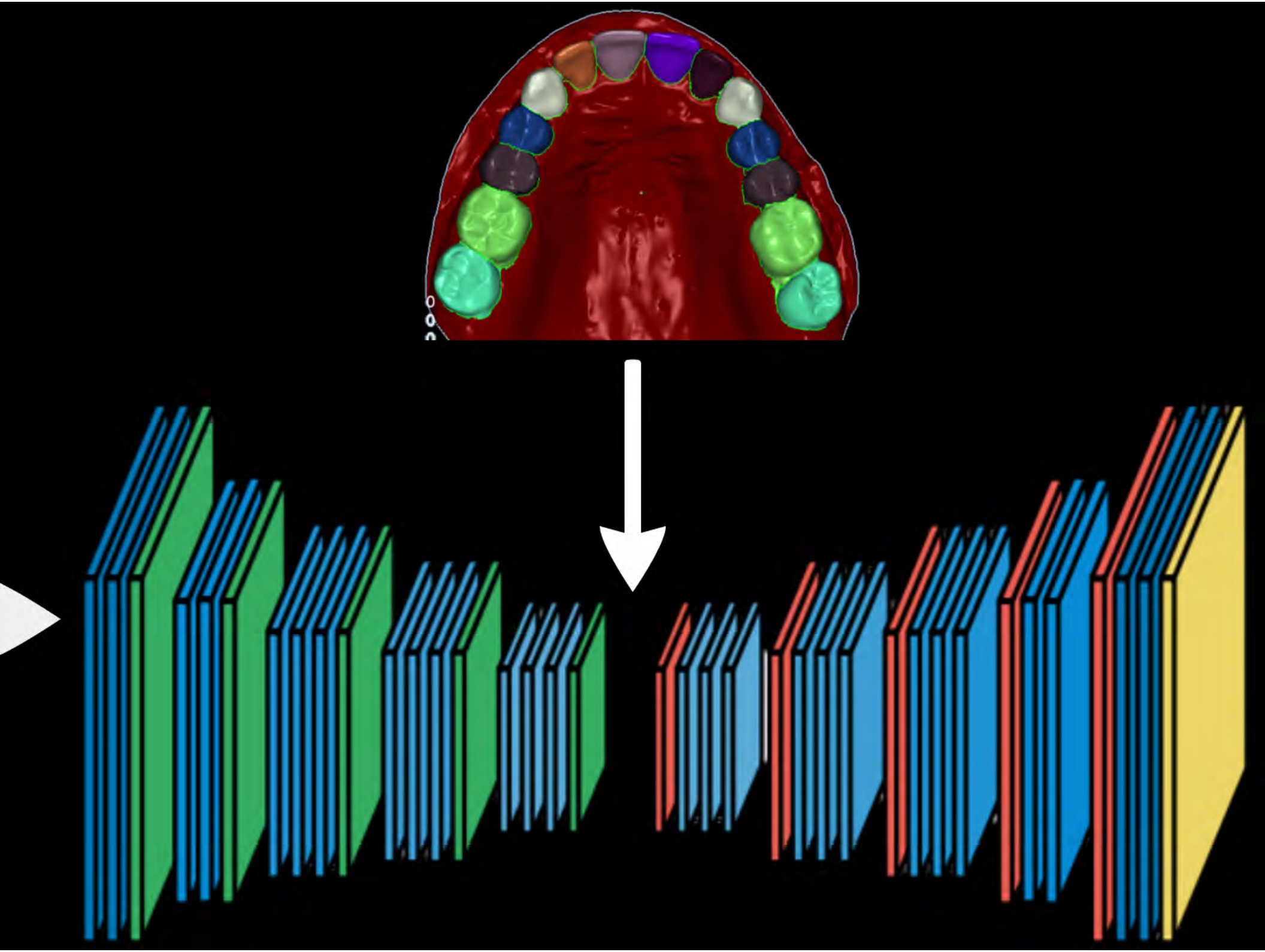
Training GANs on Natural Teeth



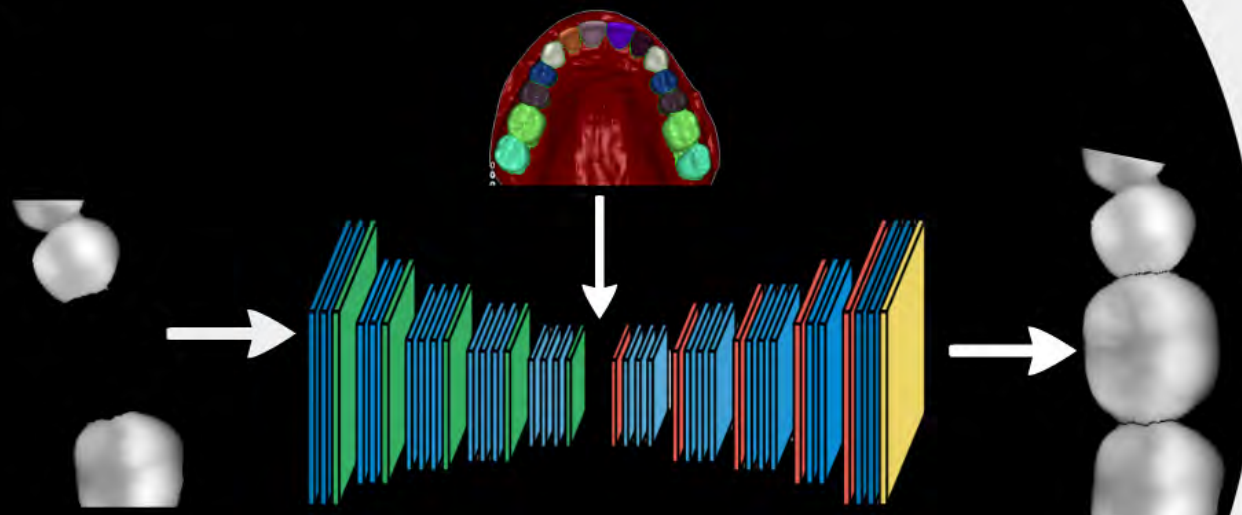
Original

GAN

More anatomical details!



Training GANs on Natural Teeth

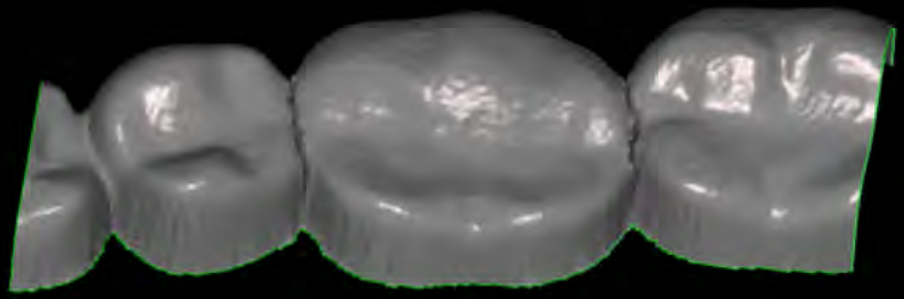


Original

GAN

More anatomical details!

Original

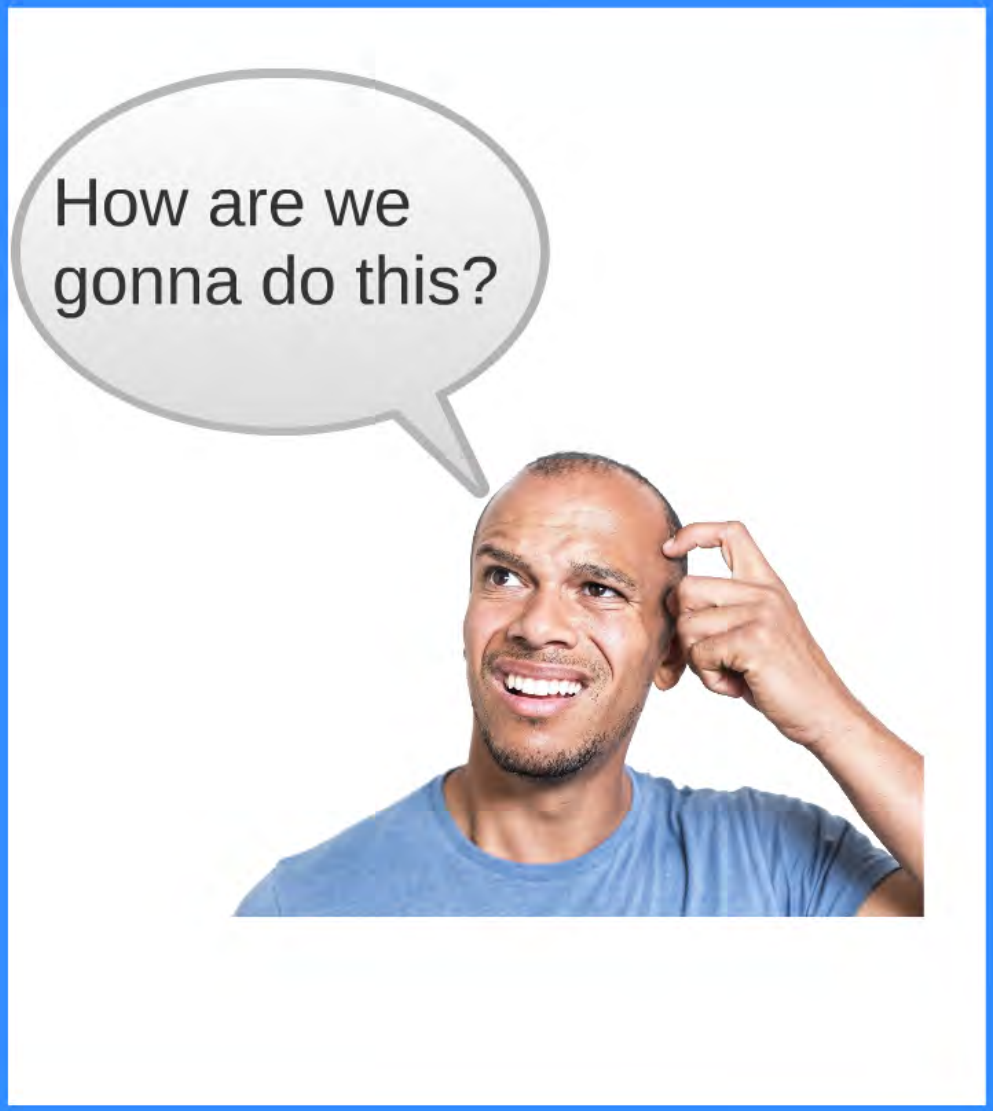


GAN

More anatomical details!

Training GANs is Hard!

- Power balance
- Oscillations
- Mode collapse
- ...


How are we gonna do this?

Collaborate with University!

Alyosha Efros

Stella Yu

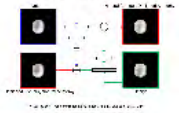
Jyh-Jing Hwang

BAIR

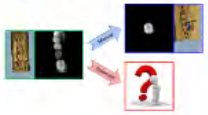
BERKELEY ARTIFICIAL INTELLIGENCE RESEARCH

Jyh-Jing Hwang

Image Style Transfer



Gildewell Dental Reconstruction Task

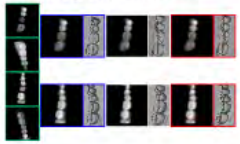


Enhance Anatomy of Natural Tooth

Desiderata

1. Shape
   - Fit internally
2. Occlusion
   - Fit with opposing teeth
3. Durability
   - Resist chewing and biting

Sample 3D Test Results



Contact Point Test (57% -> 10%)

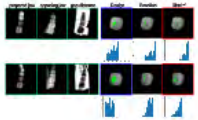
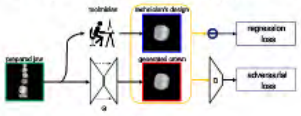


Image Generation using cGAN



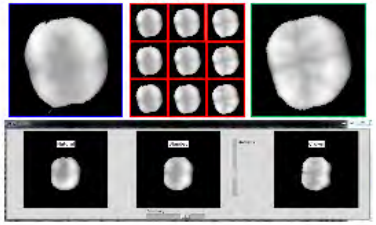
$$L_{cGAN}(G) = \mathbb{E}_{x,z}[-\log D(x, G(x, z))]$$

$$L_{cGAN}(G, D) = \mathbb{E}_{x,y}[\log D(x, y)] + \mathbb{E}_{x,z}[\log(1 - D(x, G(x, z)))]$$

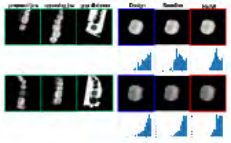
$$G^* = \arg\min_G \max_D L_{cGAN}(G, D) + \lambda_1 L_{L1}(G)$$

- Image-to-Image Translation with Conditional Adversarial Nets
  P Isola, J Zhu, T Zhou, and A Efros *CVPR'17*

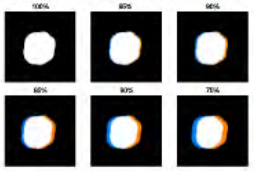
Demo GUI



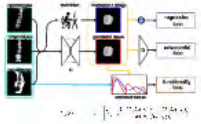
Penetration Test (85% -> 8%)



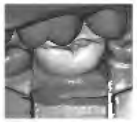
Reconstruction Quality Quality: IOU = 92%



Functionality-Aware Generation



Functionality Constraints



1. No penetration into opposing teeth

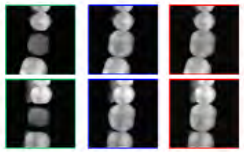
$$\tilde{G}(L, z, G) > 0$$

2. A few contact points for chewing and biting

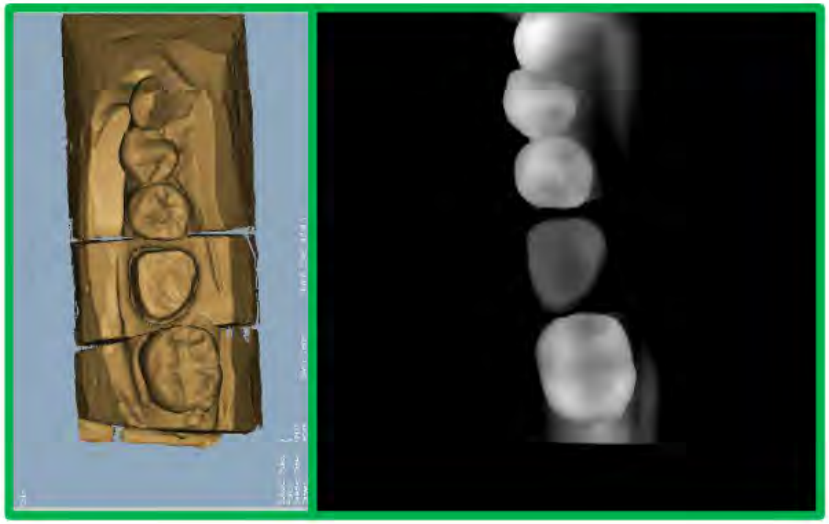
$$\tilde{f}(L, z, G) \approx \tilde{f}(L, z, y)$$

$\tilde{G}(L, z, G) = F(L, z, G) - y$ is the reconstructed gap distances

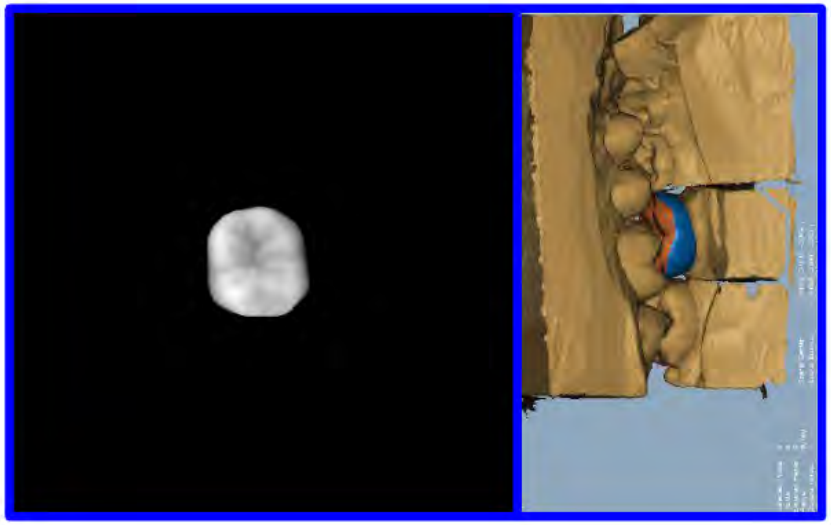
Sample Dental Reconstruction Results



Glidewell Dental Reconstruction Task

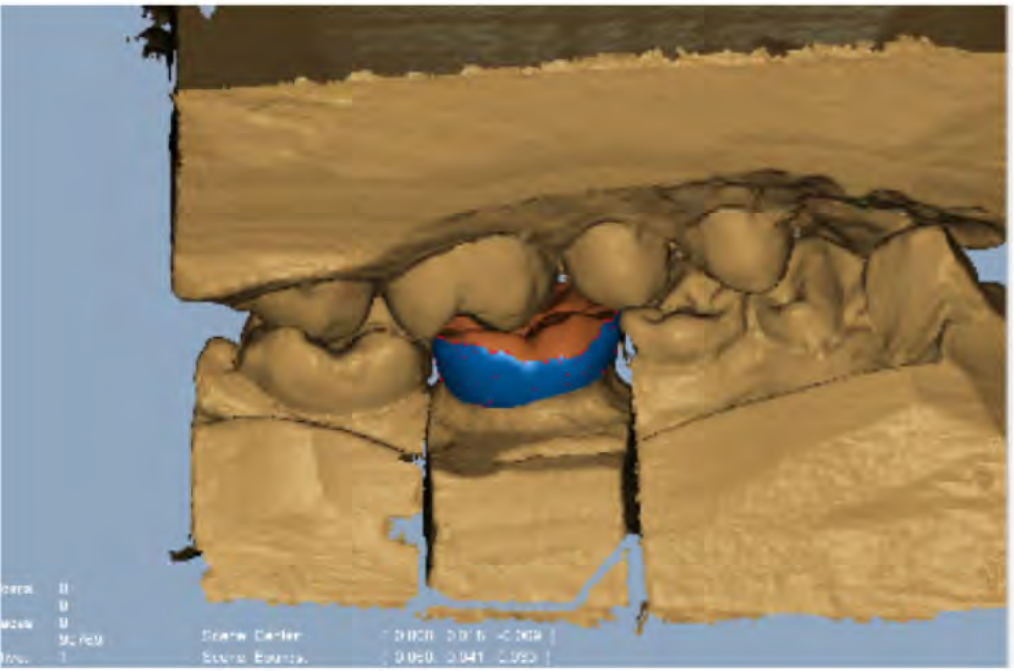


Manual



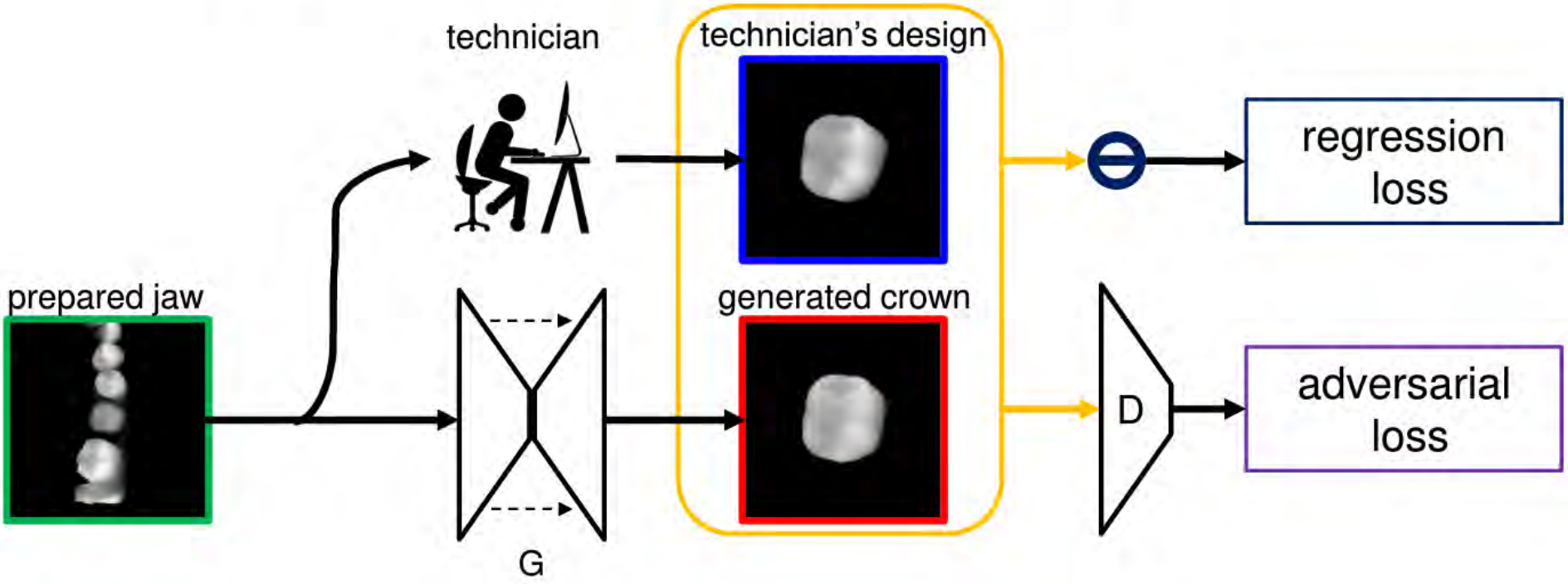
Automatic

Desiderata



1. Shape
   - ➢ Fit into cavity
2. Occlusion
   - ➢ Fit with opposing teeth
3. Dynamics
   - ➢ Fit for chewing and biting

Image Generation using cGAN



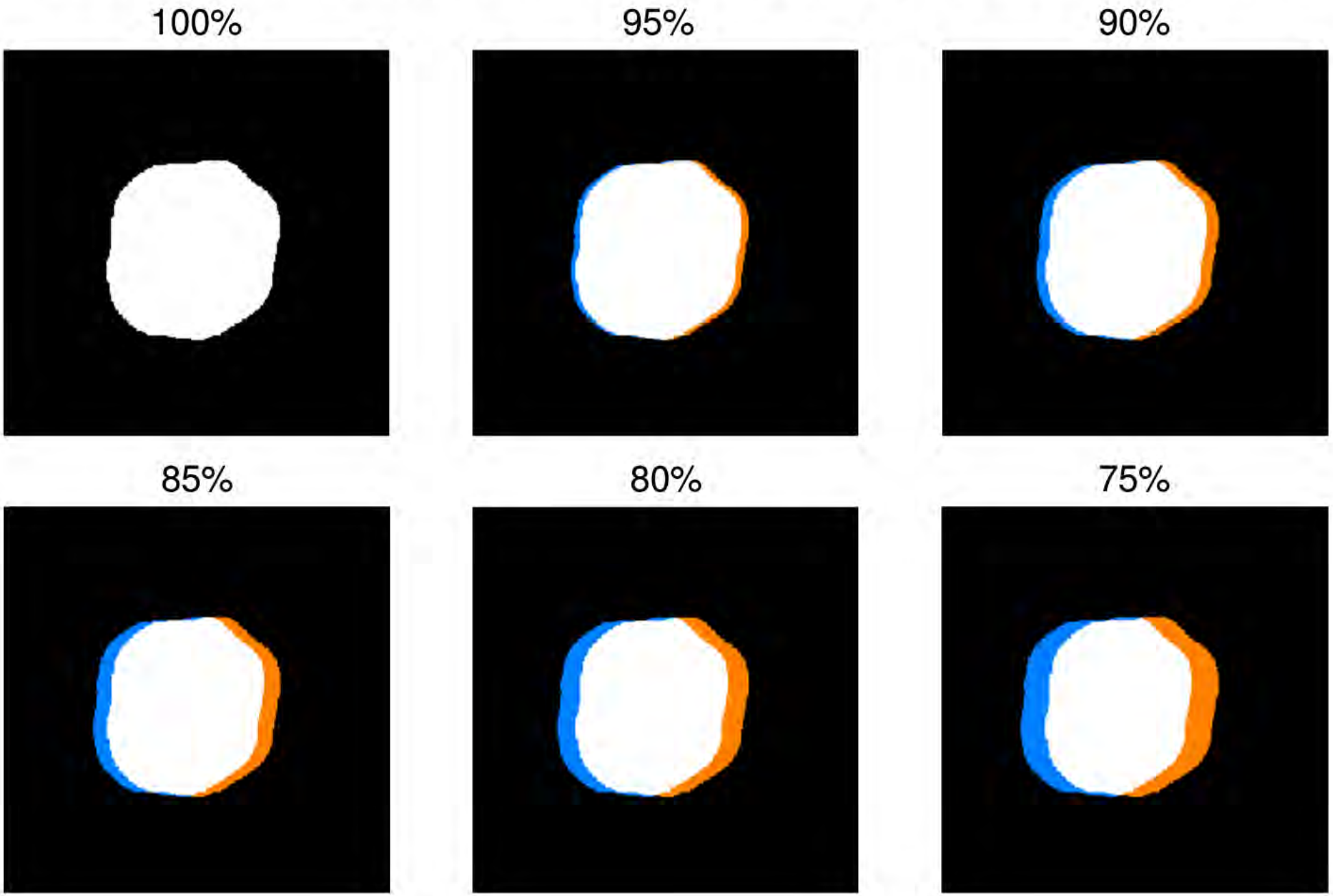
$$\mathcal{L}_{L1}(G) = \mathbb{E}_{x,y,z}[||y - G(x,z)||_1]$$

$$\mathcal{L}_{cGAN}(G,D) = \mathbb{E}_{x,y}[\log D(x,y)] + \mathbb{E}_{x,z}[\log(1 - D(G(x,z))]$$

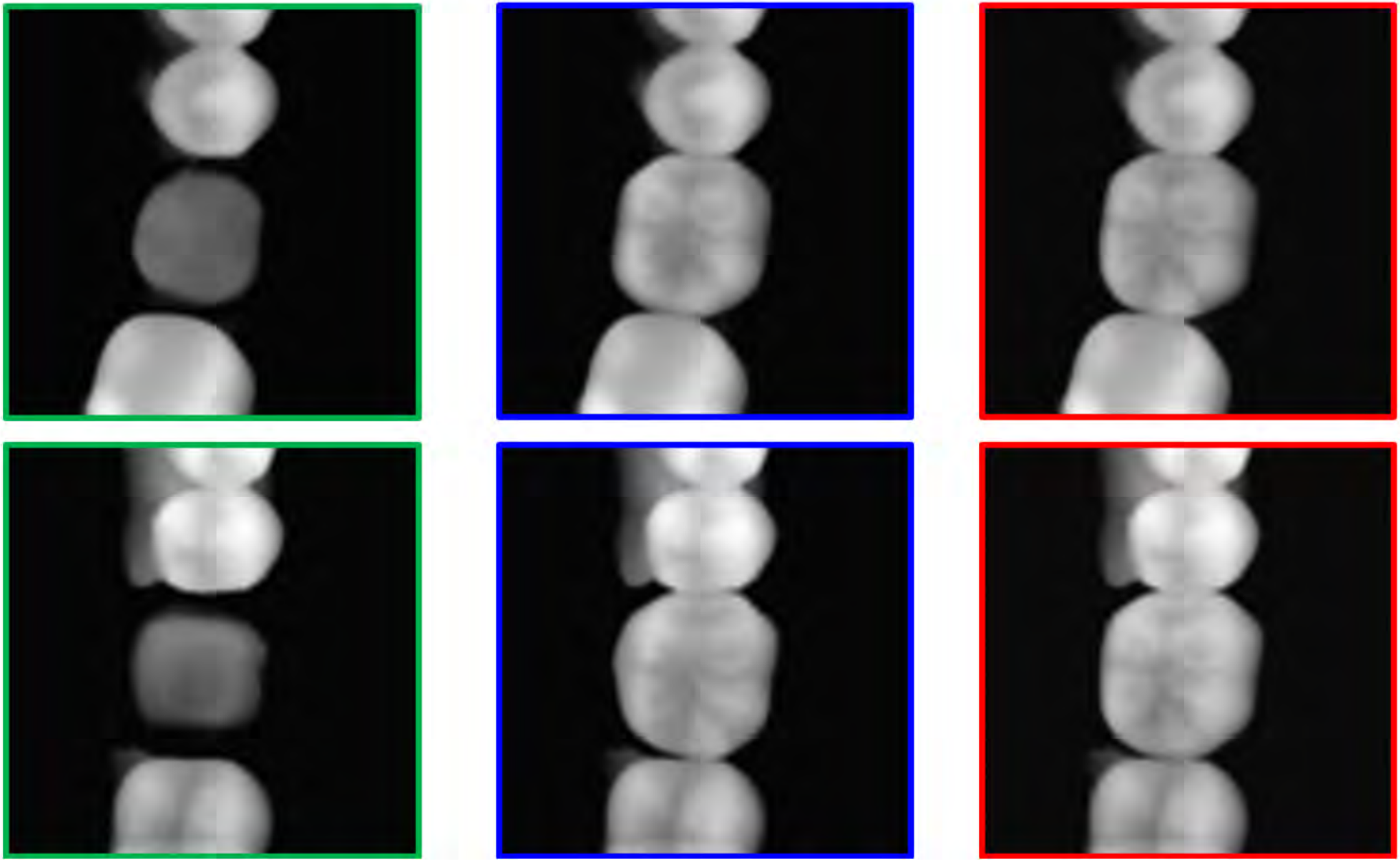
$$G^* = \arg\min_G \max_D \mathcal{L}_{cGAN}(G,D) + \lambda_{L1}\mathcal{L}_{L1}(G)$$

- Image-to-Image Translation with Conditional Adversarial Nets.
  P. Isola, J. Zhu, T. Zhou, and A. Efros. *CVPR'17*.

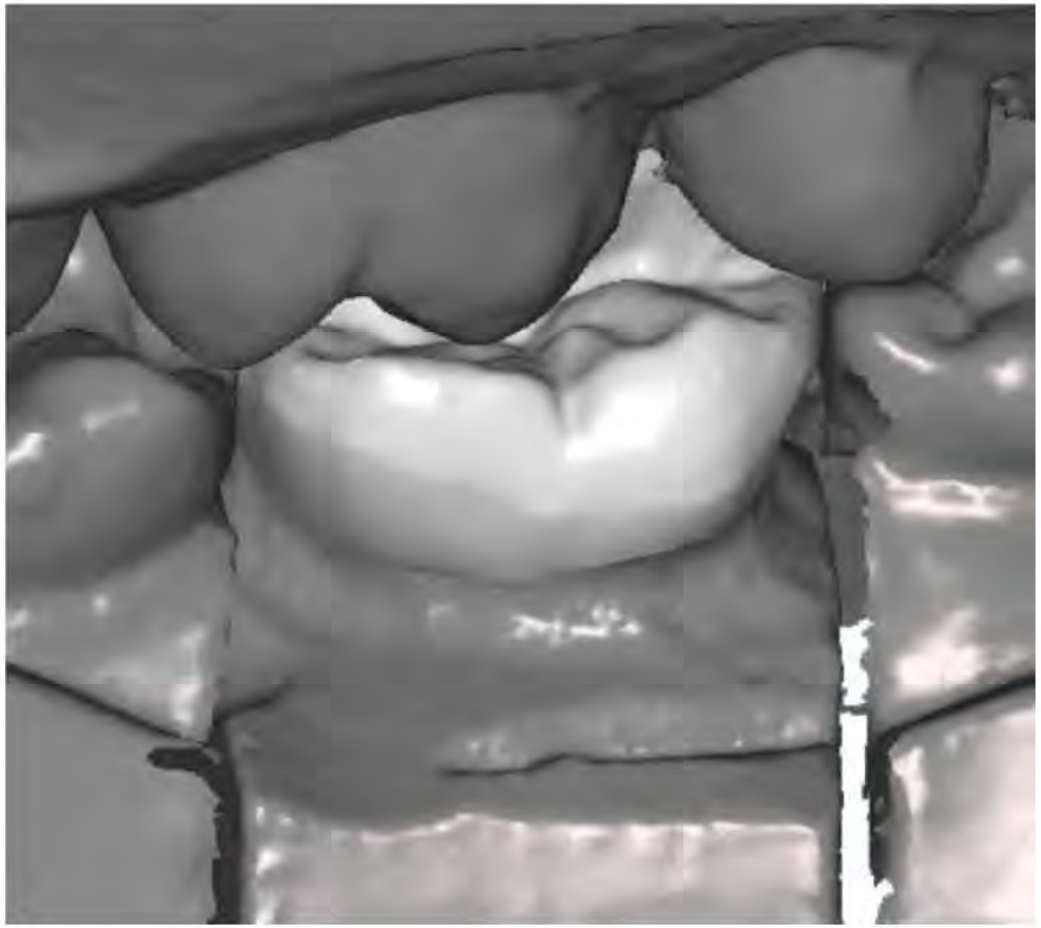
Reconstruction Quality Quality: IOU = 92%



Sample Dental Reconstruction Results



Functionality Constraints



1. No penetration into opposing teeth

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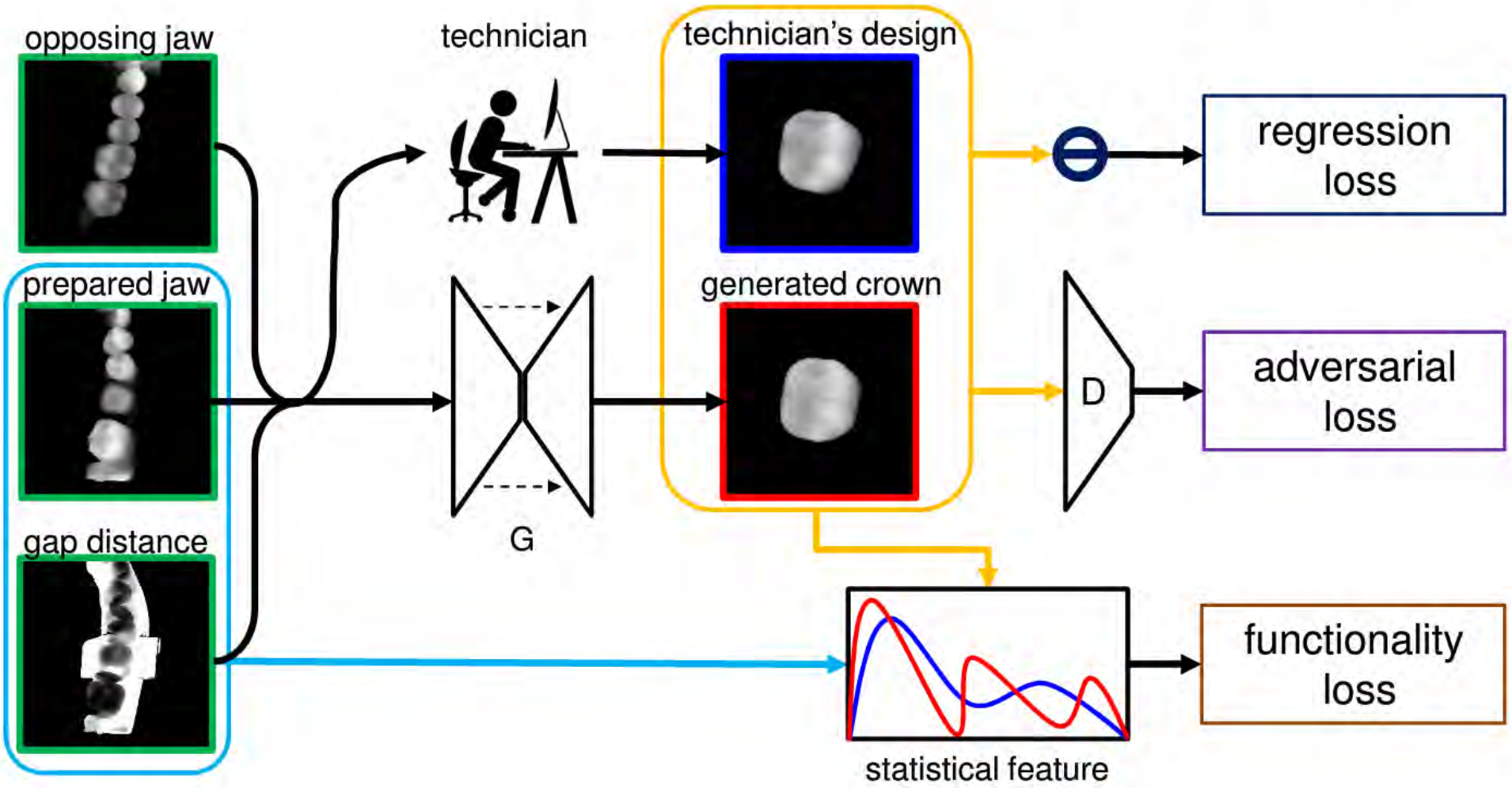
$$\hat{f}(d, x, G) \approx \hat{f}(d, x, y)$$

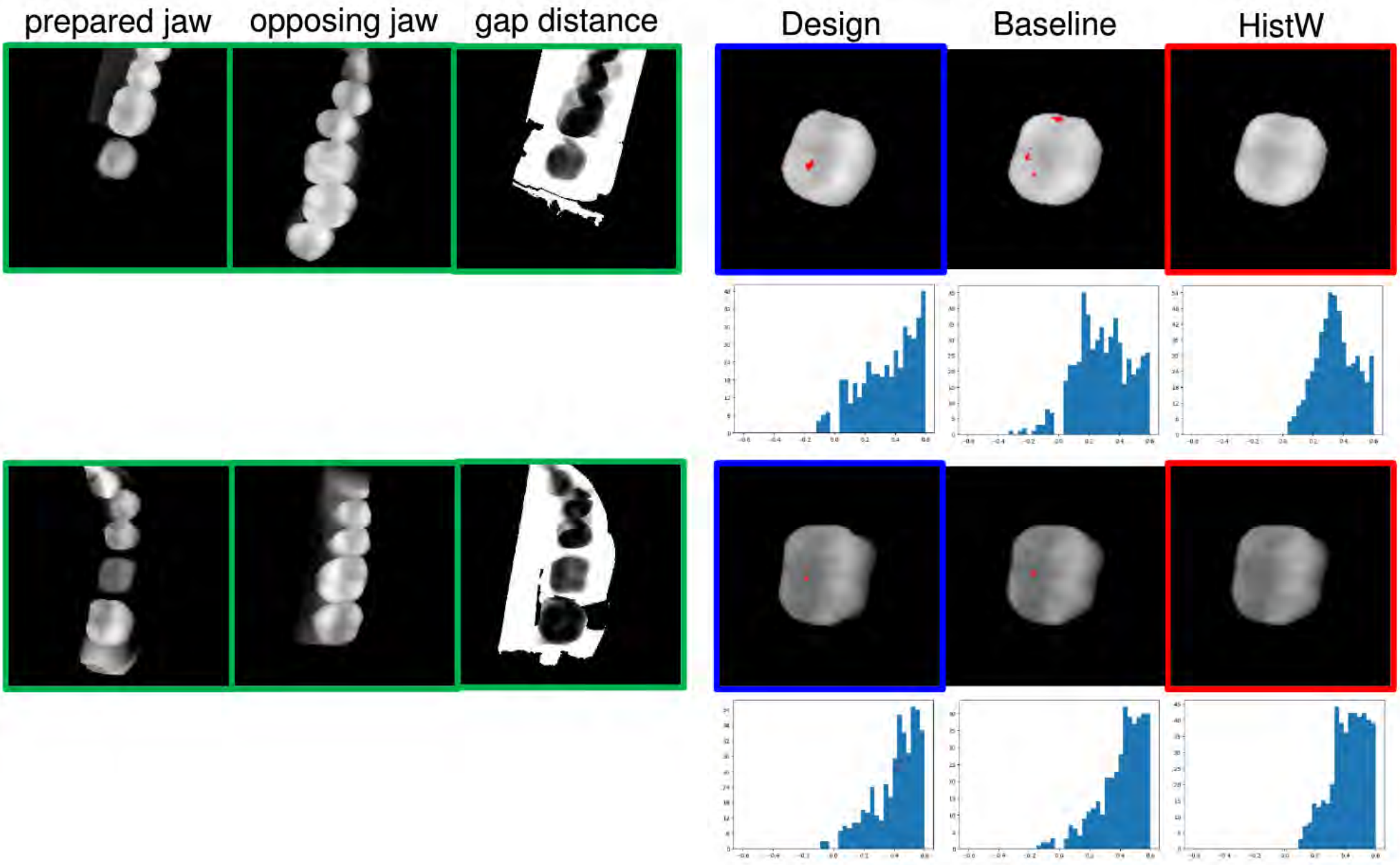
$f(d, x, \hat{y}) = d + \gamma(\hat{y} - x)$ is the reconstructed gap distances

Functionality-Aware Generation

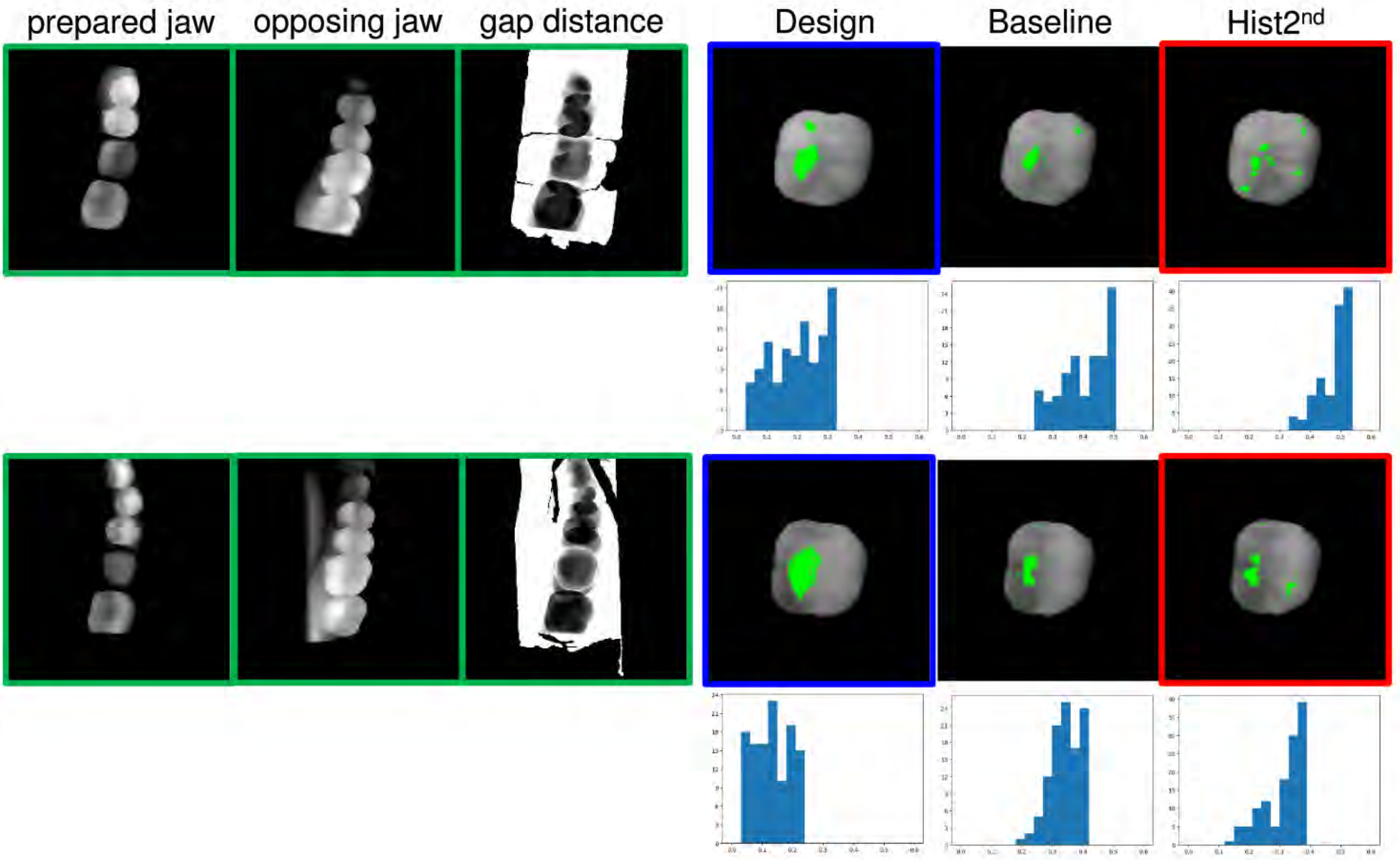


$$\mathcal{L}_{\hat{H}}(G) = \mathbb{E}_{x,\tilde{x},d,z,y}\left[\sum_i w_i \frac{\left(h_i(f(d,x,G)) - h_i(f(d,x,y))\right)^2}{\max\{h_i(f(d,x,y)),1\}}\right]$$

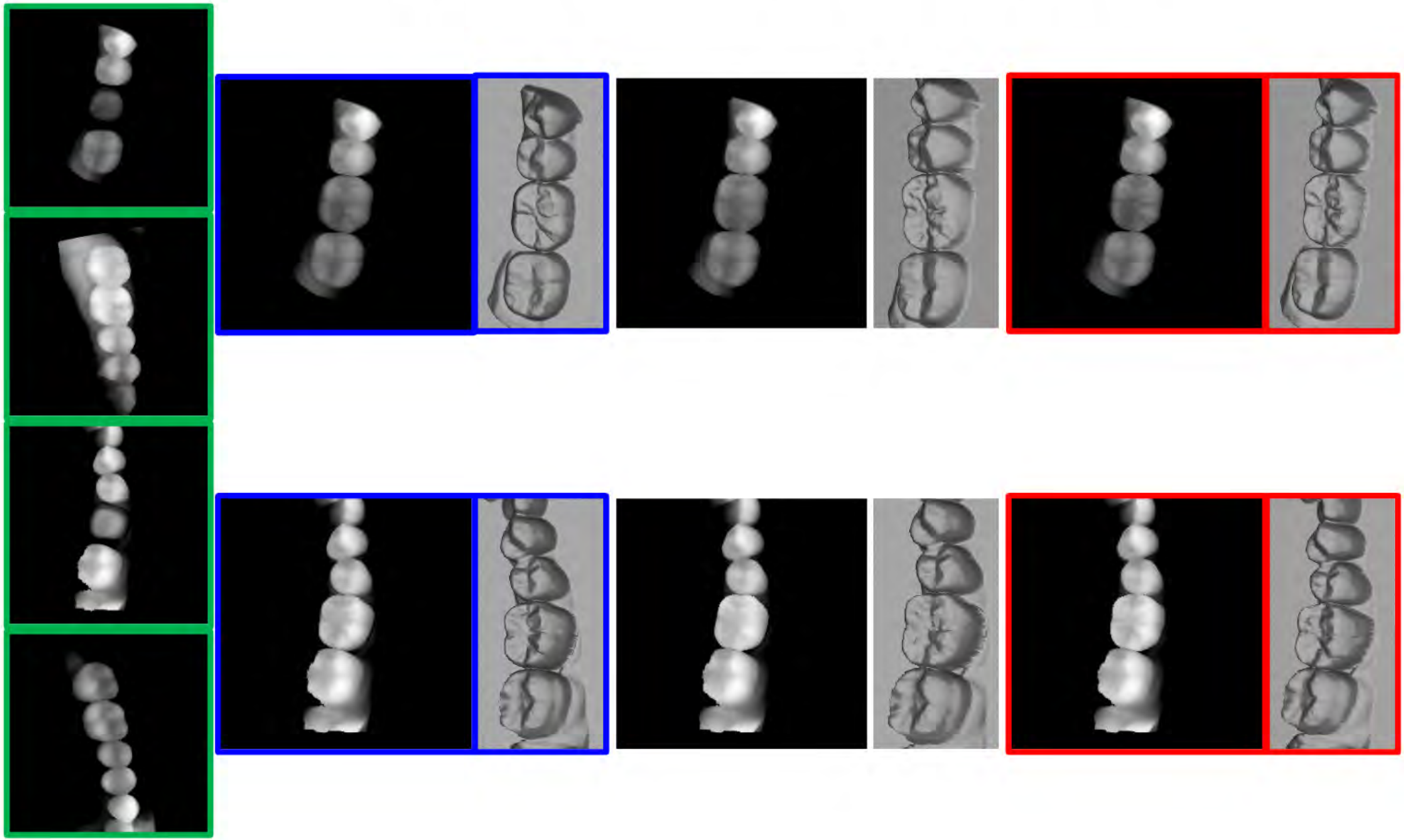
Penetration Test (85% -> 8%)



Contact Point Test (57% -> 10%)



Sample 3D Test Results

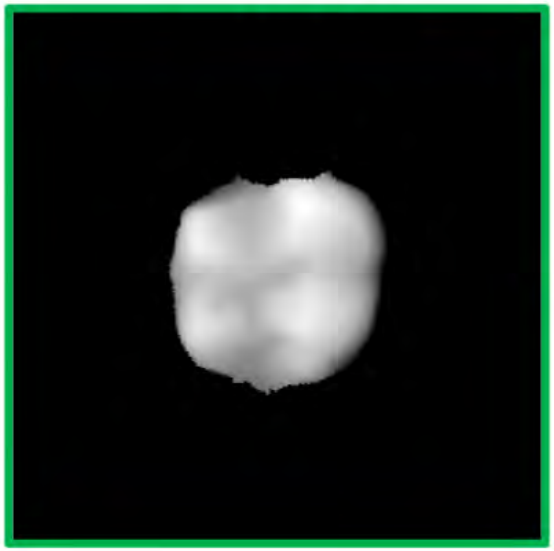


Enhance Anatomy of Natural Tooth

Natural

Design

Enhanced Natural



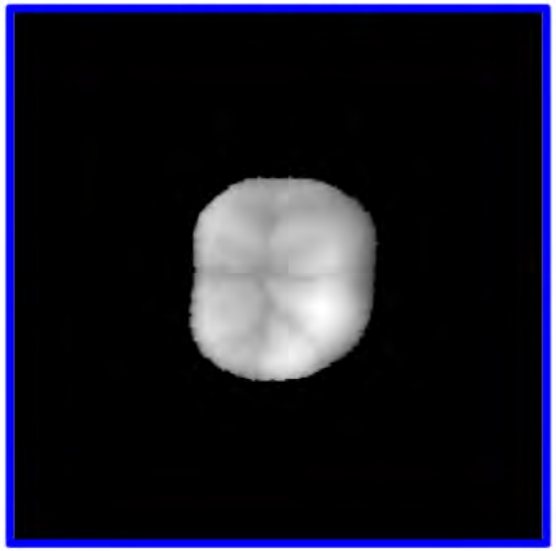
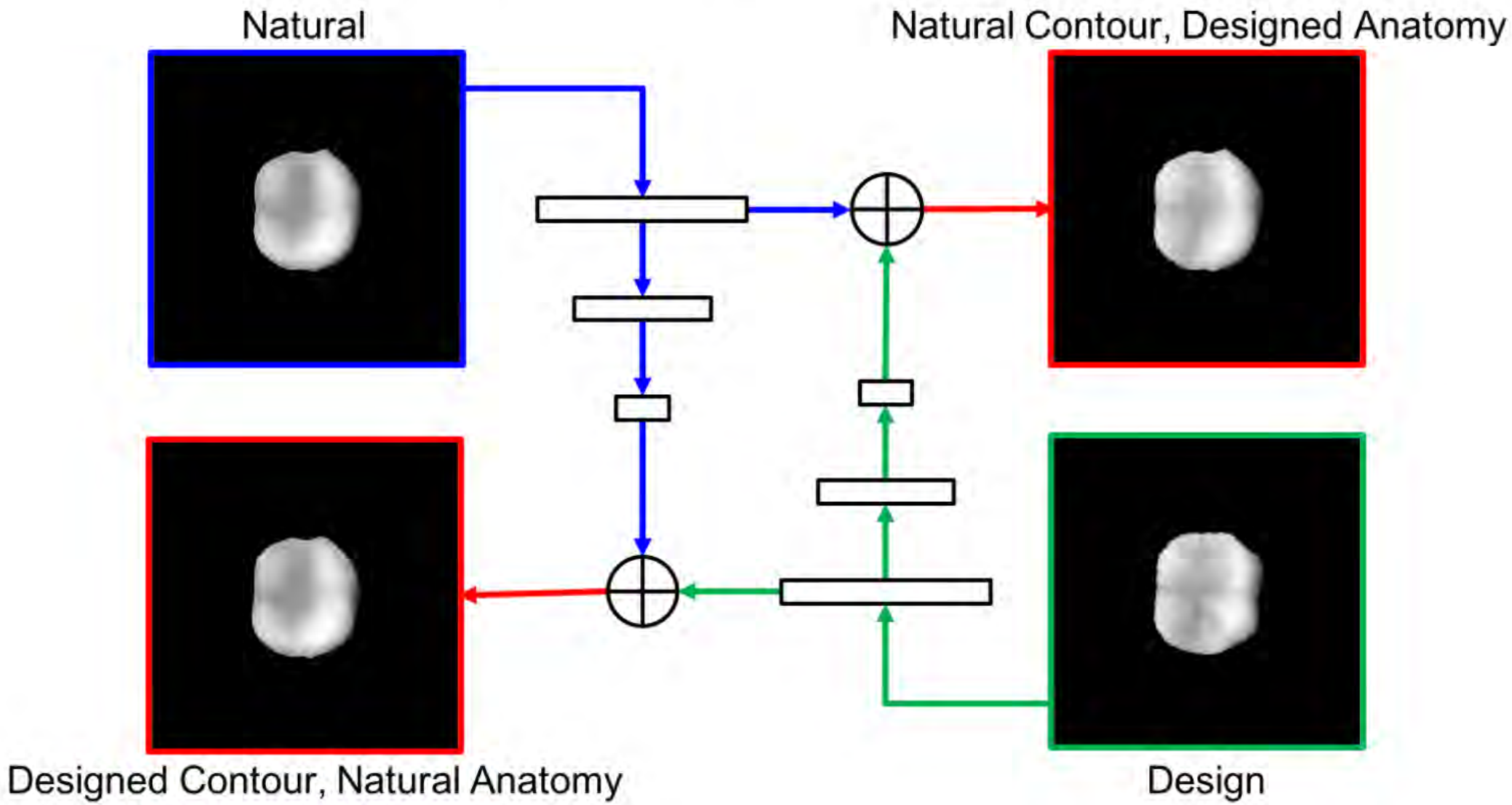
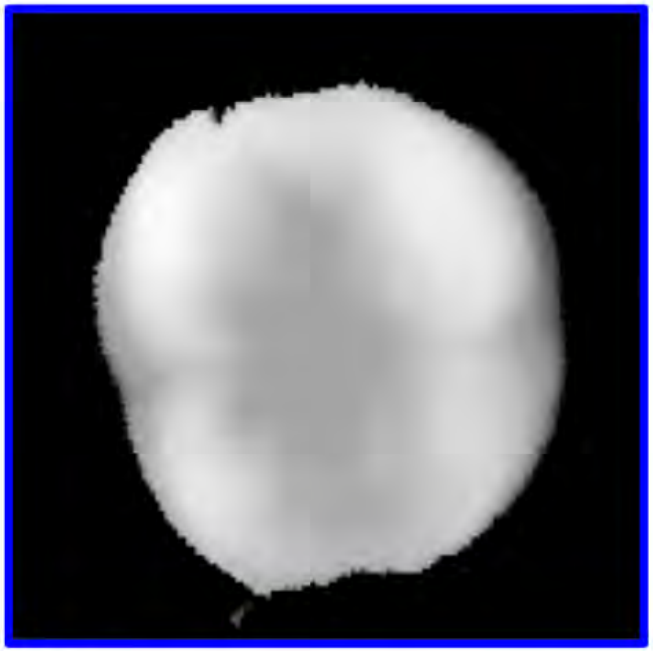


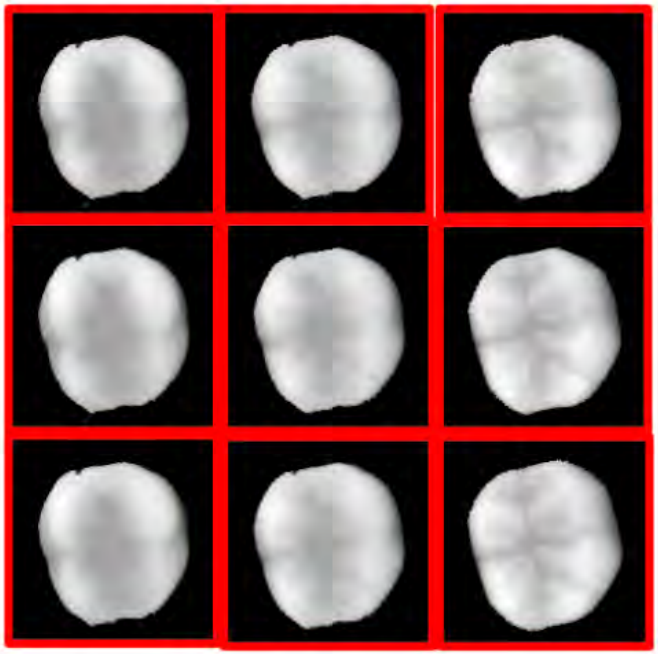
Image Style Transfer

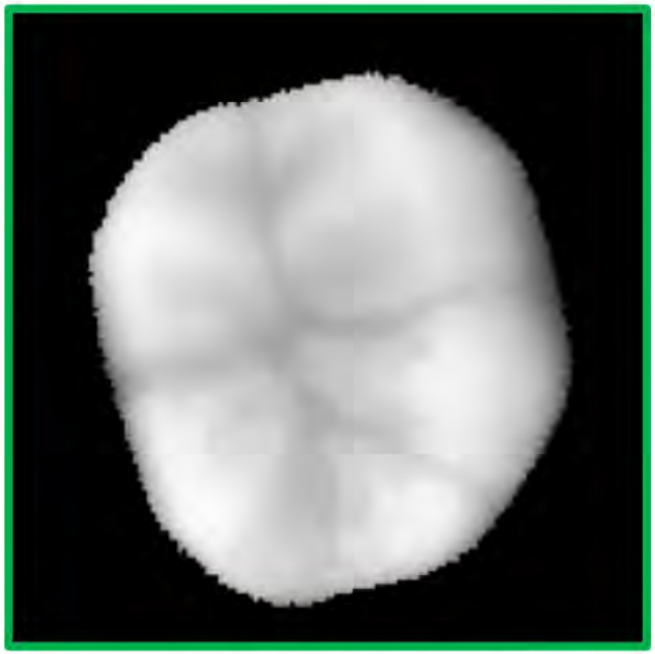


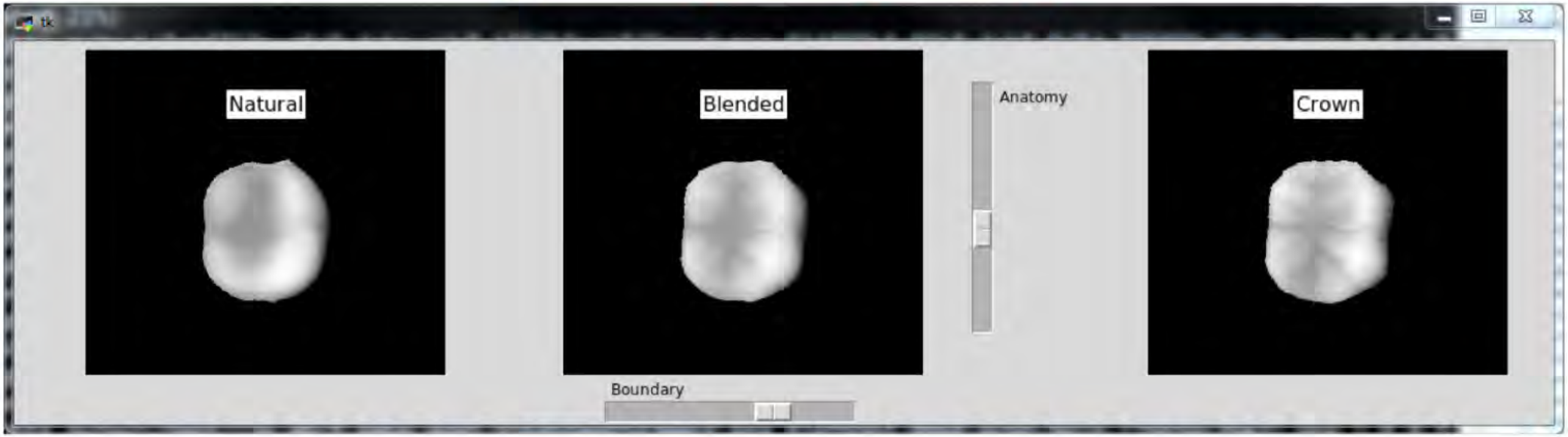
Visual Attribute Transfer through Deep Image Analogy. Liao et al. SIGGRAPH'17.

Demo GUI







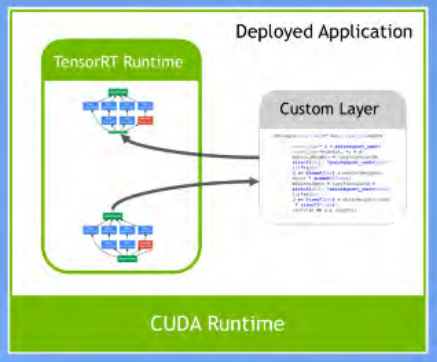


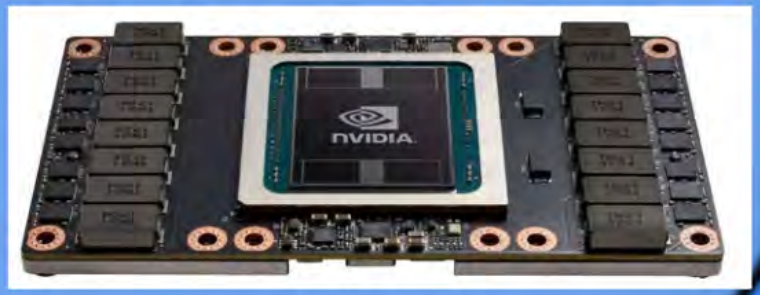
Deployment

- Model Zoo...
- Effective training vs efficient inference!

Up to x10 faster!

TensorRT


Deployed Application
TensorRT Runtime
Custom Layer
CUDA Runtime


NVIDIA

Deployed Application

TensorRT Runtime

Custom Layer

```
FCPlugin(const void* data, size_t length)
    {
        const char* d = reinterpret_cast<
        const char*>(data), *a = d;
        mKernelWeights = copyToDevice(d+
        sizeof(int), *reinterpret_cast<const
        int*>(d));
        d += sizeof(int) + mKernelWeights.
        count * sizeof(float);
        mBiasWeights = copyToDevice(d +
        sizeof(int), *reinterpret_cast<const
        int*>(d));
        d += sizeof(int) + mBiasWeights.count
         * sizeof(float);
        assert(d == a + length);
    }
```

CUDA Runtime

aws

Facebook Open Source

Microsoft

What is ONNX?

ONNX is a open format to represent deep learning models. With ONNX, AI developers can more easily move models between state-of-the-art tools and choose the combination that is best for them. ONNX is developed and supported by a community of partners.

AMD arm NVIDIA HUAWEI intel Preferred Networks QUALCOMM


CLOUDPOINT™
aws


1. Lead time
2. Quality
3. Cost

By bringing AI to manufacturing, we will deliver a digital transformation to the physical world.

-- Andrew Ng

Landing.ai, December 2017

Thank you!