Escaping the 1D Bottleneck: An Online Framework for Applying Population-Level 3D Anthropometry to Design

Matt Reed
Daniel Park
Biosciences Group

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Matthew Reed, PhD
mreed@umich.edu
http://mreed.umtri.umich.edu

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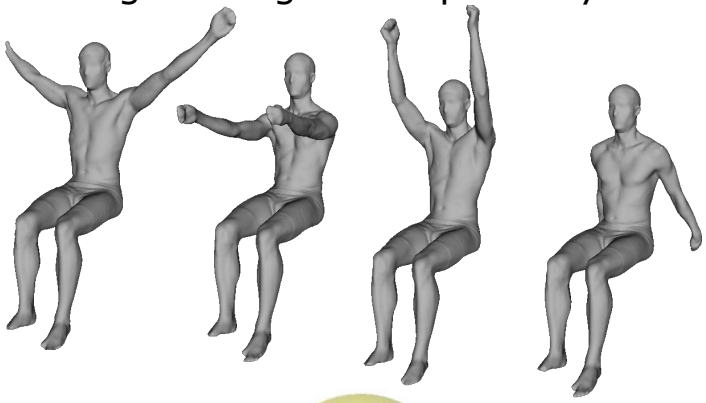
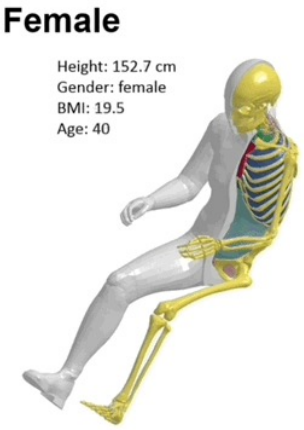
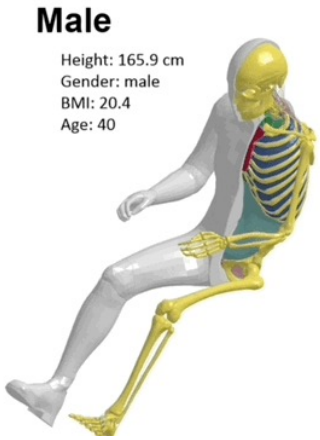
Biosciences Group: Major Research Areas

Engineering Anthropometry



Vehicle Occupant Posture Prediction and Accommodation Modeling

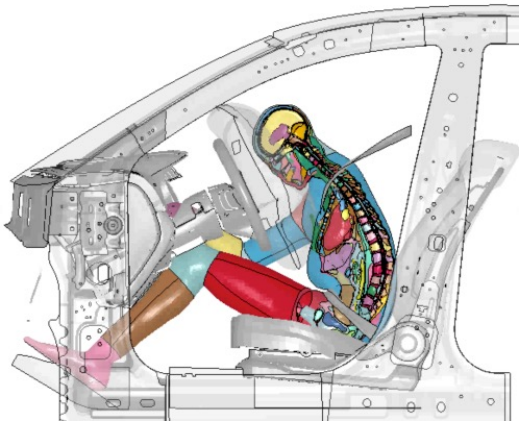


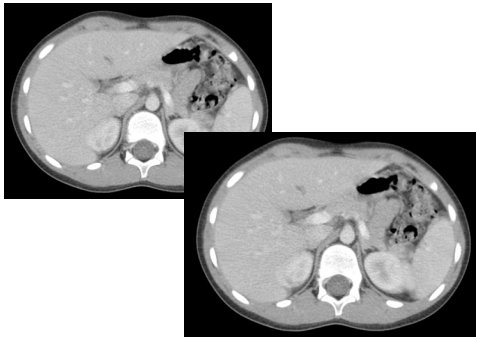


Computational Human Body Modeling

Over 25 years of research with U.S. Department of Defense

Occupant Crash Protection





Injury Biomechanics

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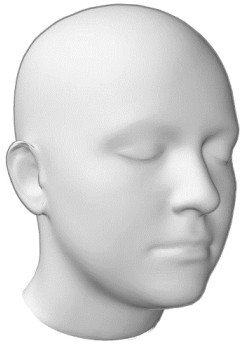
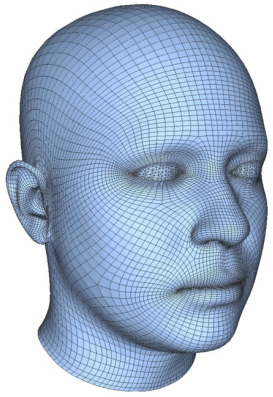
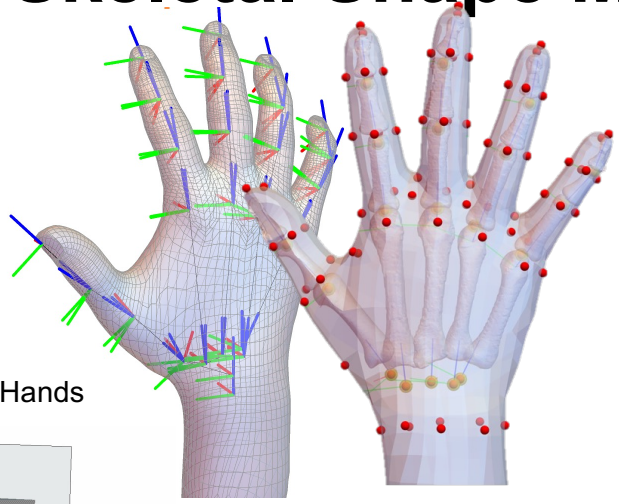
Regional and Skeletal Shape Modeling

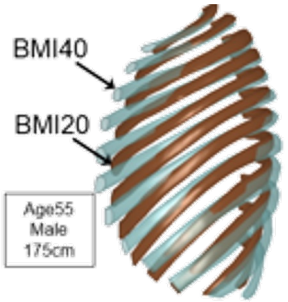


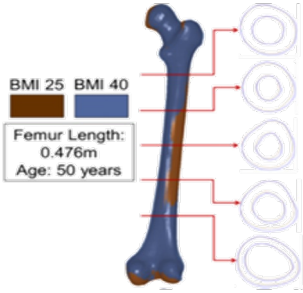


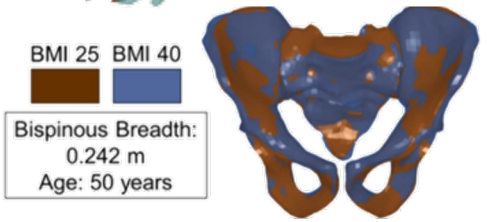
Head with accurate scalp

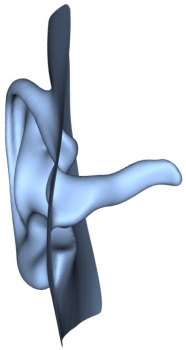


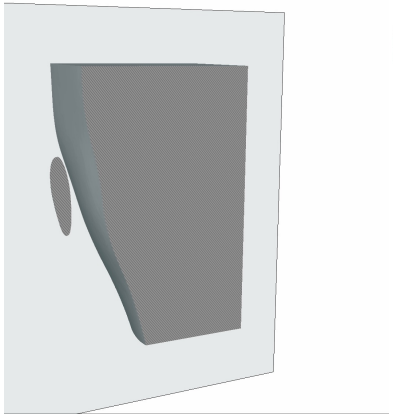
Hands



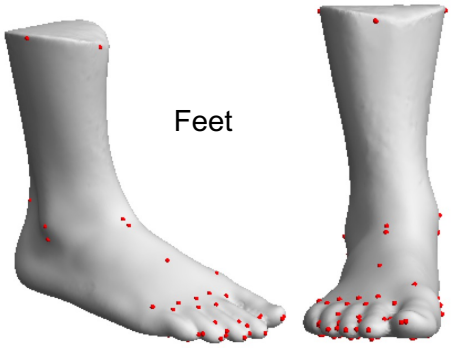




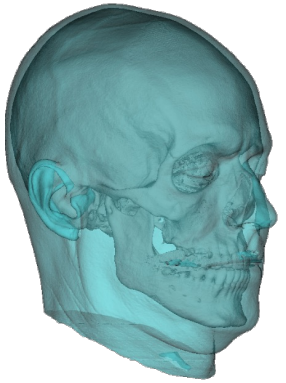




Detailed ear geometry with canal



Feet



skeletal structures

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Online models at http://HumanShape.org/

Applied Anthropometry is Stuck in the 1950s

How do nearly all product designers find and use anthropometric data?

- do a Google search; when that fails, ask AI! or
- look in a reference text for a dimension that looks like it might be relevant
- select a 5^{th} or 95^{th} percentile value

or

- use a manikin, template, headform, or some other pre-defined reference: even when 3D forms are used, usually fewer than 6 and often **only one 3D form** is used

What are the problems with this approach?

- univariate
- one-dimensional data
- wrong dimension
- wrong population
- wrong size (manikin approach)

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Surely things are better for military applications?

Not much better:

- In the U.S., detailed **3D** anthropometric information for warfighters (e.g., ANSUR II) is generally not available to product designers; 10s of thousands of warfighters have been scanned, but only a few people have access due to privacy concerns
- Most designers are using univariate statistics from published reports
- Tools for actually using population-level 3D data in design are not available and hence aren't in acquisition requirements

What are the problems with this approach?

- ✓ univariate
- ✓ one-dimensional data

often

- wrong dimension (limited to what's been measured previously)
- wrong population (surface Navy?)
- wrong size (manikin approach)*

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*The so-called "50th percentile male" is never a limiting case

Thought Experiment: How would you do product design…

If you had infinite resources ….

and a time machine?

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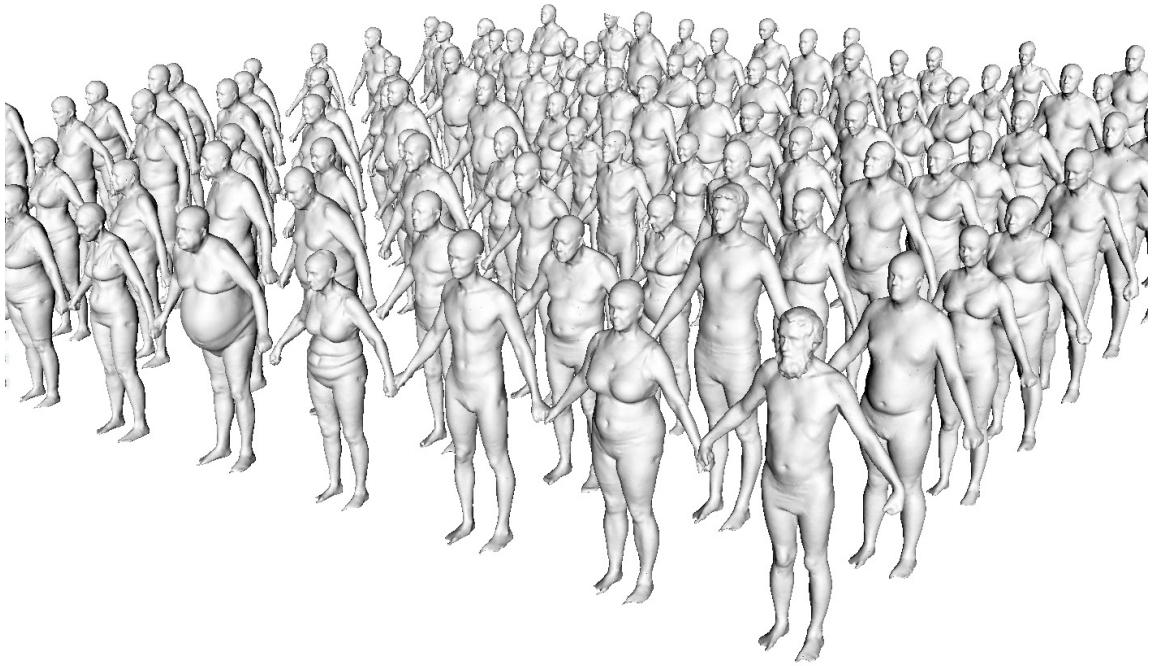
Fantasy Design World

- Infinite physical protoypes!
- Try everything on everyone!
- Optimize designs (size/shape/adjustability/sizing etc.) across the whole population by doing physical try-ons!



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Back in the Real World: Virtual Fit Testing

Individual-level population characteristics that affect product interaction

Concept of fit: how is the product supposed to fit and how do you know if it fits

Model of product interaction

Cost functions that convert product interaction outputs into a quantitative score

Simple idea: count the number of users in a population who obtain “good fit”

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VFT Data Requirements

Population data:

- correct population
- correct variables
- can be more than anthropometry: strength, age, etc – anything we can know about the population that influences the interaction with the product

Product interaction data:

- objective and subjective outcomes from parametric, structured interaction (fit/accommodation) testing
- statistical relationships between outcomes and population variables

Need data for **individuals** who **represent*** the **population**

* can be weighted or unweighted

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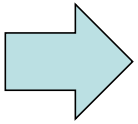
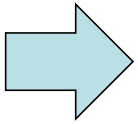
Simple VFT

individual-level 1D anthropometric dimensions



assumed 1:1 relationship between anthro and fit/accommodation



Multivariate binary cost functions (fits/doesn't fit)

Example: HFES Multivariate Accommodation Test Tool (MATT)

https://my.hfes.org/online-store/publications

Multivariate Accommodation Testing Tool

IMPORTANT - Change only the **green** cells. The red cells will update automatically in response.

Fraction Male **0.3** (between 0 and 1)

	Quantiles - Men			Quantiles - Women			Associated Dimension Value		Percent Accommodated		
Measures	5%	50%	95%	5%	50%	95%	Low	High	Men	Women	Both
Stature (mm)	1634	1758	1882	1501	1621	1741					
BMI (kg/m^2)	21	28	39	20	28	43					
Seated Measures											
Abdominal Extension Depth (mm)	228	290	420	212	288	424					
Buttock-Knee Length (mm)	559	616	679	532	591	656					
Buttock-Popliteal Length (mm)	440	486	548	420	474	529					
Elbow Rest Height, Sitting (mm)	193	242	290	192	235	281					
Eye Height, Sitting (mm)	736	802	859	686	748	805					
Forearm-Forearm Breadth (mm)	482	566	681	410	491	633					
Hip Breadth, Sitting (mm)	333	382	455	353	421	530		530	99.4%	94.9%	96.2%
Knee Height (mm)	508	557	606	459	504	550		600	91.7%	99.7%	97.3%
Popliteal Height (mm)	390	434	478	338	382	426	340	470	90.1%	93.7%	92.6%
Shoulder Breadth (mm)	444	498	562	387	436	524					
Thigh Clearance (mm)	138	168	204	124	150	196					
Elbow Height Above Floor Estimated (mm)	615	679	739	554	618	681					
Thigh Clearance Above Floor Estimated (mm)	540	602	662	480	536	594					
Knee Depth Estimated (mm)	214	319	387	187	299	371					
Foot Depth Estimated (mm)	334	460	544	283	422	511					
Standing Measures											
Eye Height, Standing (mm)	1517	1640	1762	1400	1512	1631					
Elbow-Fingertip Length (mm)	431	470	512	386	421	462					
Elbow Rest Height, Standing (mm)	997	1084	1177	914	1001	1090					
Foot Length (mm)	244	266	291	220	239	260					
							Total Accommodation		**86.8%**	**89.9%**	**89.0%**

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But What About 3D?

To a reasonably approximation, <1% of 3D body shape data that have been gathered have ever been used in product design

Typical Approaches to 3D Databases

Faster tape measure: extract the same 1D dimensions that would have measured by hand, proceed as if 1975 [VFT on 1D measures]

PCA on the wrong variables: pick some overall body dimensions (stature, sitting height, …) do a PCA & generate boundary cases, find nearest neighbors in 3D, ignore the rest of the 3D data while using the boundary cases for specific analyses not related to these variables

Why Haven't 3D Data Helped (much)?

Scan data is rarely and minimally used. Why?

- scan files are hard to use, effectively impossible for most designers; template fitting is essential but uncommon
- privacy limits access
- doing good scanning is hard (and still expensive)
- sampling bias is worse than with 1D dimensions
- statistical knowledge needed for shape analysis is not broadly distributed
- **few software tools available to do useful things with 3D data**
- **even fewer tools available to useful things at a population level**

Some good 3D work has been done for clothing, body armor, helmets, etc. by DOD researchers, but this has not resulted in widely used methods or software, even within the goverment

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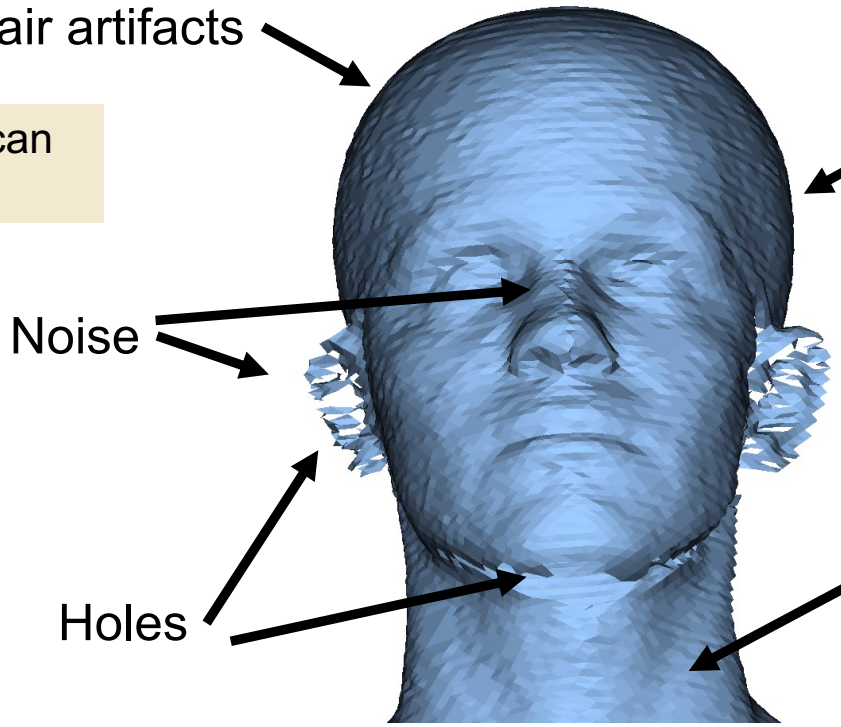
Some of the Problems with 3D Scan Data

Typical standing scan before processing



No widely available software well-suited for using 3D scan data

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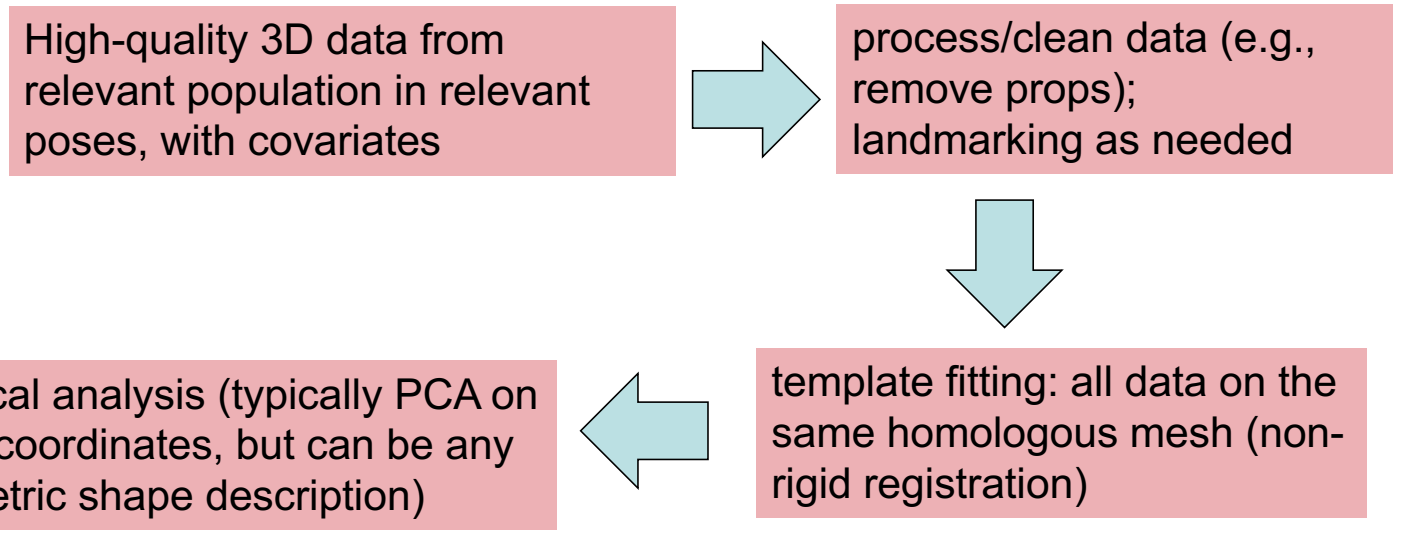
What is Needed to Use 3D Data?

1. **Software**
2. Design methods
3. Education

Preliminaries: Database Development



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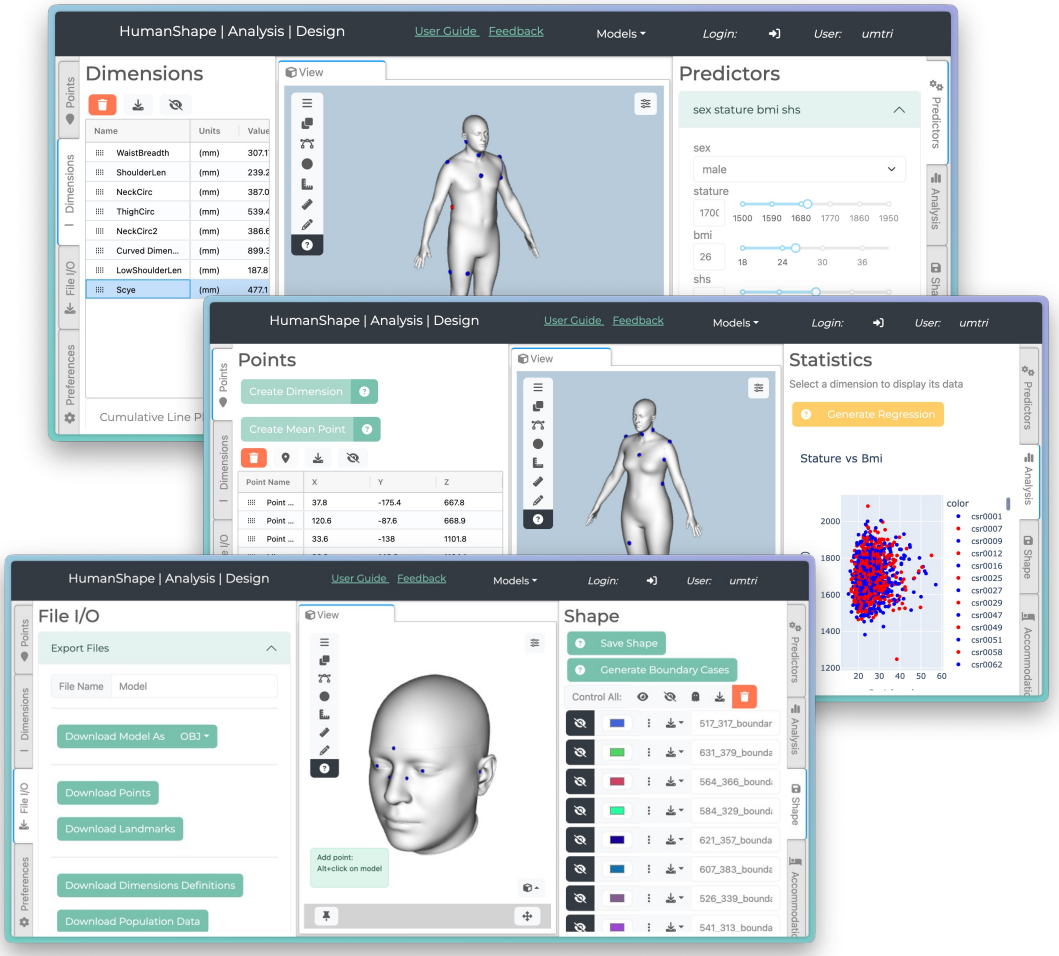
HumanShape App: Online Human-Centered Design

- Unified interface for working with all types of human body shape data, from whole-body to anatomical regions: hands, heads, ears, feet
- Online app means no software installation problems and accessible from anywhere
- Working with large populations of virtual avatars, not raw scan data
- Synthesis techniques ensure accuracy while eliminating privacy-related constraints

https://HumanShape.app/



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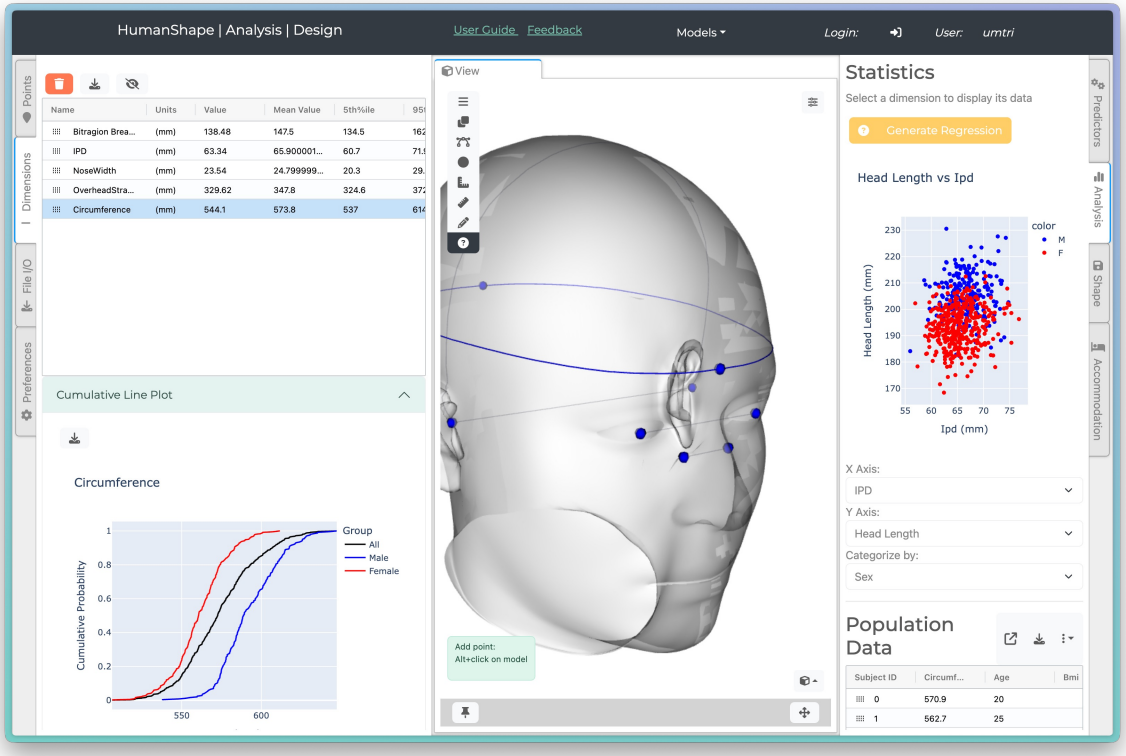
HumanShape App: Online Human-Centered Design

- User-defined measurements – not limited to predefined measures
- Point-to-point dimensions, single-axis measurements, curves, circumferences, angles, centroids…
- All dimensions are automatically computed for every individual in the population
- Statistical analyses of population distributions of user-defined measures for male & female



US Navy Aircrew head model available

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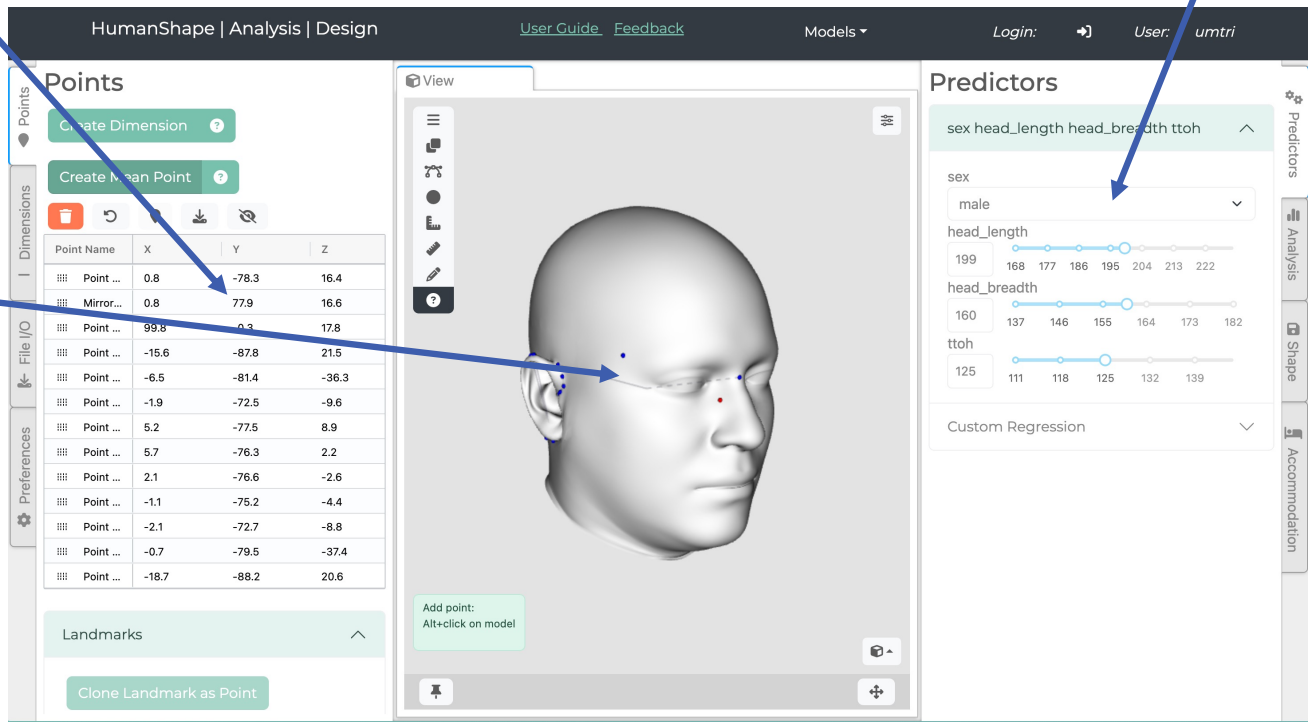
HumanShape App: Functionality

User defined points

User defined dimensions: point to point, circumferences, surface curves, angles…

Pre-defined and user-defined regressions



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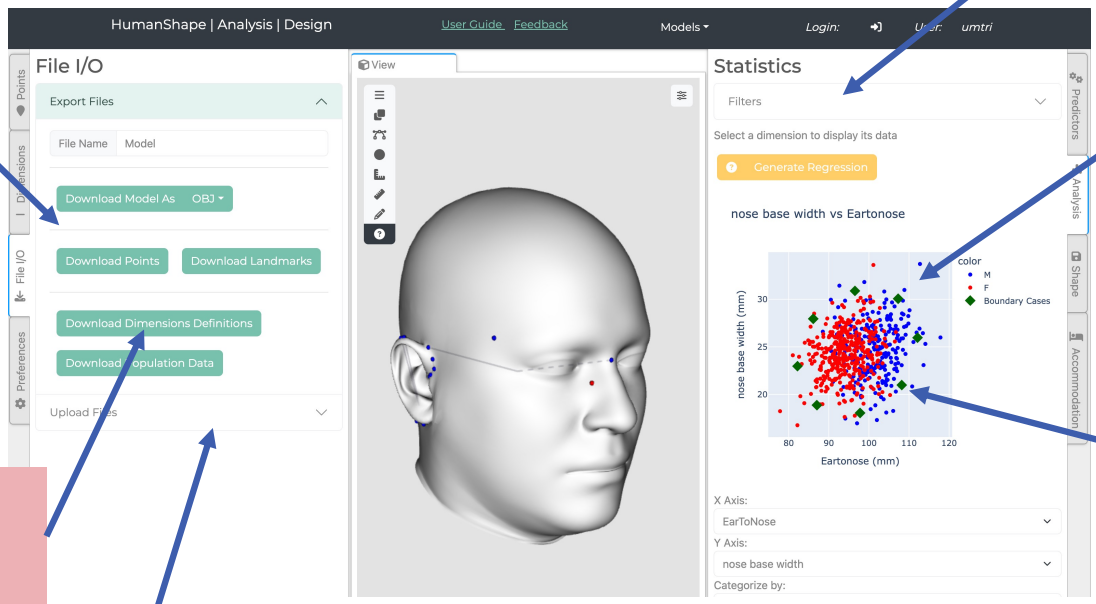
HumanShape App: Functionality



Apply range filters

Download shapes

Bivariate plots

Download points, landmarks, dimensions, …

Boundary case generation on user-defined variables

Upload geometry

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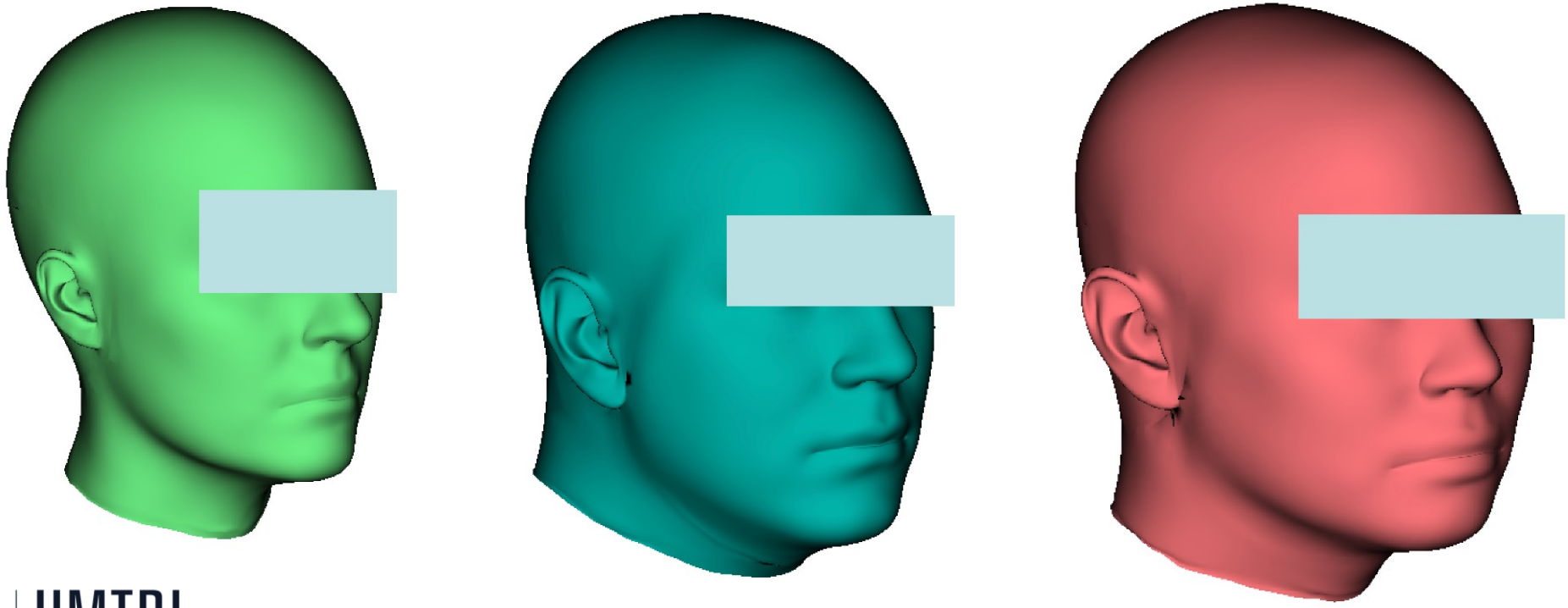
Sidebar: De-Identification

Problem: privacy issues greatly restrict the use of head/face scan data



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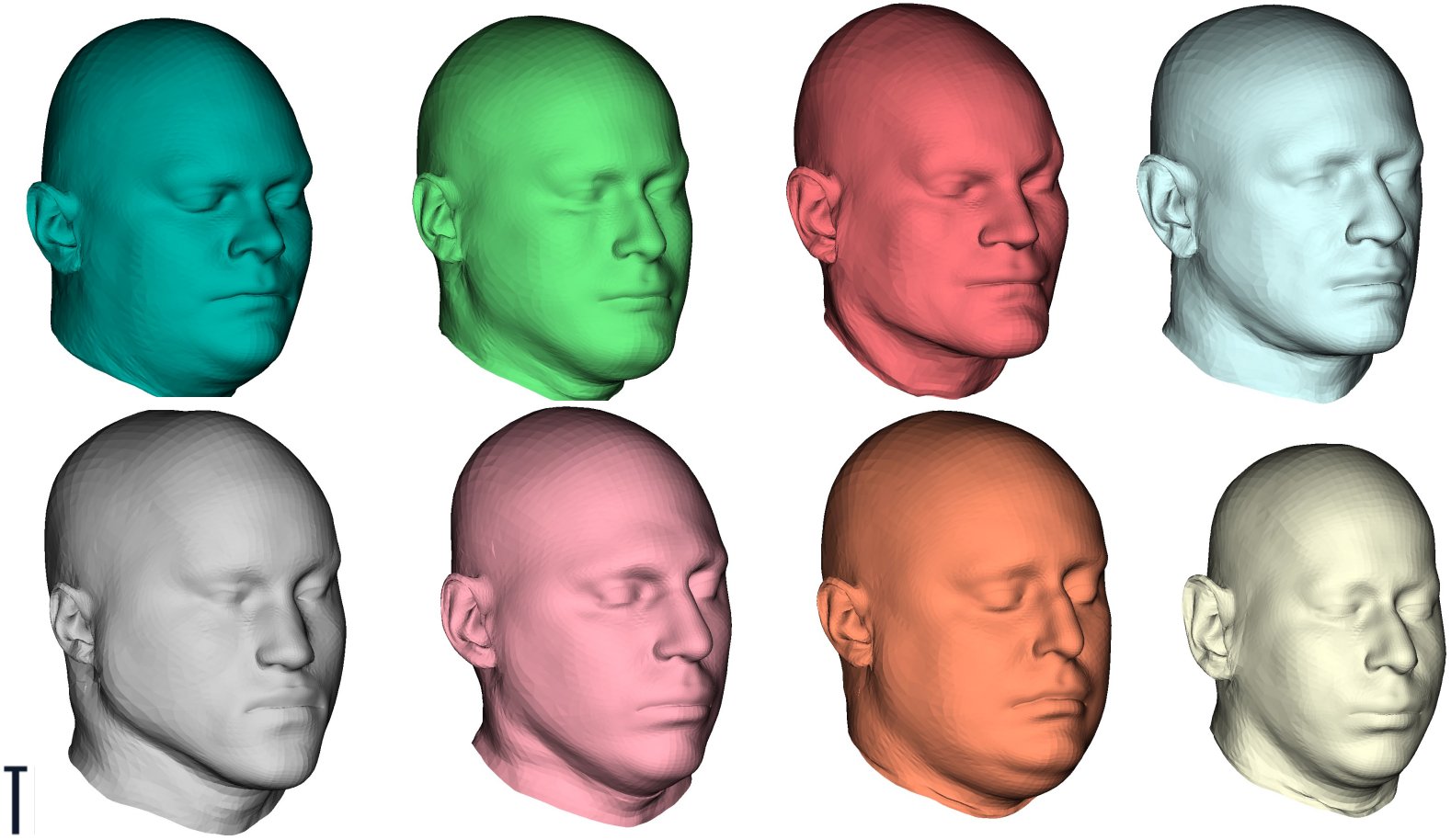
De-Identification through Synthesis

Synthesized versions of the same subject (none of these is an actual person)



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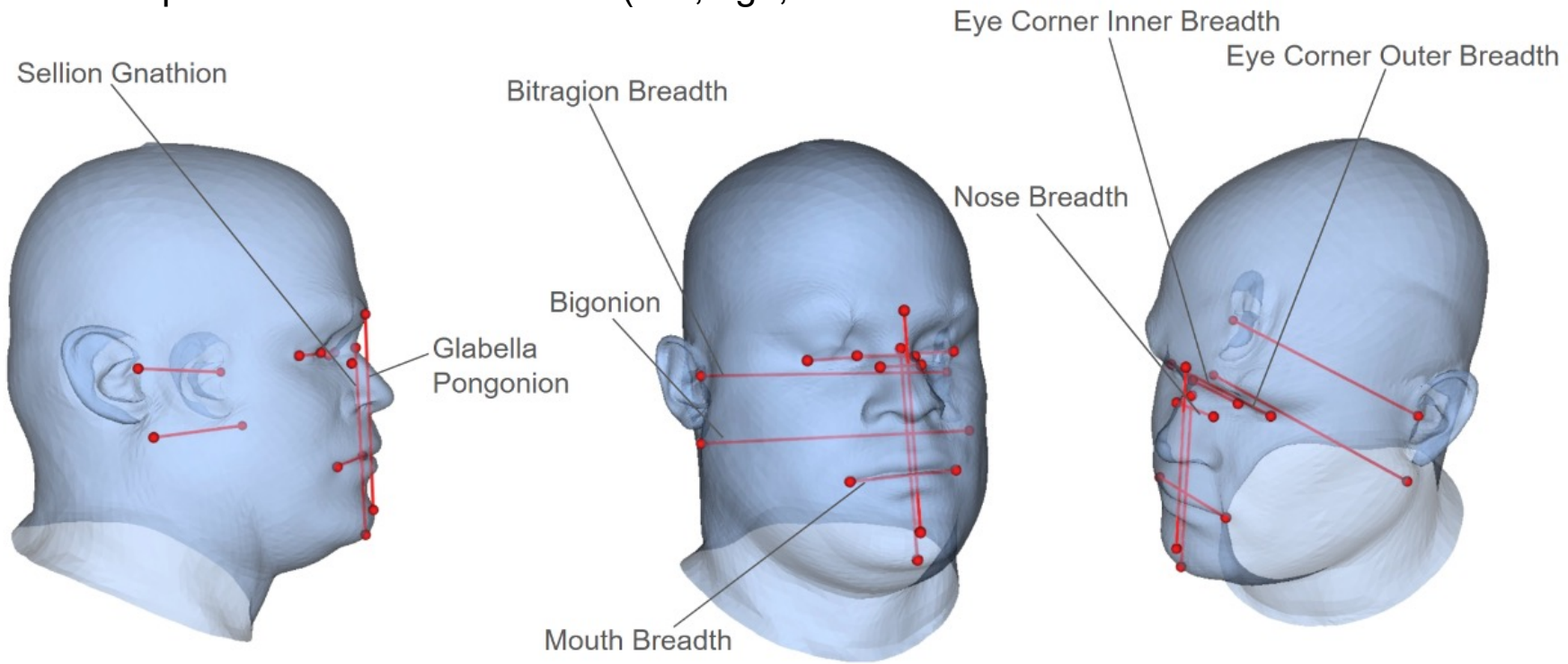
Head Synthesis Validation

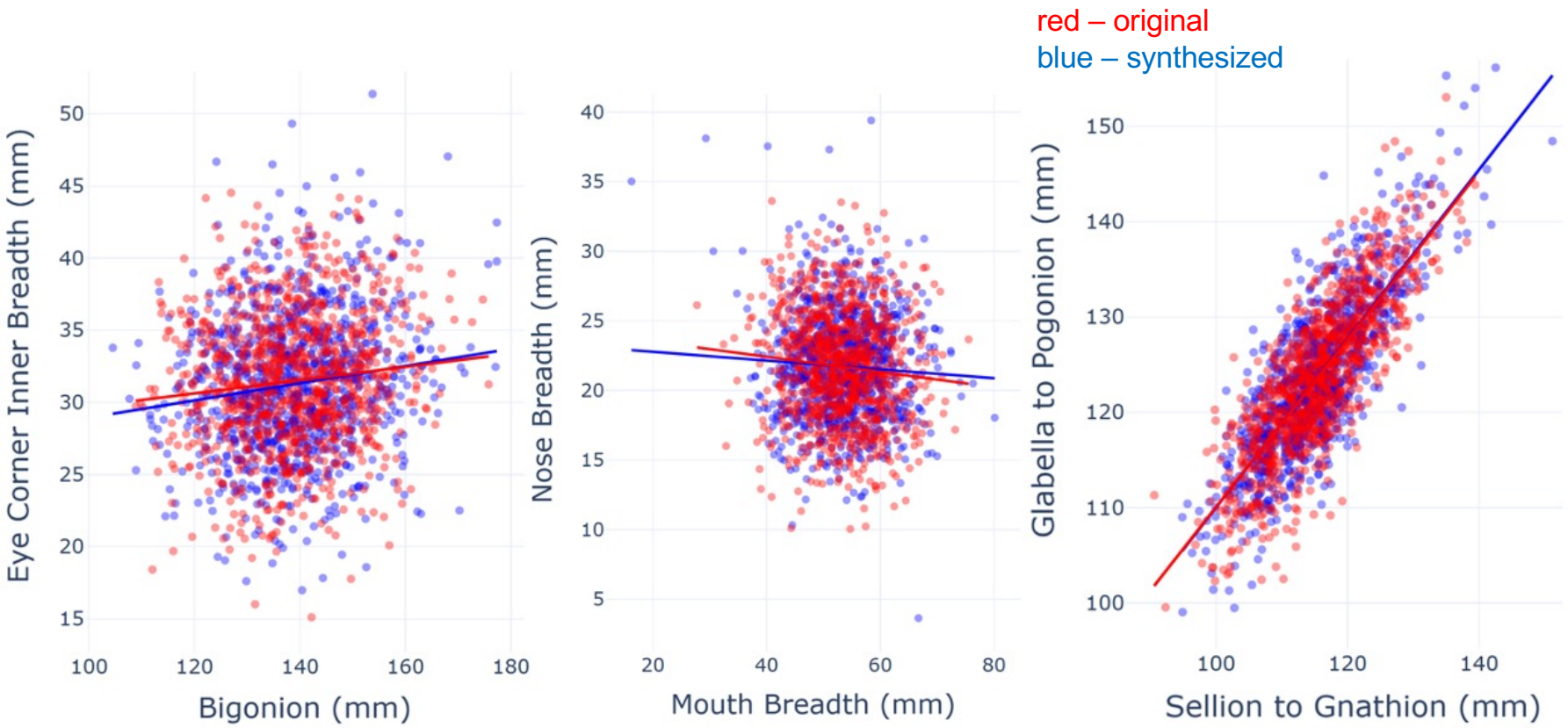
But does it work? The method must retain:

1. Summary statistics on head dimensions for population
2. Relationships among dimensions
3. Relationships with external covariates (sex, age, etc.



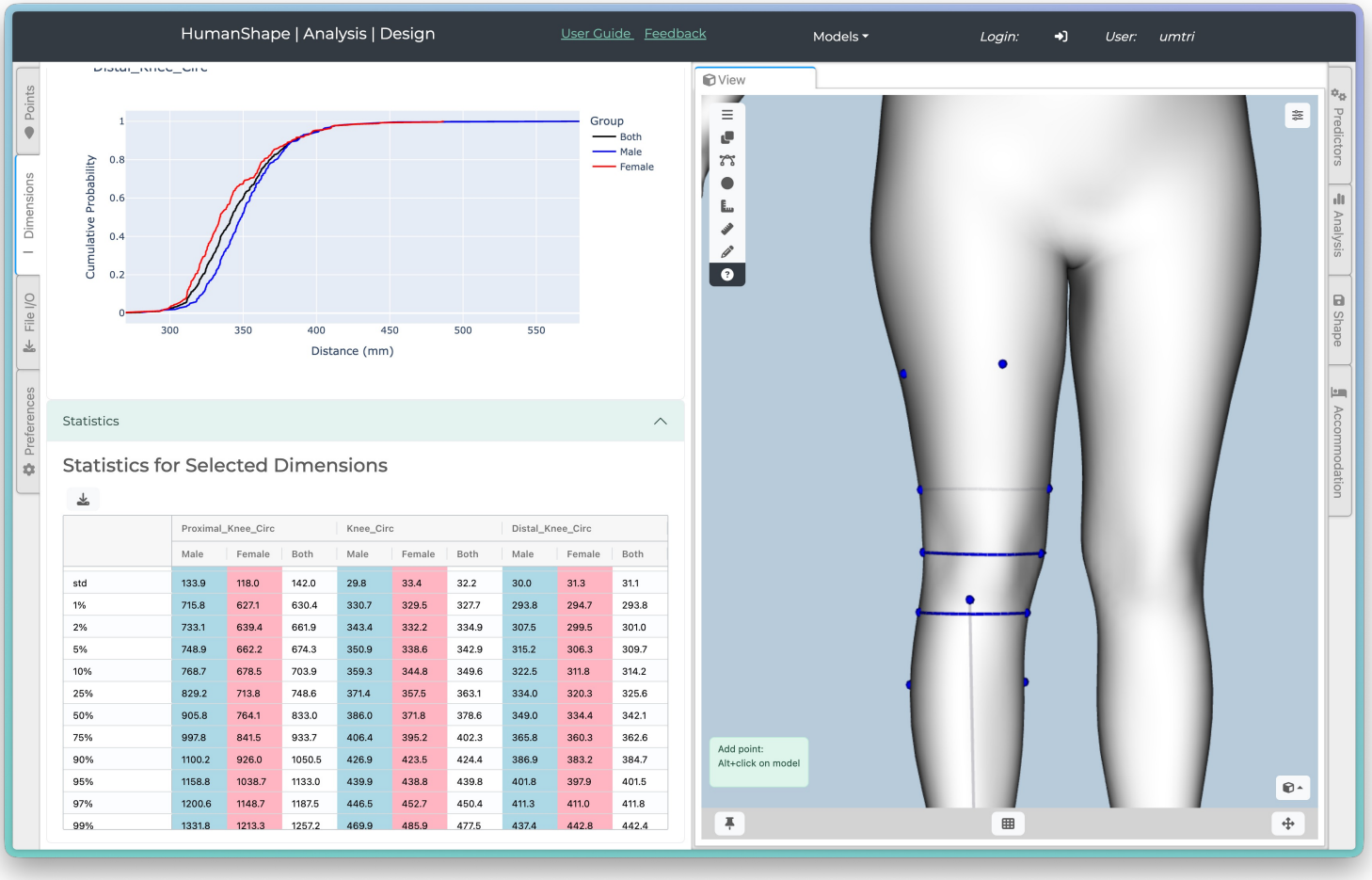
Head Synthesis Validation

Statistical analyses for de-identified population are essentially identical



Case Study: Knee Brace

Extract novel measures across the population



	Proximal_Knee_Circ			Knee_Circ			Distal_Knee_Circ		
	Male	Female	Both	Male	Female	Both	Male	Female	Both
std	133.9	118.0	142.0	29.8	33.4	32.2	30.0	31.3	31.1
1%	715.8	627.1	630.4	330.7	329.5	327.7	293.8	294.7	293.8
2%	733.1	639.4	661.9	343.4	332.2	334.9	307.5	299.5	301.0
5%	748.9	662.2	674.3	350.9	338.6	342.9	315.2	306.3	309.7
10%	768.7	678.5	703.9	359.3	344.8	349.6	322.5	311.8	314.2
25%	829.2	713.8	748.6	371.4	357.5	363.1	334.0	320.3	325.6
50%	905.8	764.1	833.0	386.0	371.8	378.6	349.0	334.4	342.1
75%	997.8	841.5	933.7	406.4	395.2	402.3	365.8	360.3	362.6
90%	1100.2	926.0	1050.5	426.9	423.5	424.4	386.9	383.2	384.7
95%	1158.8	1038.7	1133.0	439.9	438.8	439.8	401.8	397.9	401.5
97%	1200.6	1148.7	1187.5	446.5	452.7	450.4	411.3	411.0	411.8
99%	1331.8	1213.3	1257.2	469.9	485.9	477.5	437.4	442.8	442.4

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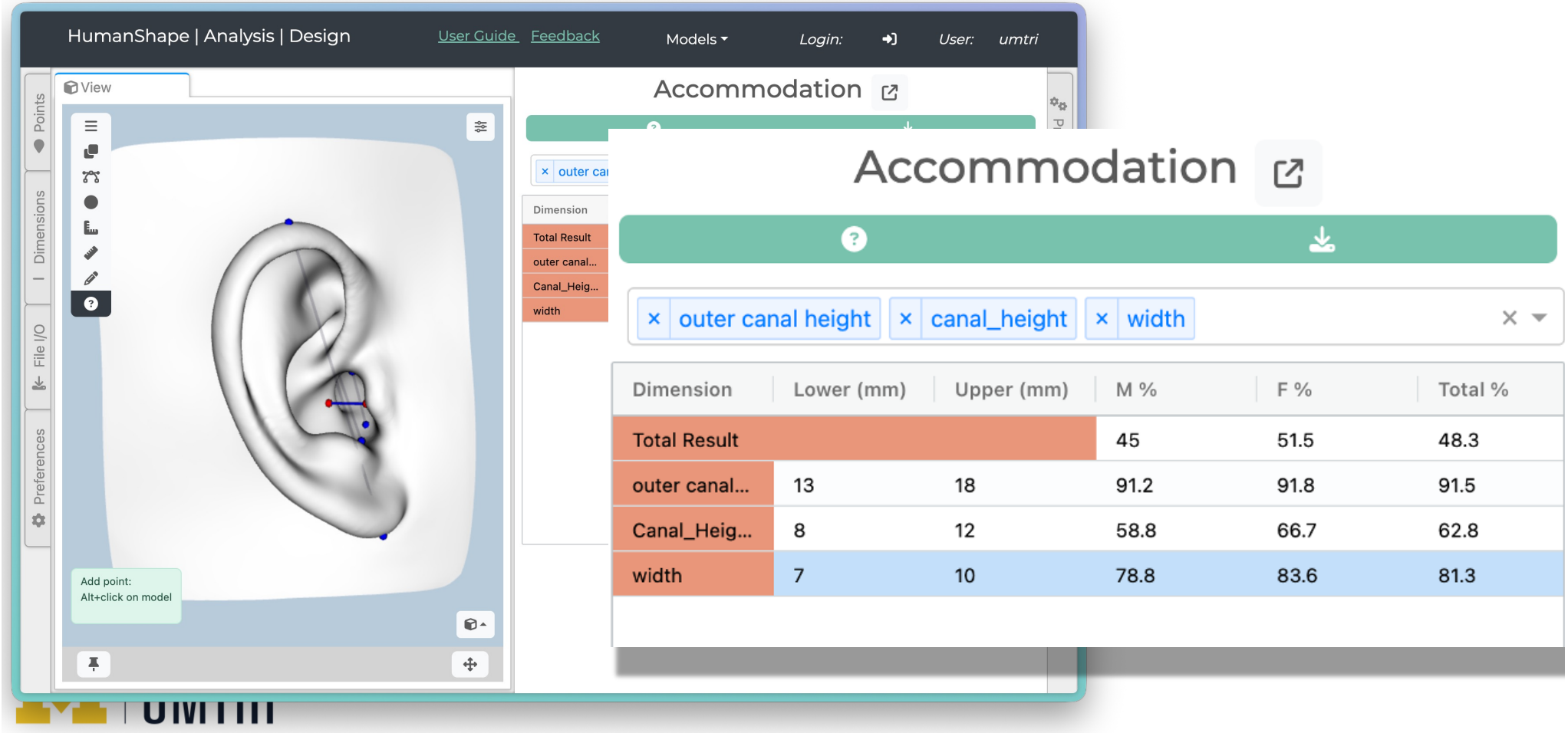
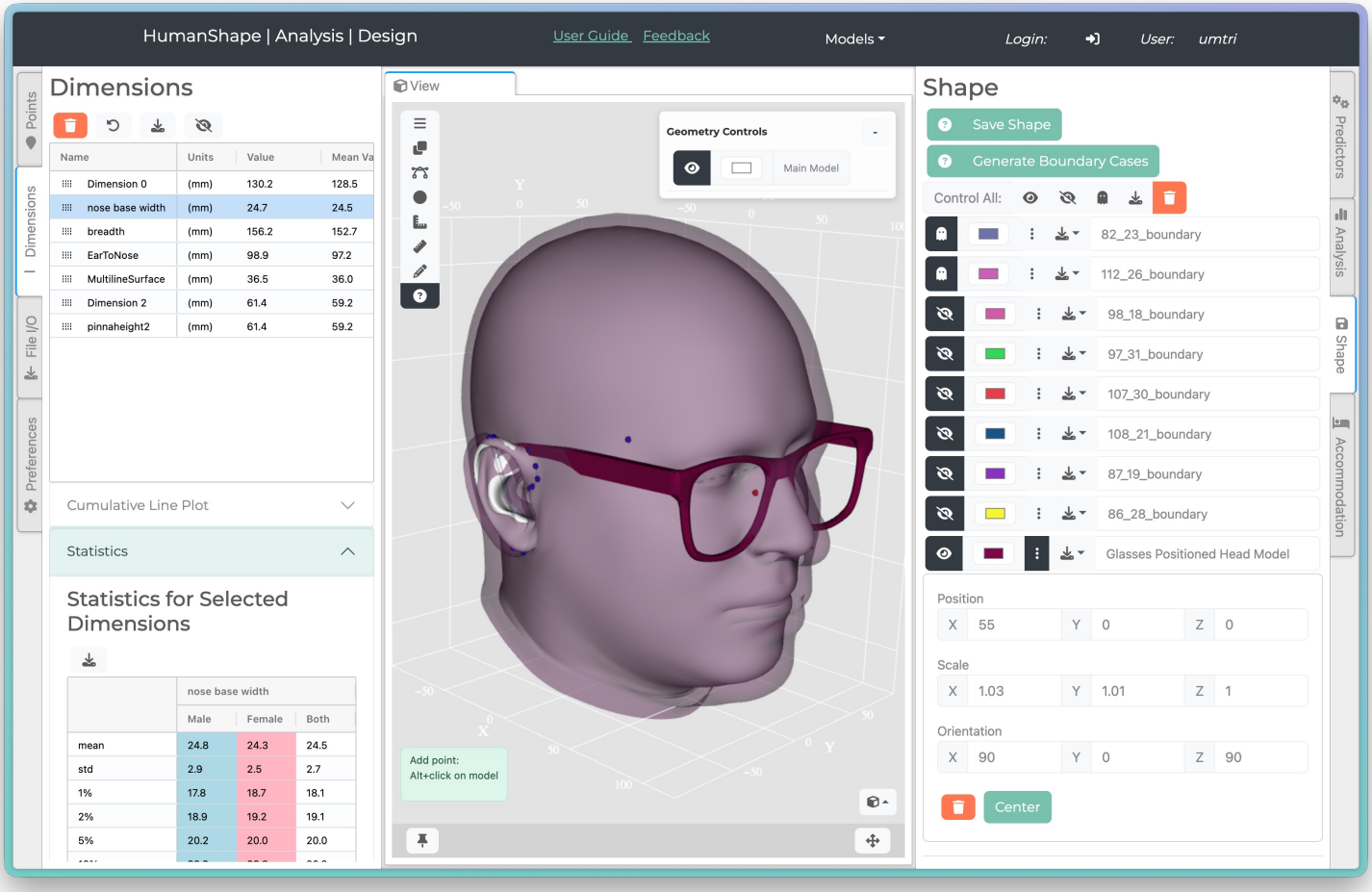
Case Study: In-Ear Audio

Multivariate accommodation



Case Study: Smart Glasses

Explore correlations and create boundary cases using regression or PCA



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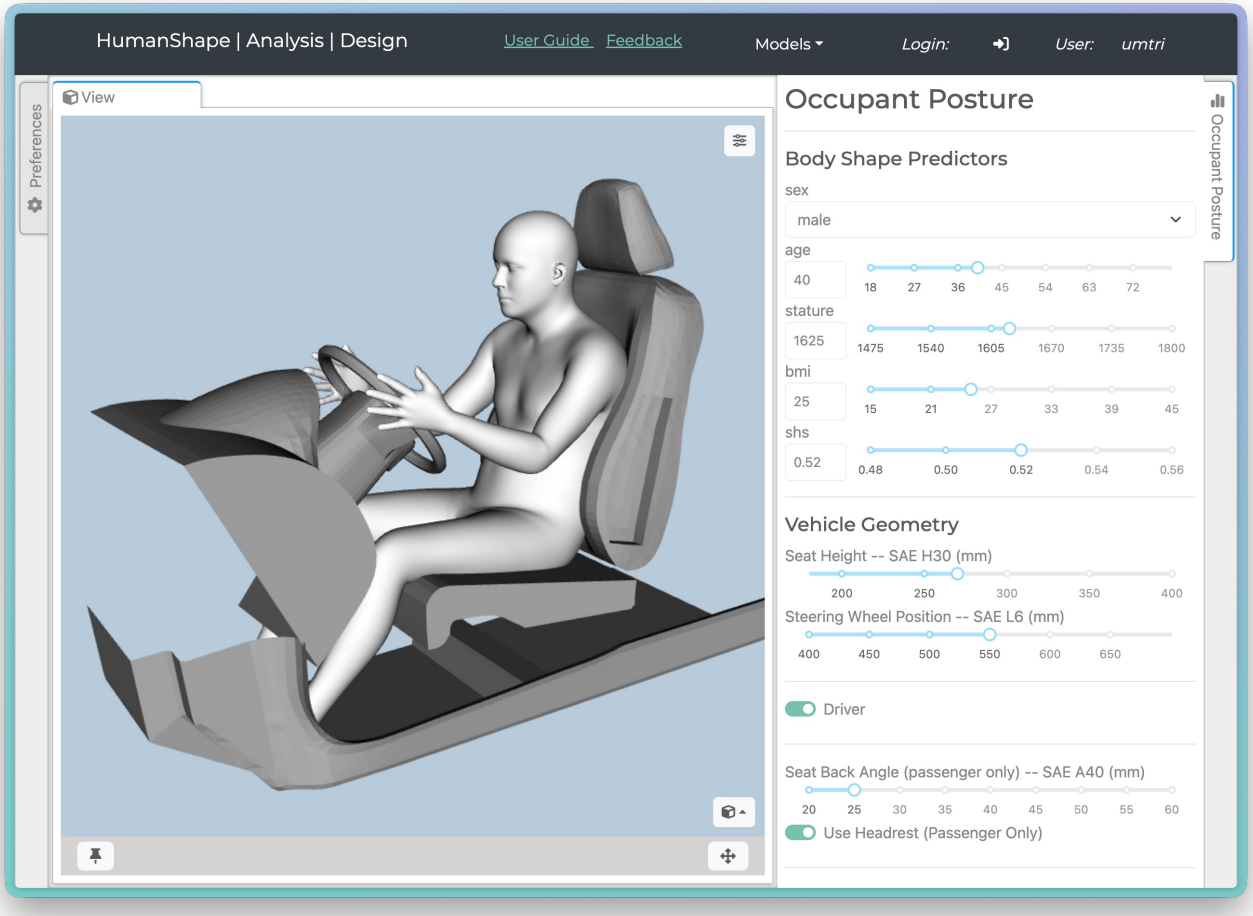
Case Study: Vehicle Interior Analysis

Generate body shapes in realistic postures as a function of vehicle layout



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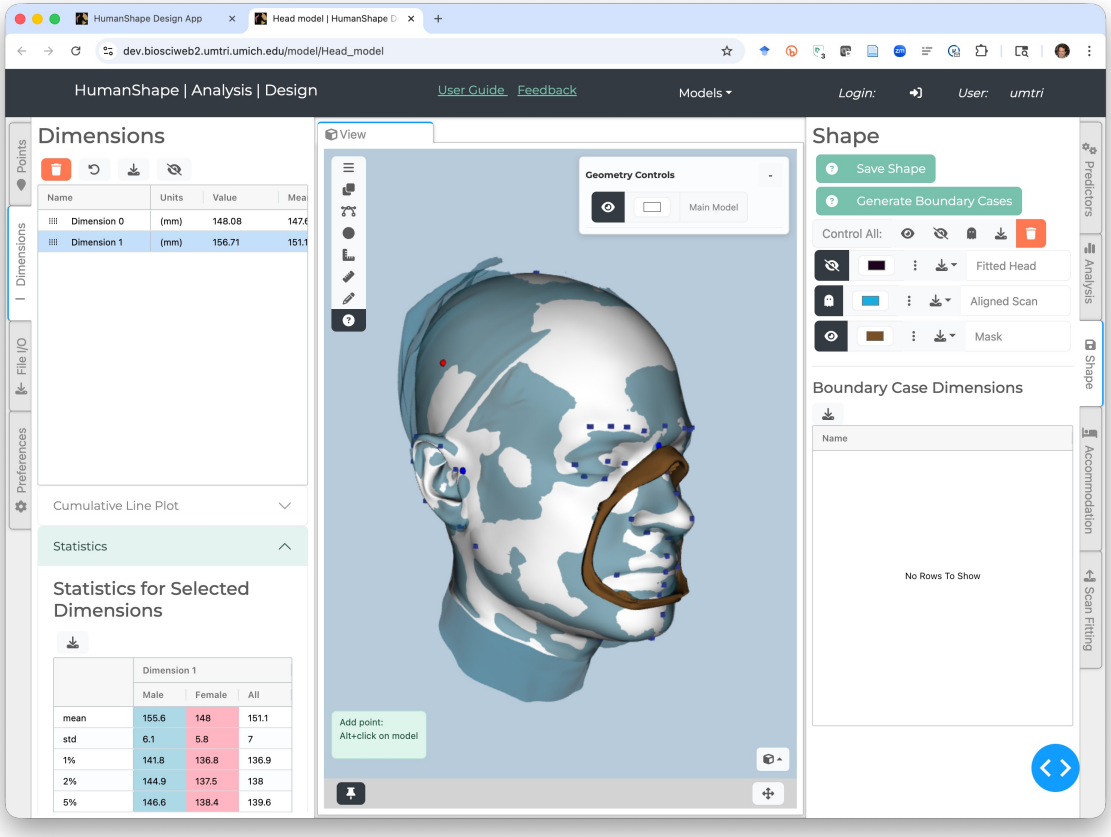
Case Study: Scan-to-Measurement

Upload a head scan, fit it, instantly get landmarks and all predefined measures, measuree anything else of interest, and place it within a population



Bonus: get recommended mask size!

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Future Functionality: Parametric Product Models

Design wizards for common analyses

Why: Designers should not have to decide which aspects of body size & shape matter for their design, and figure out how to convert between body dimensions and product dimensions

What: Generic, parametric design models for common analyses; input your parameters → get your targets for product **design variables rather than anthropometric variables**

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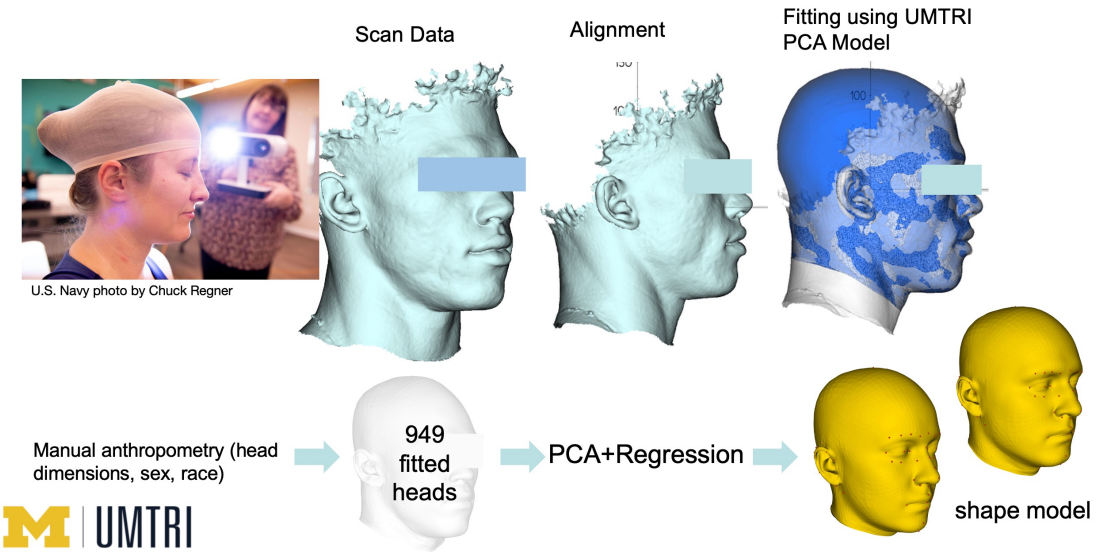
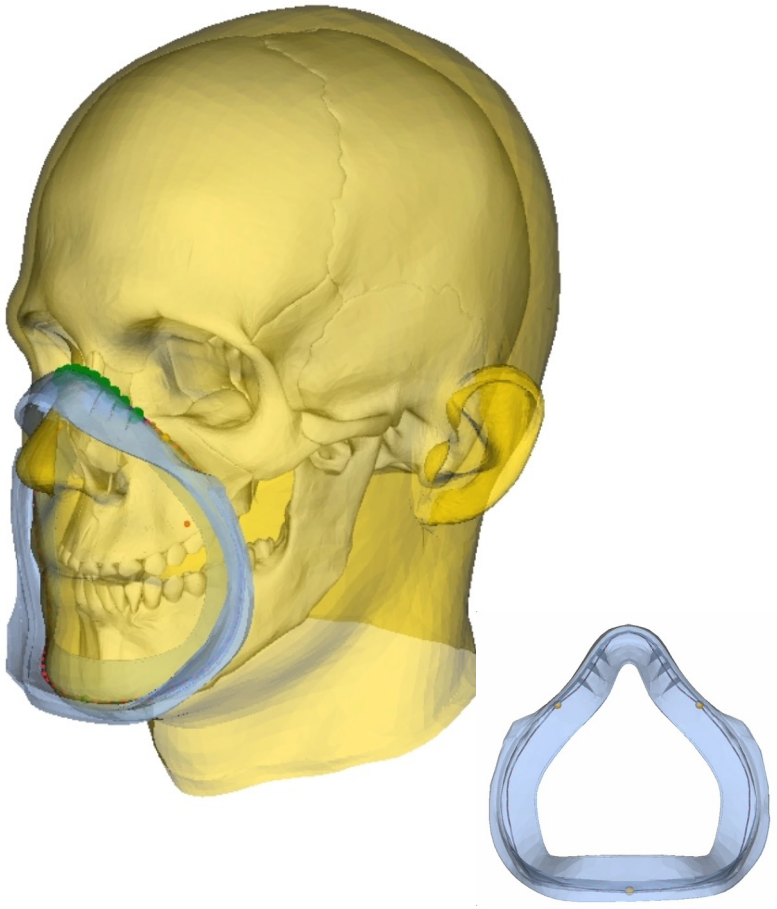
Case Study: Pilot Oxygen Masks (work in progress)

Navy Dataset Data from Lori Basham @ NAVAIR DREAMS lab under CRADA





Collaboration with Gentex funded by Navy

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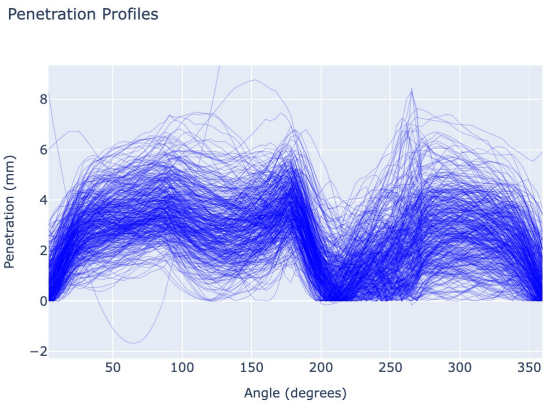
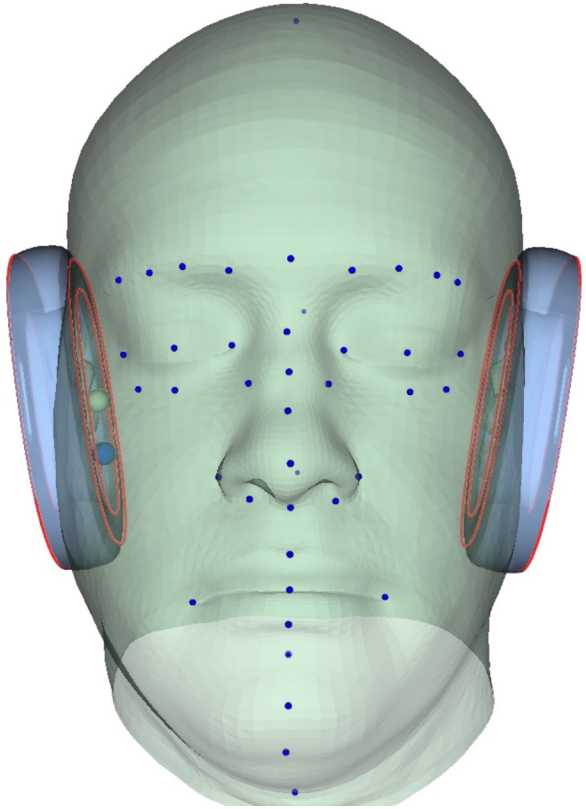
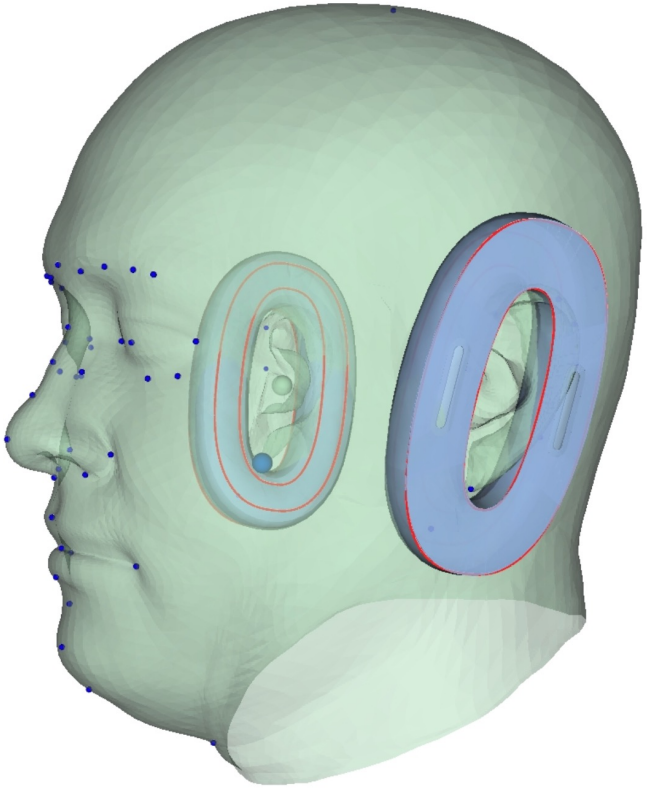
Case Study: Earcups (work in progress)

- Define parametric product model
- Conduct VFT across population
- Optimize design using quantitative metrics







Collaboration with Gentex

What about *my* population?

- We can fit any existing scan data, synthesize a matching, de-identified dataset, and add it to the app (U.S. Navy aircrew heads – thanks Lori!)
- Because we have statistical shape models, we can readily synthesize new populations that lie within shape spaces for which we have data.
- With data from thousands of U.S. and European military and civilian adults 18 to 80 years, and U.S. children ages 3 to 17 years, we can synthesize most “Western” populations of interest, including all U.S. military populations for which we have demographic descriptors (sex, age, race/ethnicity, stature & BMI if available)

Limitations and Future Work

Still an anthropometry tool: needs to be enable the user to work in design variables, with the software creating the link to anthrometry

Posing: our BioHuman avatar is fully posable, but creating a good UI for posing is challenging; posing is necessary, but often creates more problems than it solves (valid posture prediction is much better)

More anatomy: we have linked skeletal geometry, organ geometry available

Many more models: foot, hand with grasp, head/neck with face/neck movement…

Linkage to FE and musculoskeletal models: We can immediately generate runnable models

Product geometry interaction: users can upload polygonal geometry, but the software doesn't play well with native CAD geometry; CAD system implementations?

Customized populations:

- currently no interface; requires us to generate the model (but this is programmatic)
- legal roadblocks due to addressable privacy concerns

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Matthew Reed, PhD
mreed@umich.edu
http://mreed.umtri.umich.edu

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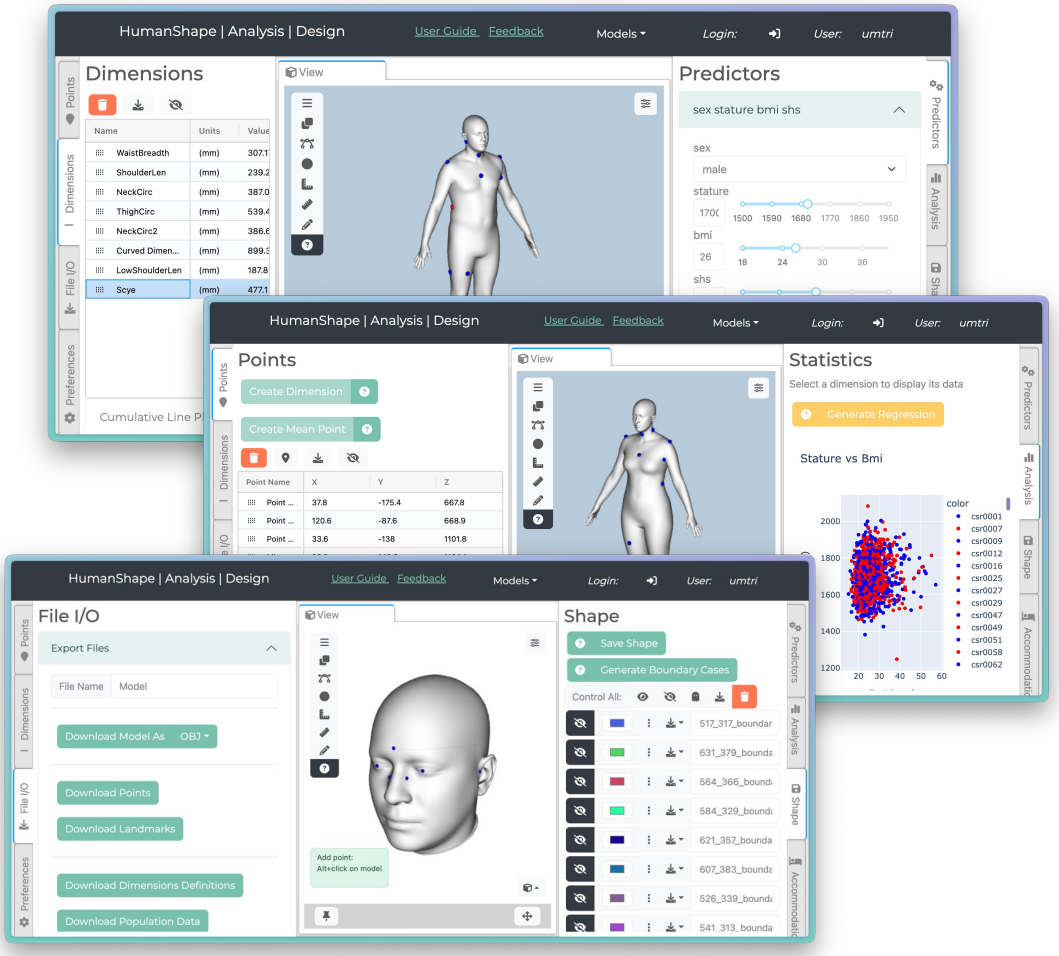
HumanShape App: Online Human-Centered Design

- Unified interface for working with all types of human body shape data, from whole-body to anatomical regions: hands, heads, ears, feet
- Online app means no software installation problems and accessible from anywhere
- Working with large populations of virtual avatars, not raw scan data
- Synthesis techniques ensure accuracy while eliminating privacy-related constraints

https://HumanShape.app/



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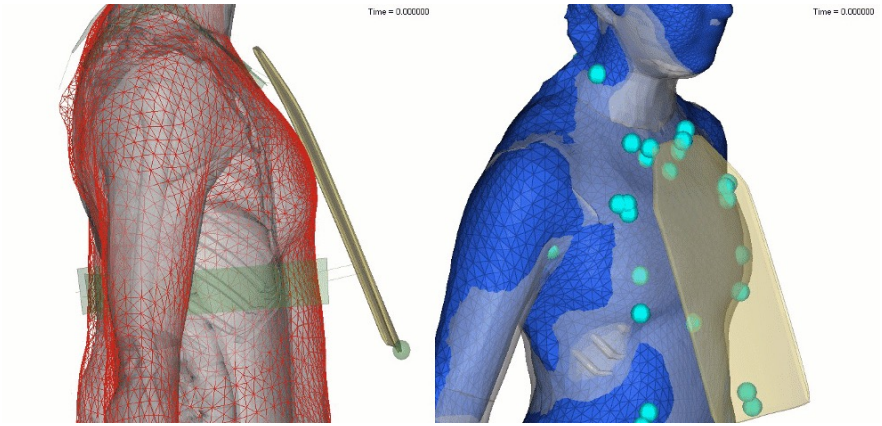
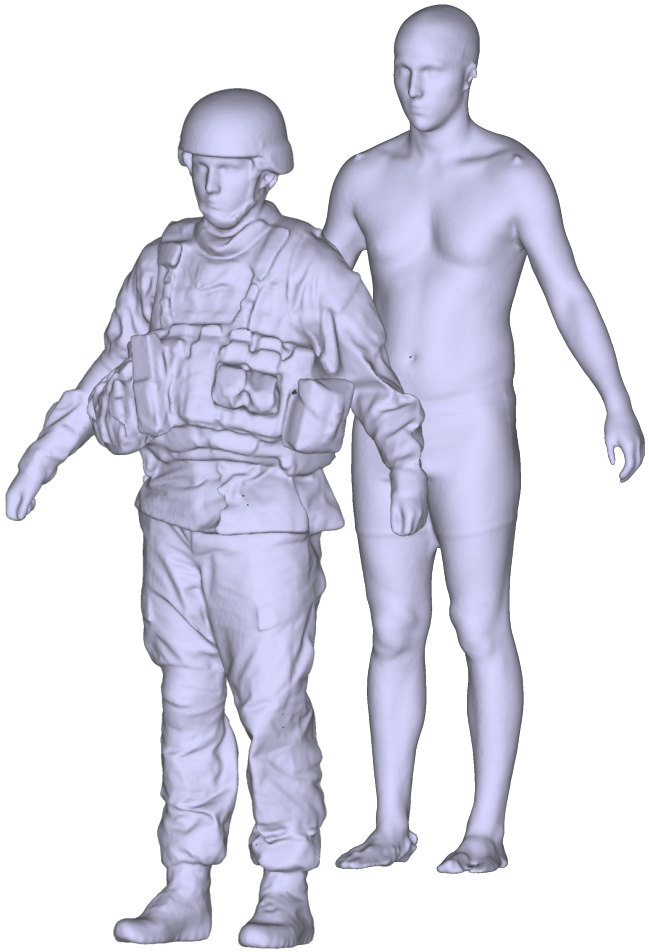
Additional Applications

Anything that fits close to the body:

- Glasses and goggles
- Head-worn displays
- Hearing protection
- Body armor
- Gloves
- Splints and other medical devices



Simulated plate interaction with parametric human model



Scans from UMTRI studies

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