Hand-Object Contact During Grasping: Capture, Analysis, and Applications

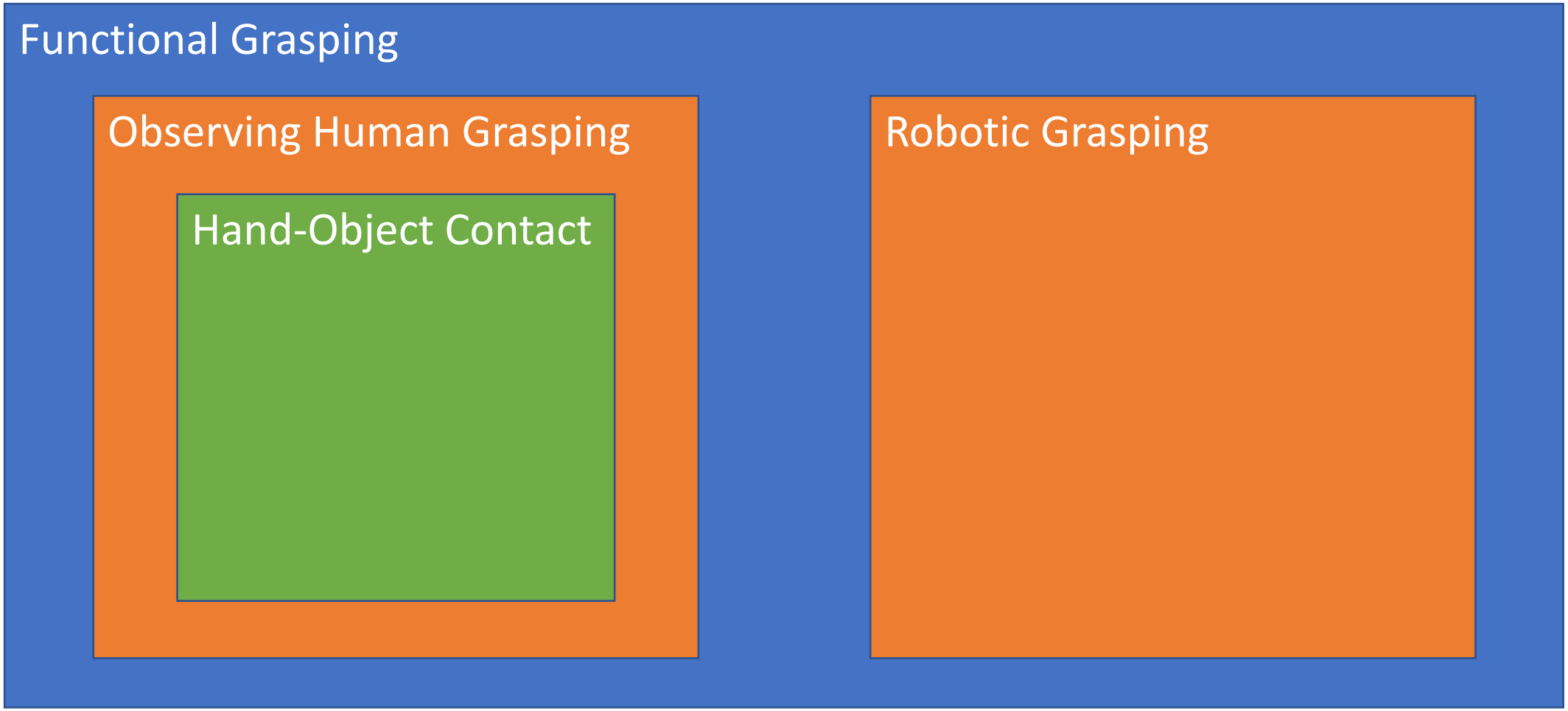
Samarth Brahmbhatt

https://samarth-robo.github.io

Postdoctoral Researcher, Intel Intelligent Systems Lab

Santa Clara, California, USA

Research Interests

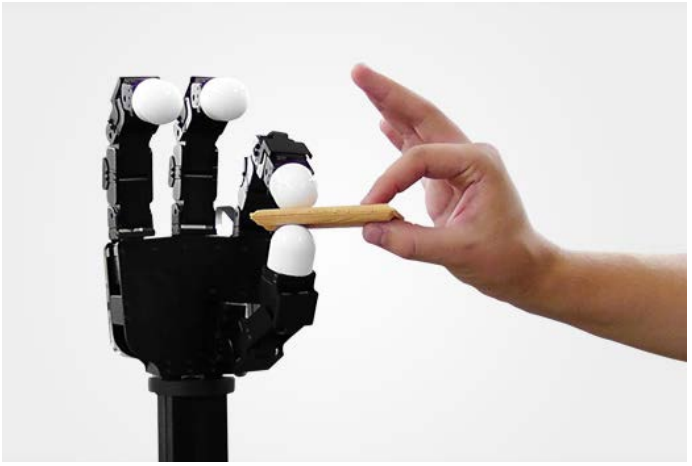


Motivation

Understanding hands in action

contact

Contact – Important for Physical Interactions

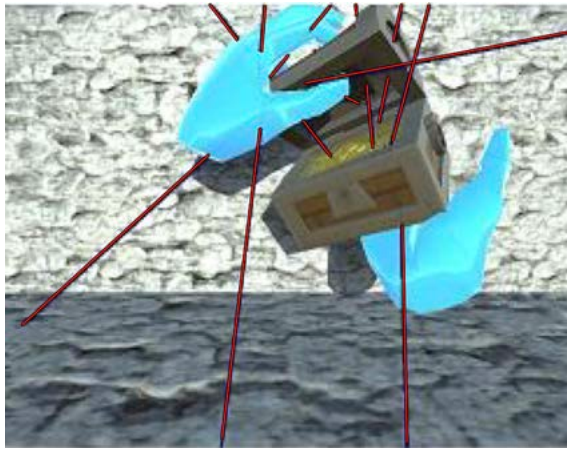


Contact Modeling – Possible Applications

Soft robotics – simulation & design

[Deimel et al, IJRR ‘16]

Realistic VR Experiences



[Höll et al, VR ‘18]

Assistive robots, grasping

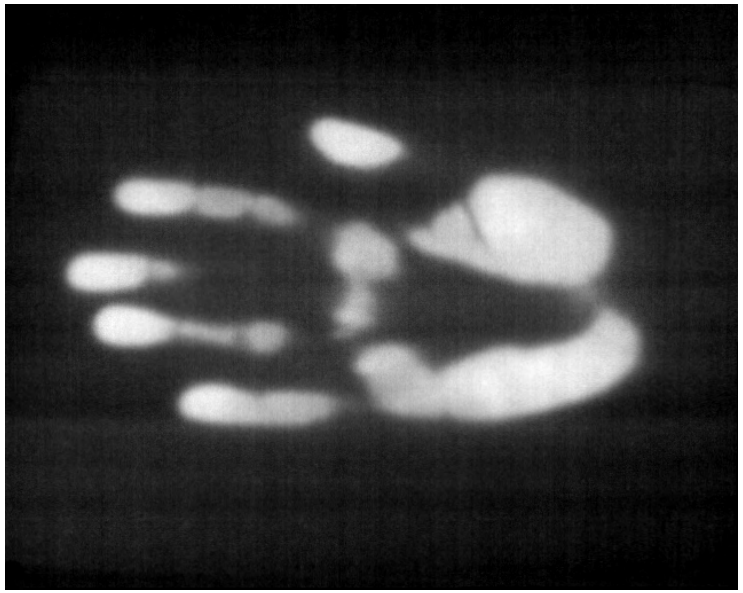
Why is observing contact difficult?

- Occlusion
- Model-based approach: difficult to fit hand model to real images

Capturing Contact

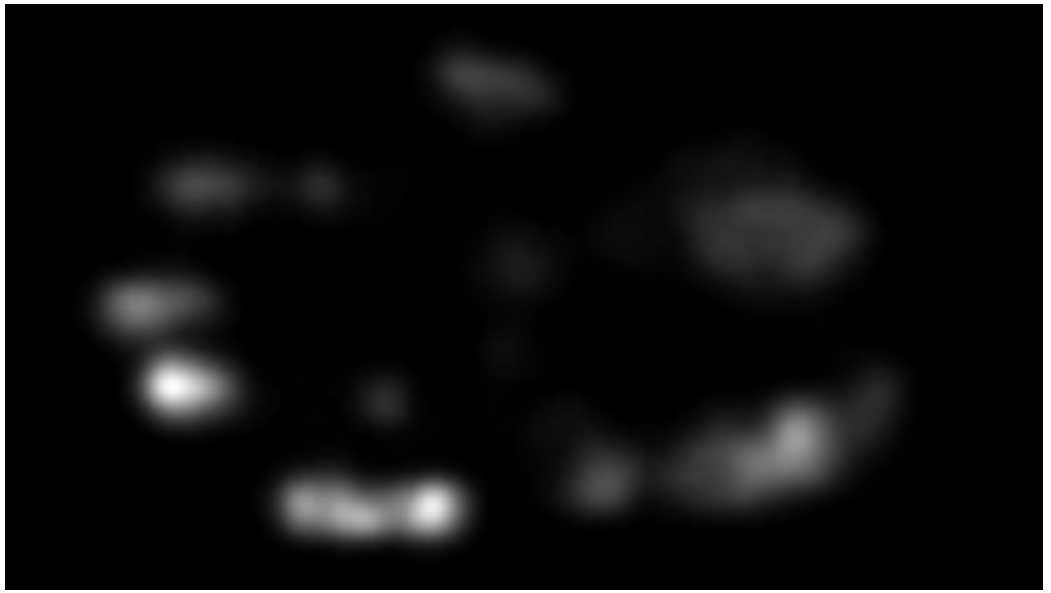
- Pressure is exerted
- Heat is transferred
  - (in solids) conduction > convection and radiation

Higher spatial resolution
Works for arbitrary surface shapes
Non-invasive



Thermal image

Focus on actual contact pressure



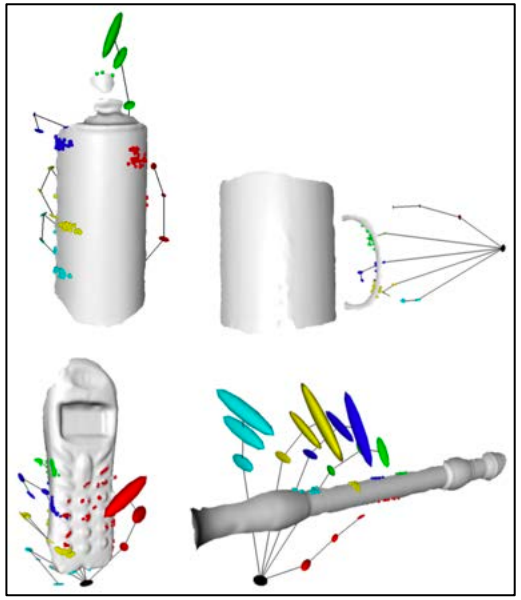
Pressure image from a Sensel Morph

ContactDB: Analyzing and Predicting Grasp Contact via Thermal Imaging

Samarth Brahmbhatt, Cusuh Ham, Charles C. Kemp, and James Hays

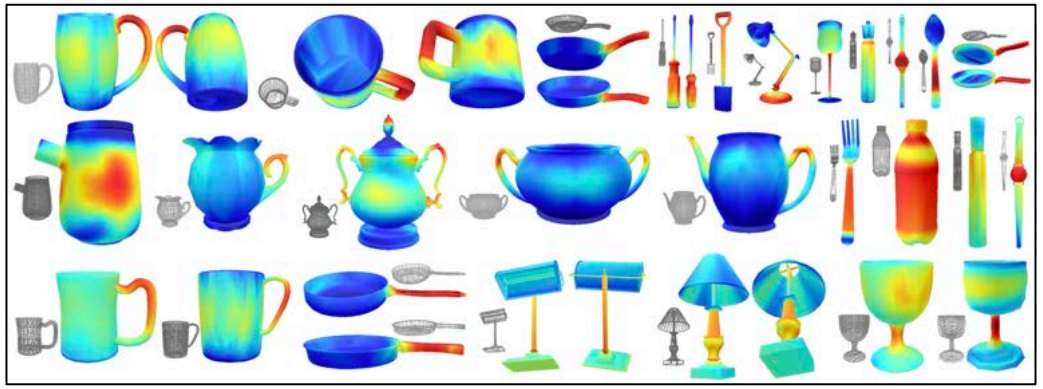
CVPR 2019

Related Work

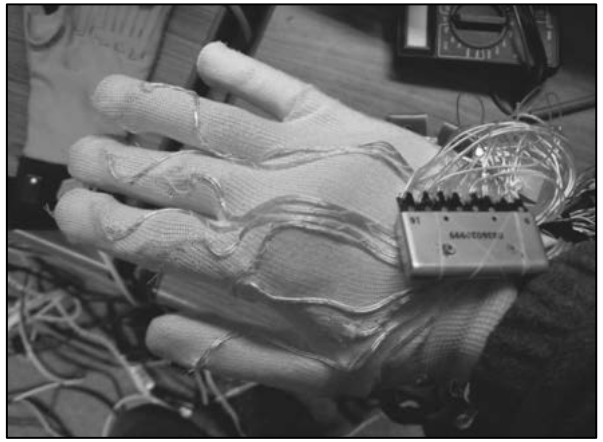


[Hamer et al, CVPR ‘10]

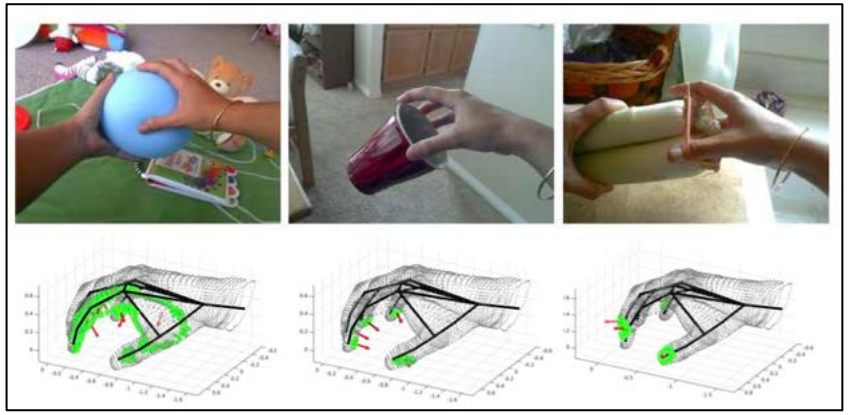
[Pham et al, T-PAMI ‘18]



[Lau et al, SIGGRAPH ‘16]

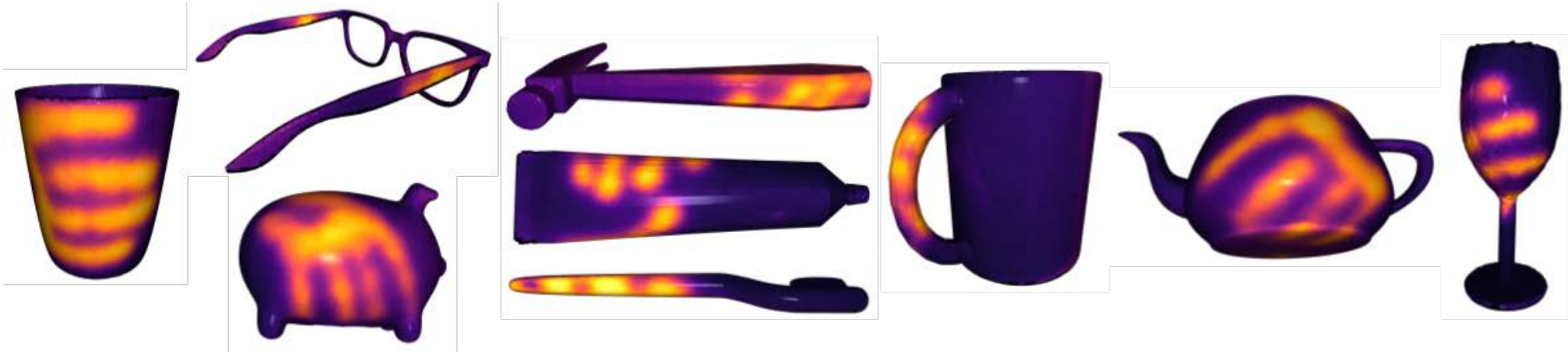


[Bernardin et al, T-RO ’05,
Sundaram et al, Nature ‘19]



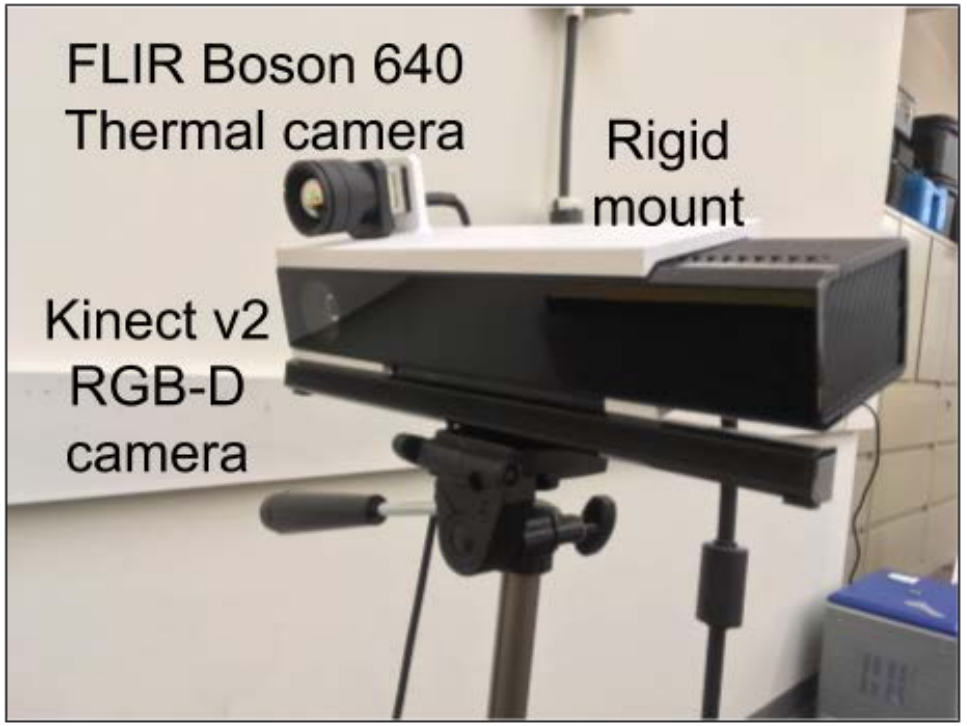
[Rogez et al, ICCV ‘15]

ContactDB



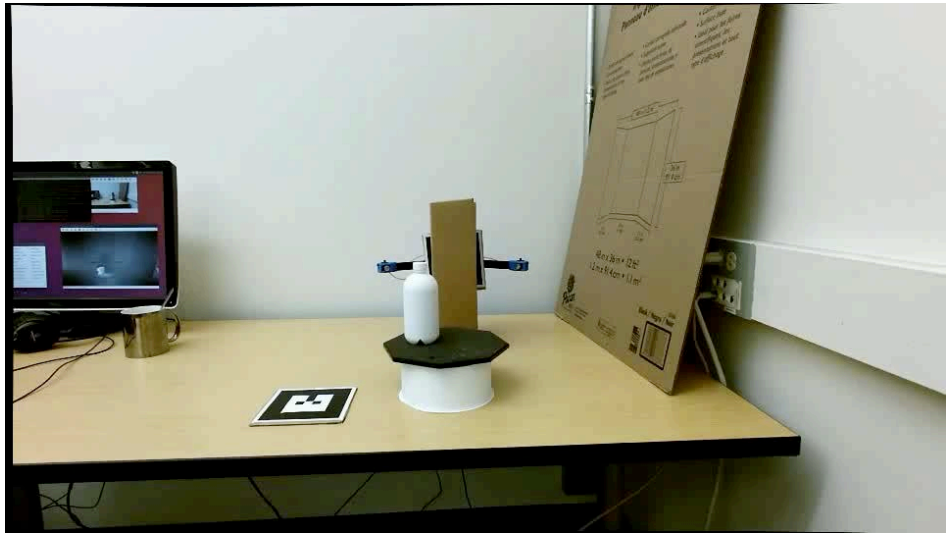
Observing Contact Through a Thermal Camera

Heat transfer from (warm) hand to object surface

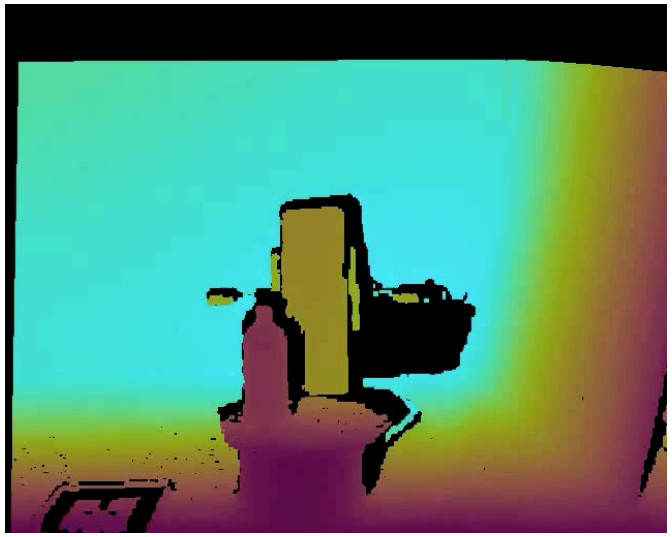


Data Stream

RGB



Depth



Thermal

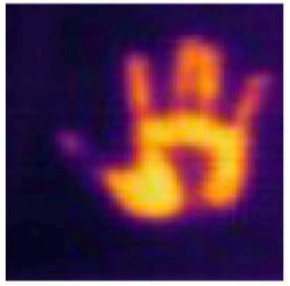
3D Printed Replicas of Household Objects

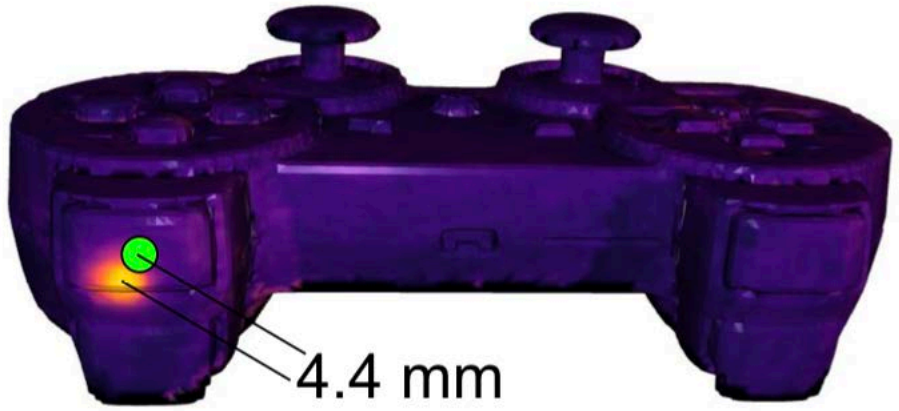
Heat Dissipation and Texture Mapping Accuracy

0 s

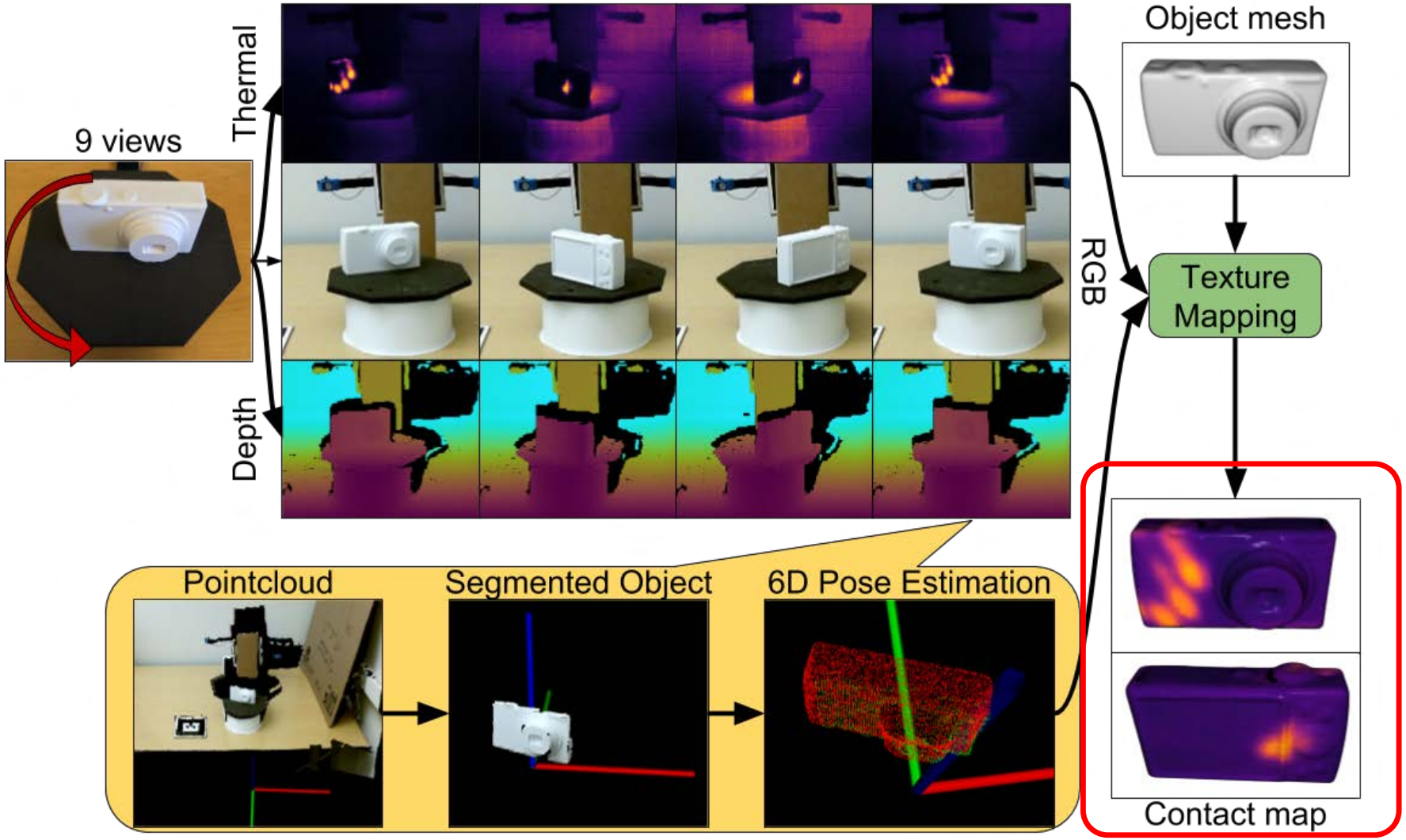
18 s

35 s

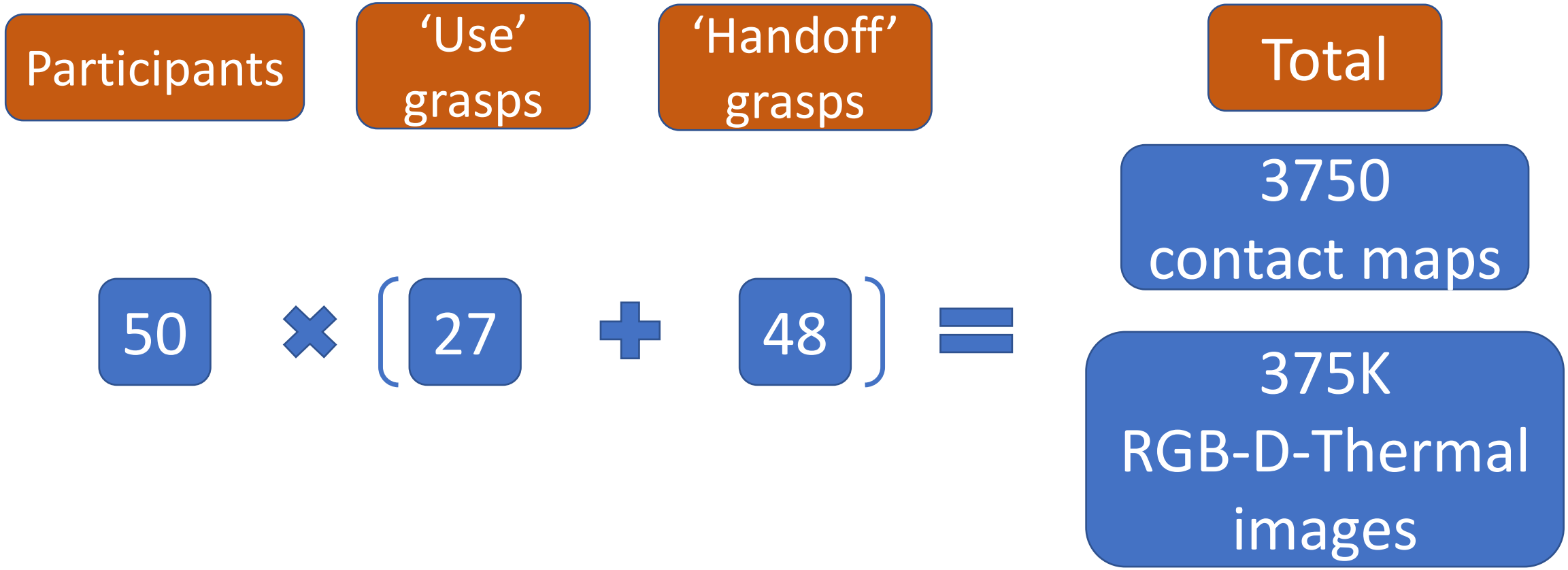




Texture Mapping to create **Contact Maps**

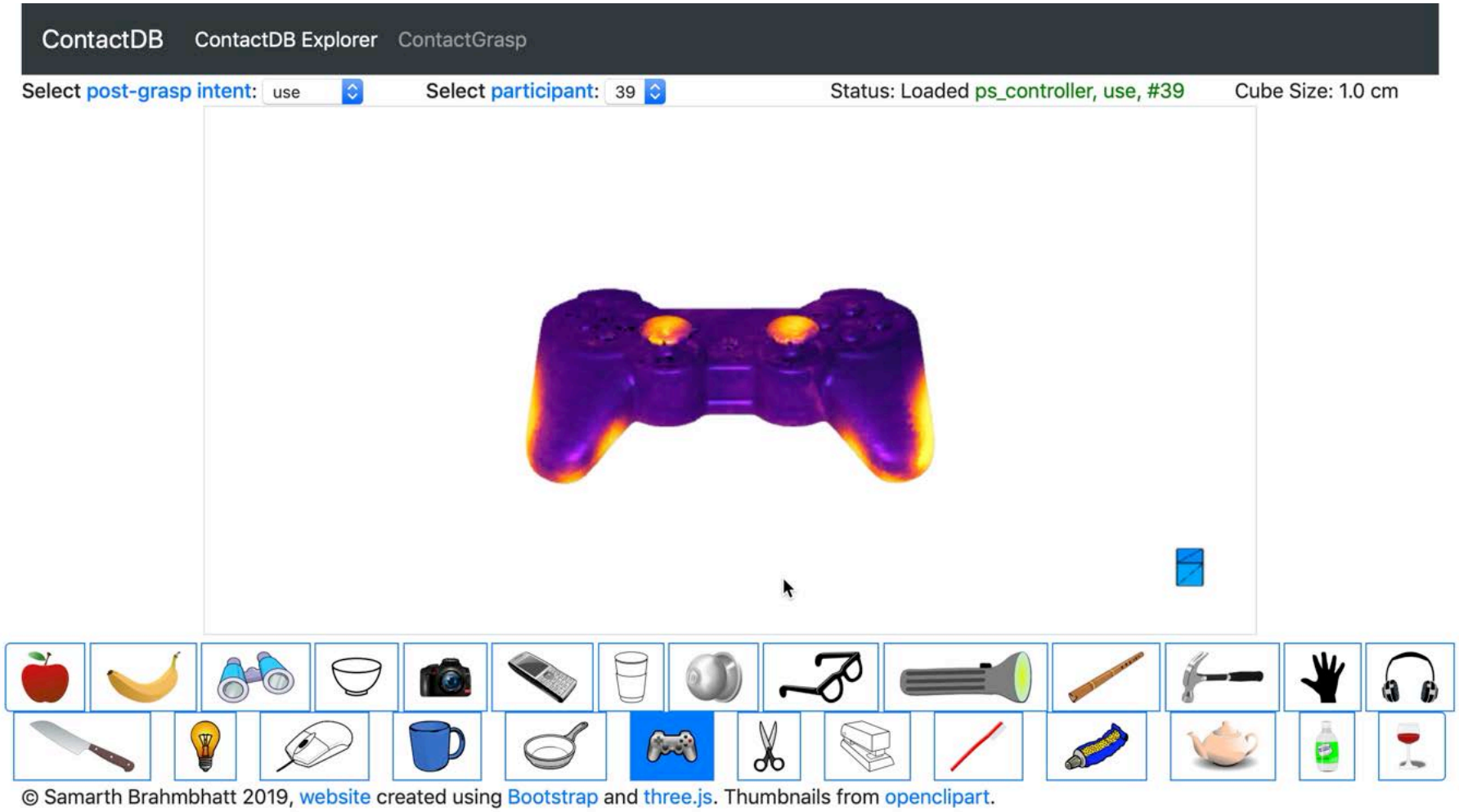


The ContactDB Dataset



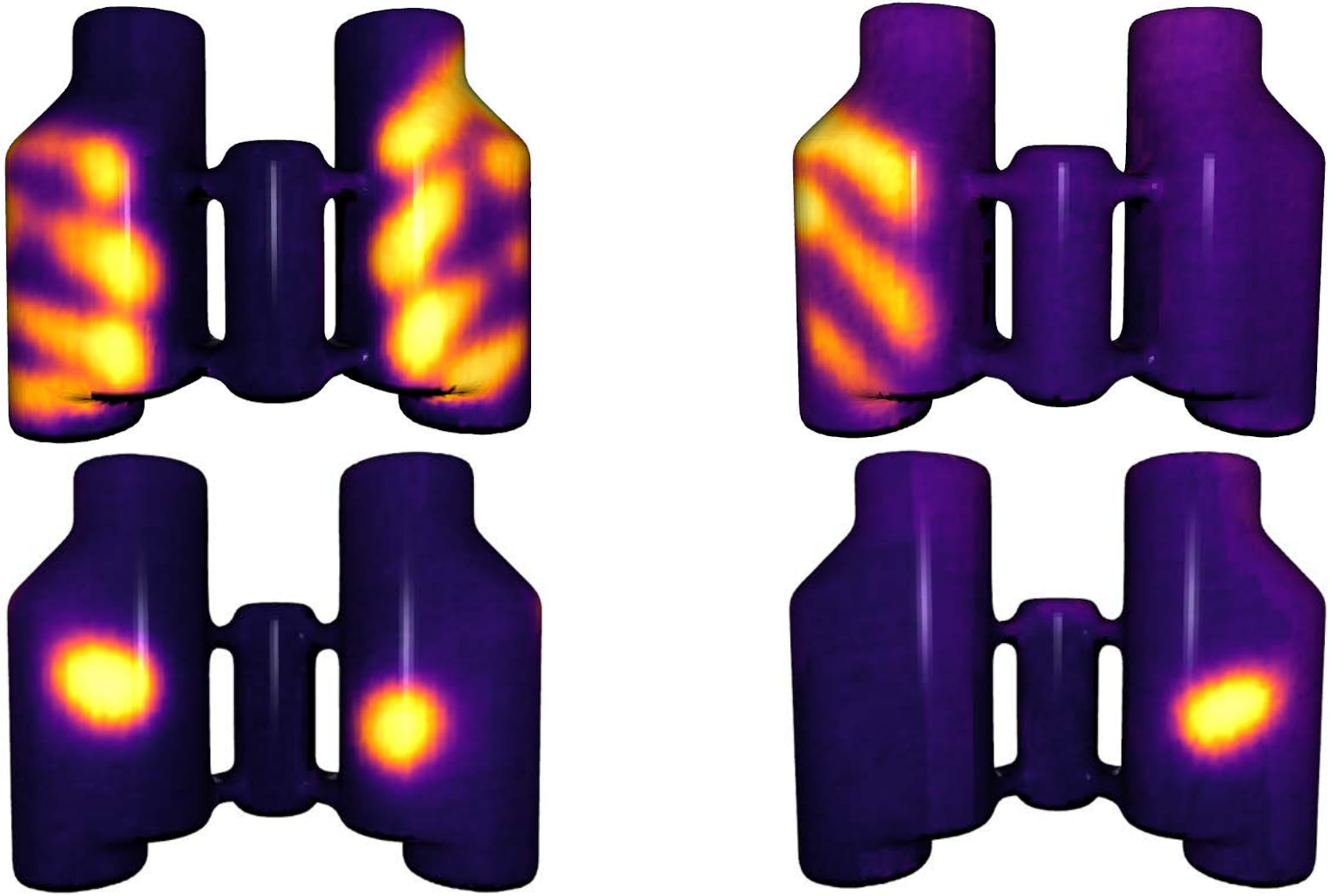
Data, Code and Models

https://contactdb.cc.gatech.edu



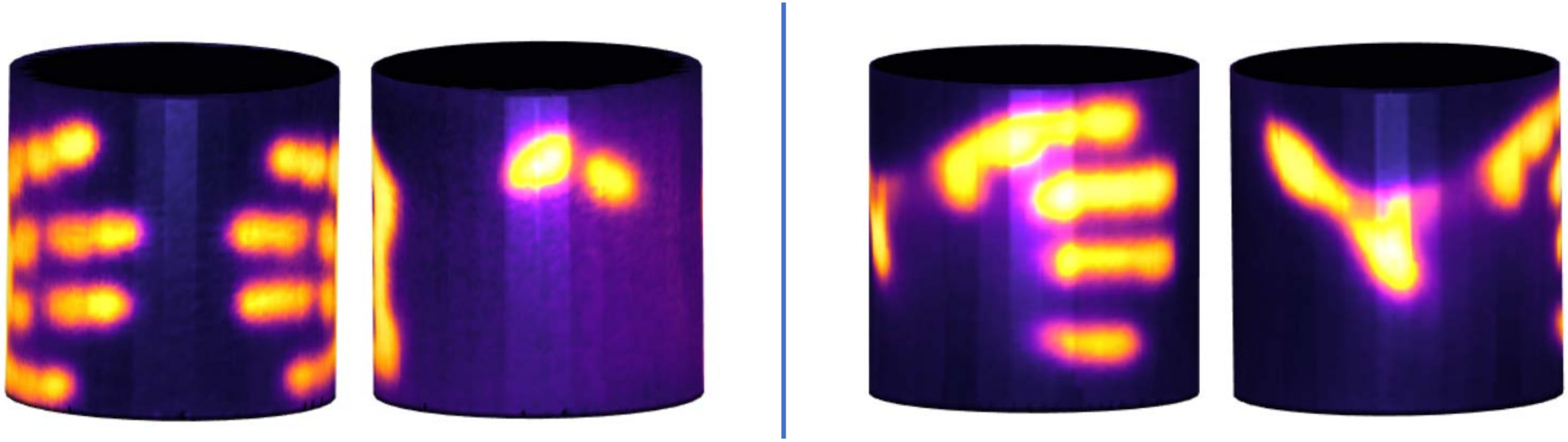
Effect of Functional Intent

Use



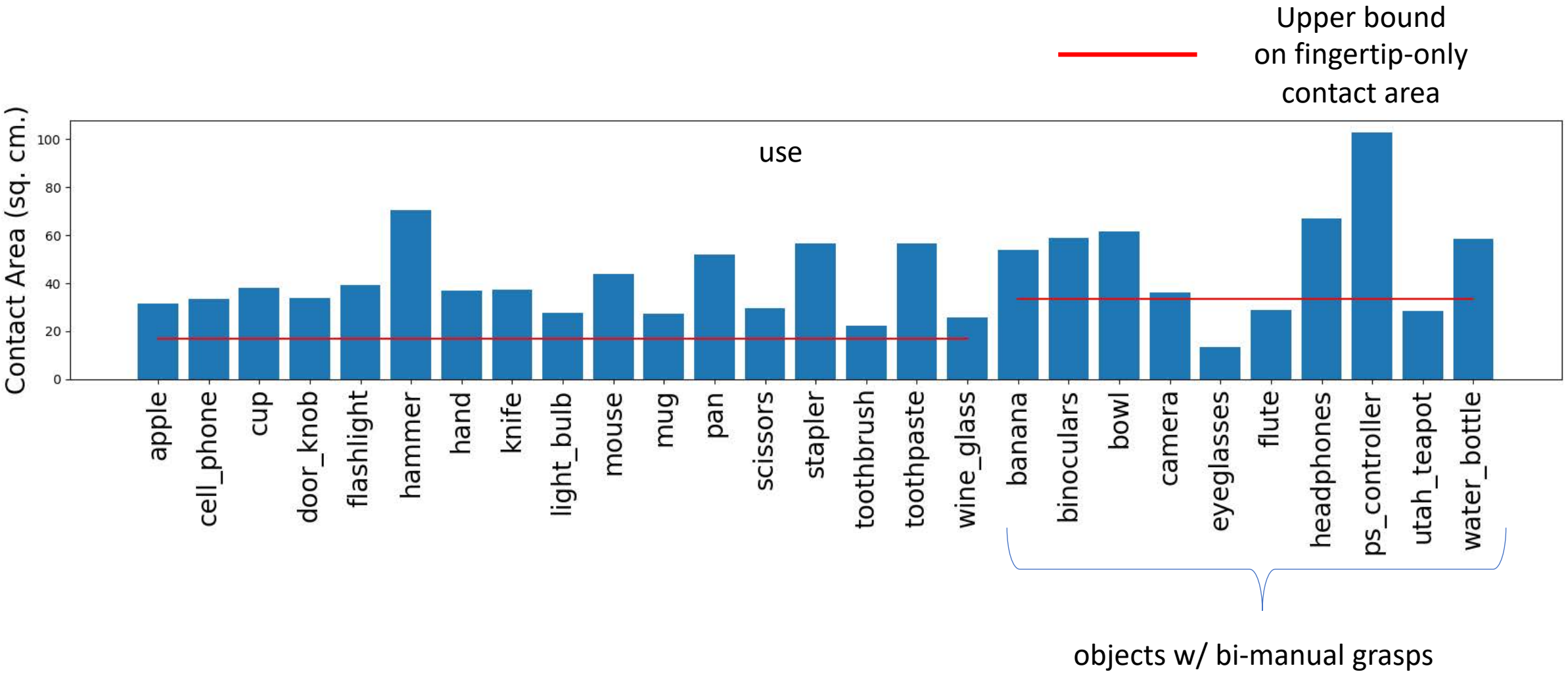
Handoff

Effect of Relative Hand Size

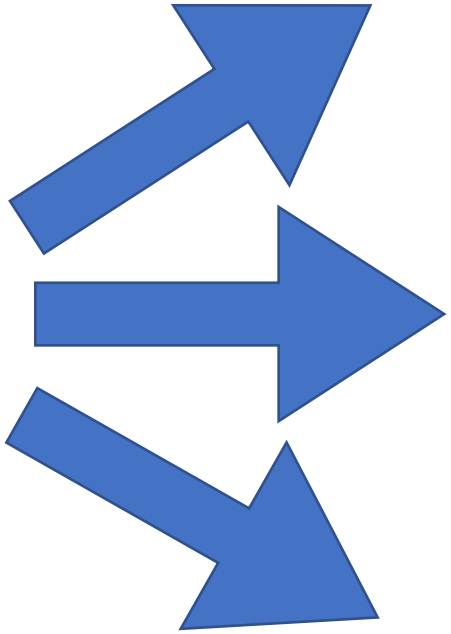


Larger Hand

How much of the contact is at fingertips?

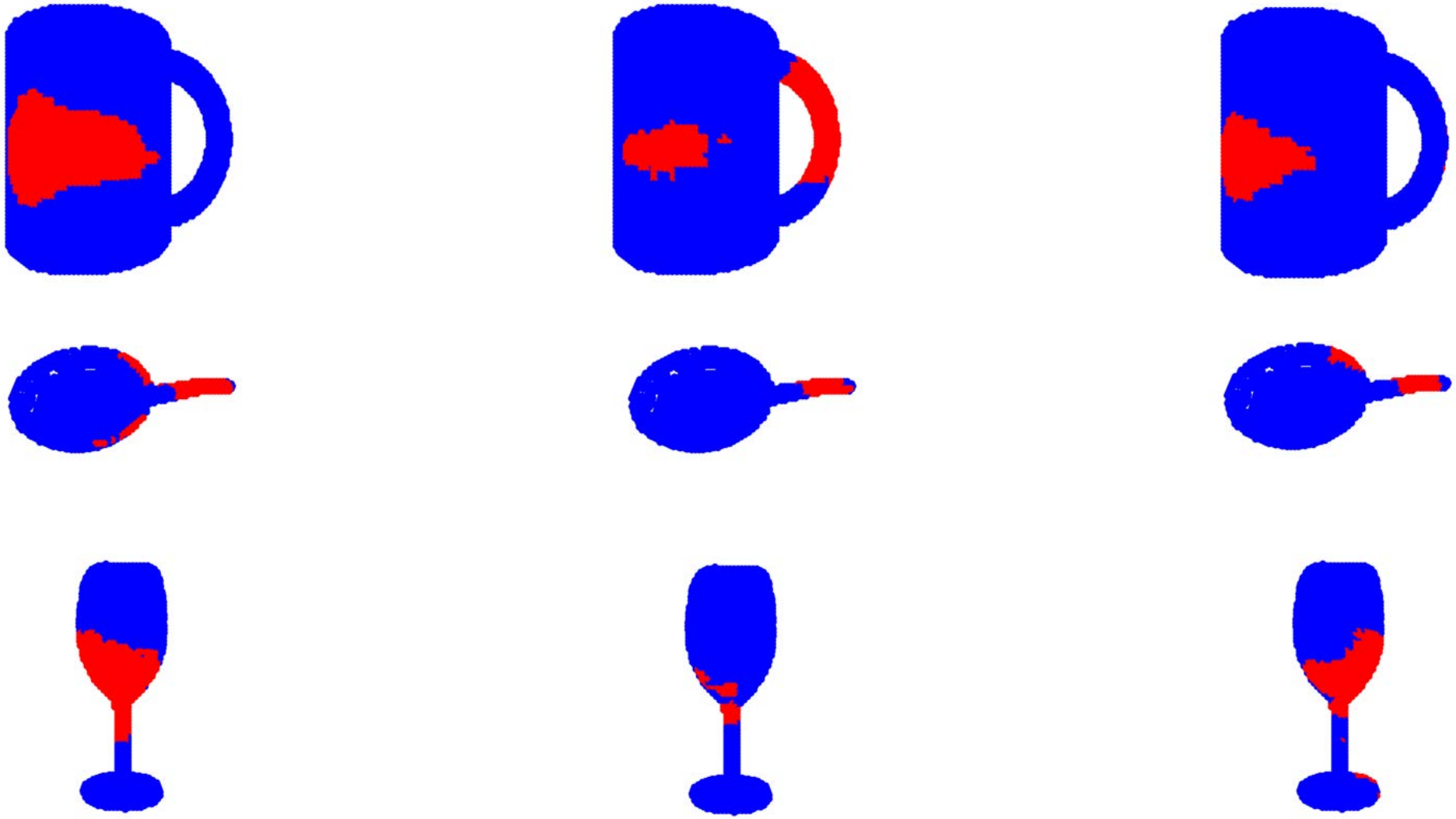


Predicting Contact Maps from Object Shape

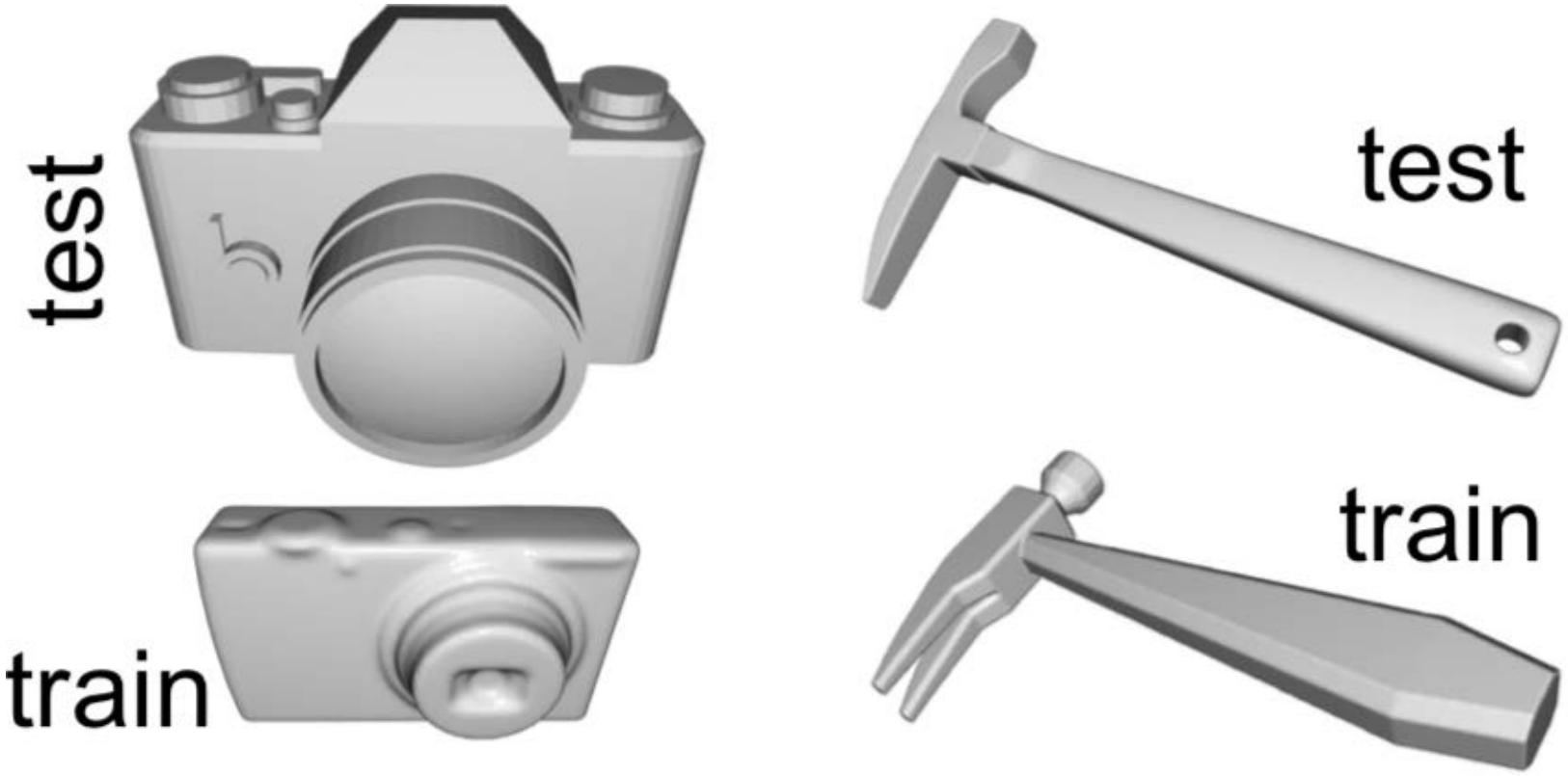


Generalization: Unseen Object **Classes**

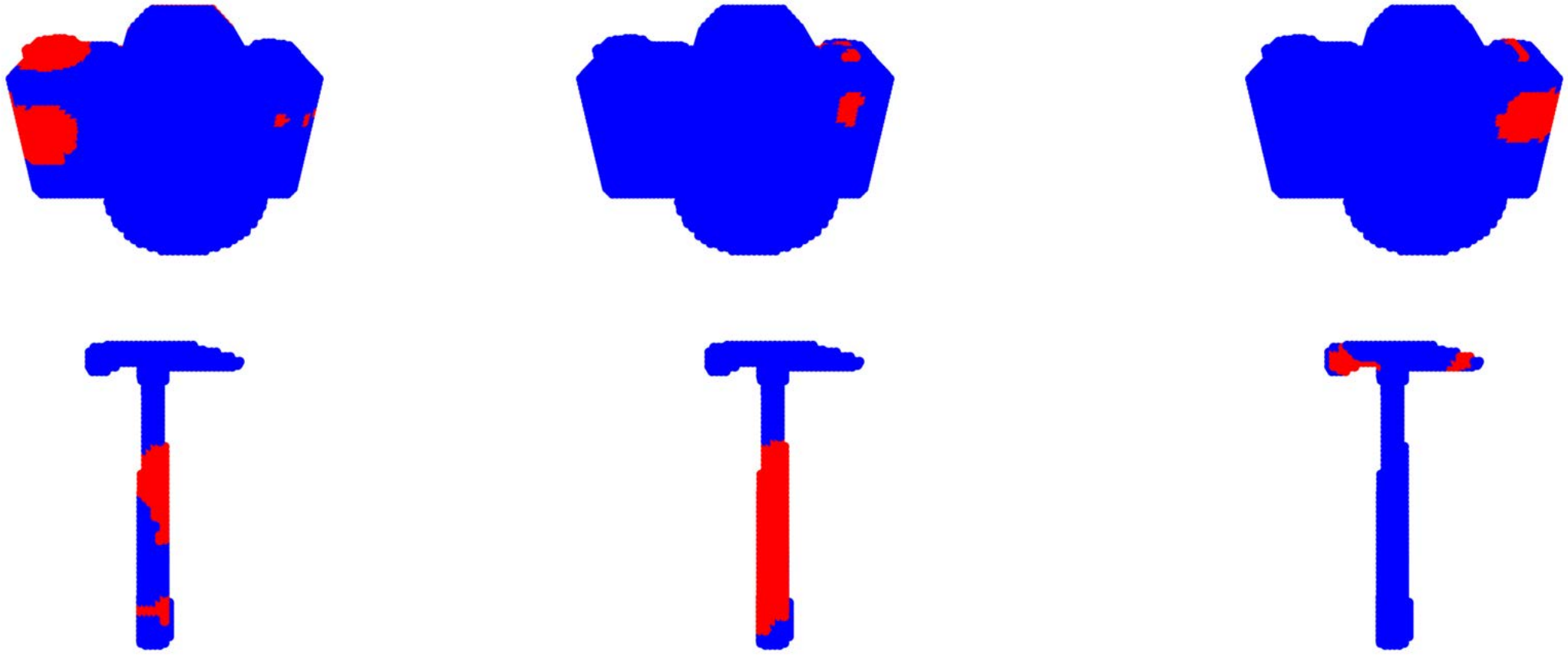
Model: “use”, DiverseNet, Voxel-grid



Generalization: Unseen Object **Shapes**



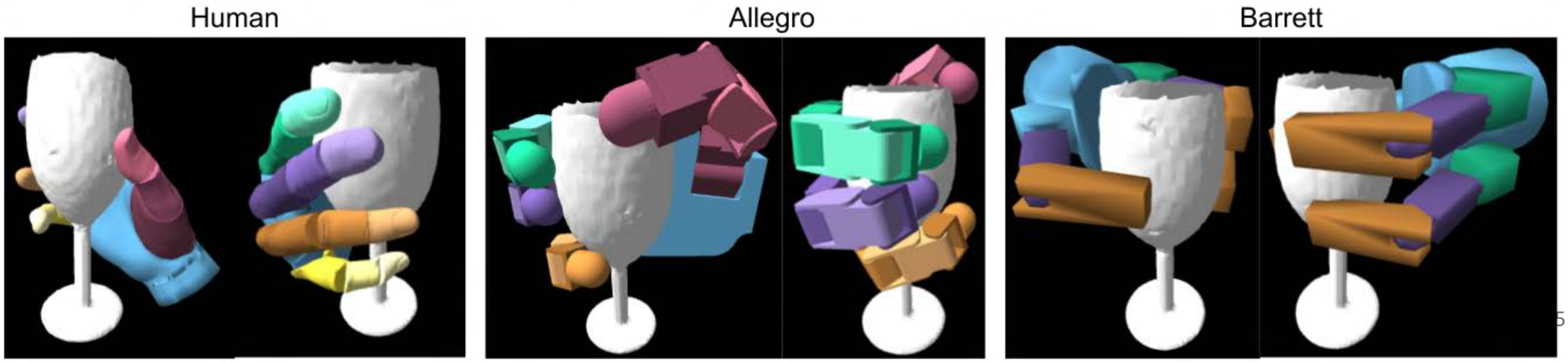
Generalization: Unseen Object **Shapes**



ContactGrasp: Functional Multi-finger Grasp Synthesis from Contact

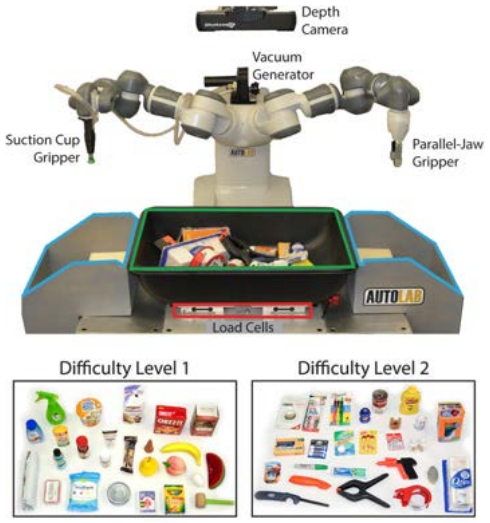
Samarth Brahmbhatt, Ankur Handa, James Hays, and Dieter Fox

IROS 2019

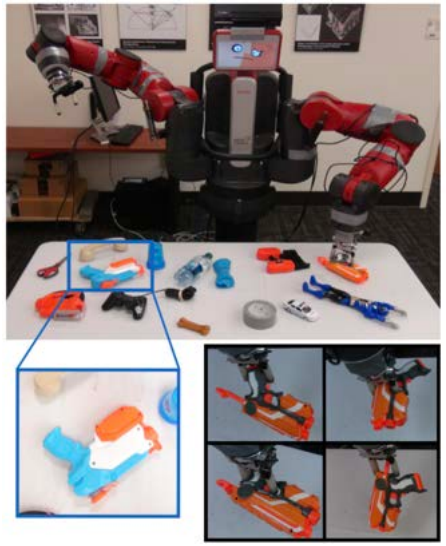


Progress in Robotic Grasping

Bin Picking



DexNet 4.0
[Mahler et al. Science Robotics ‘19]



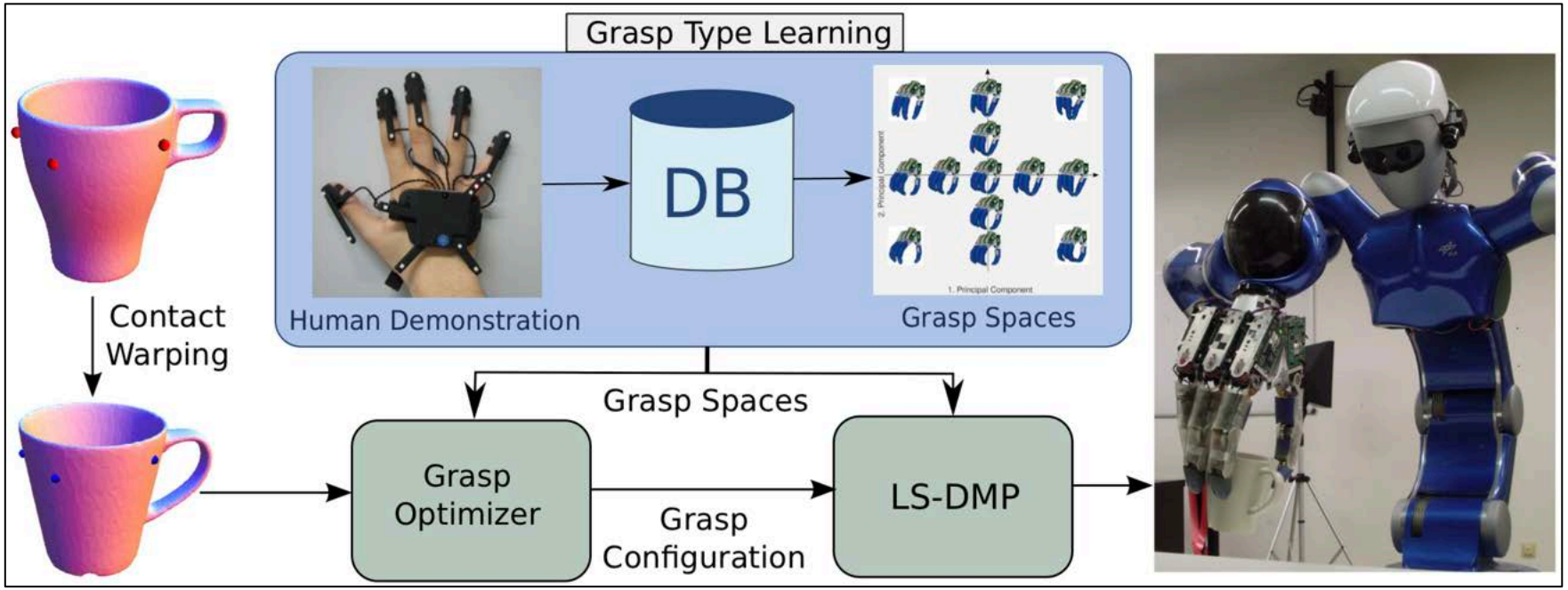
[Pinto et al. ICRA ‘16]

Functional Grasping

??

Learning from Human Demonstrations: Joint Space

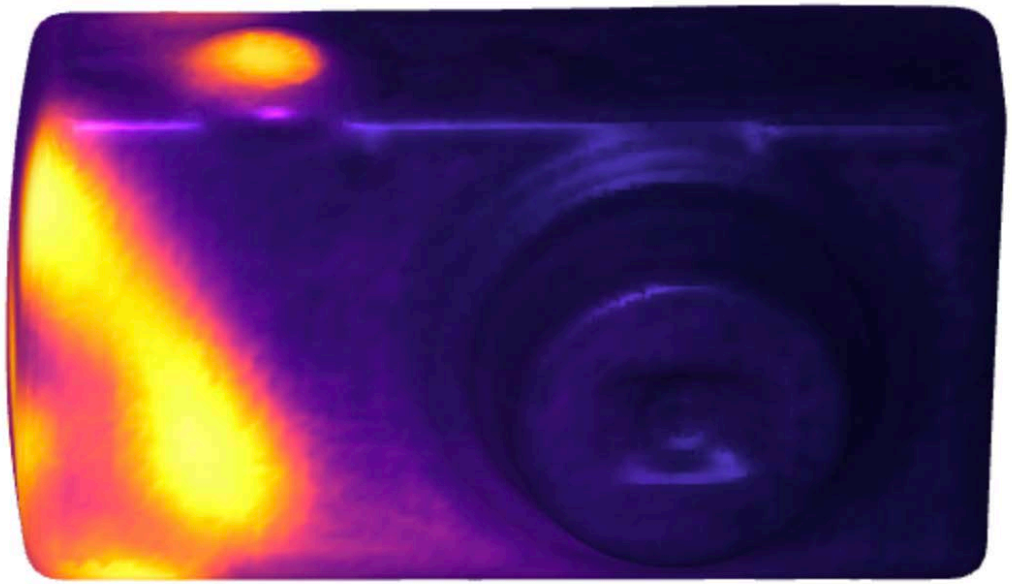
Instrumented Hands, Hard-coded transformation to target robot hand



Ben Amor et al[1]

[1] Amor, Heni Ben, et al. "Generalization of human grasping for multi-fingered robot hands." 2012 IEEE/RSJ International Conference on Intelligent Robots and Systems. IEEE, 2012.

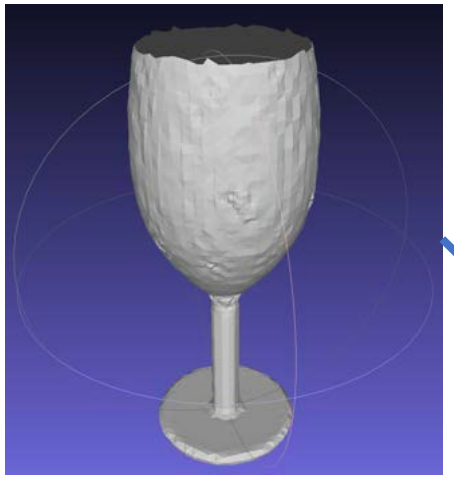
Learning from Human Demonstrations: Contact Space



contact map

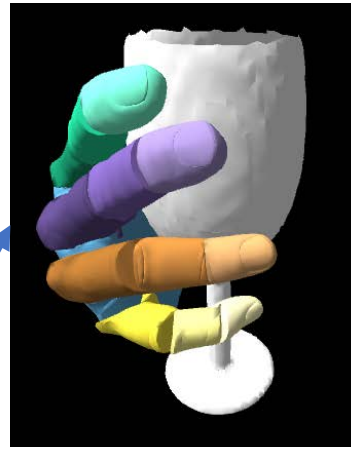
Problem Definition

Object geometry

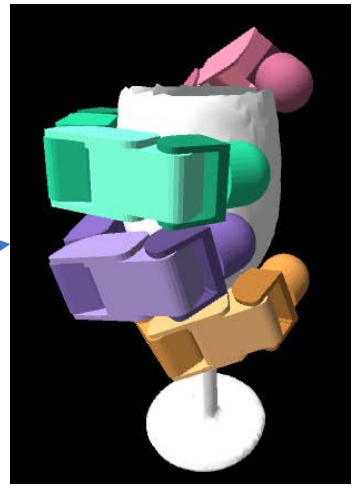


Contact map

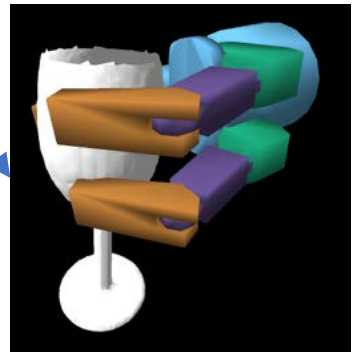
ContactGrasp



Human Hand grasp

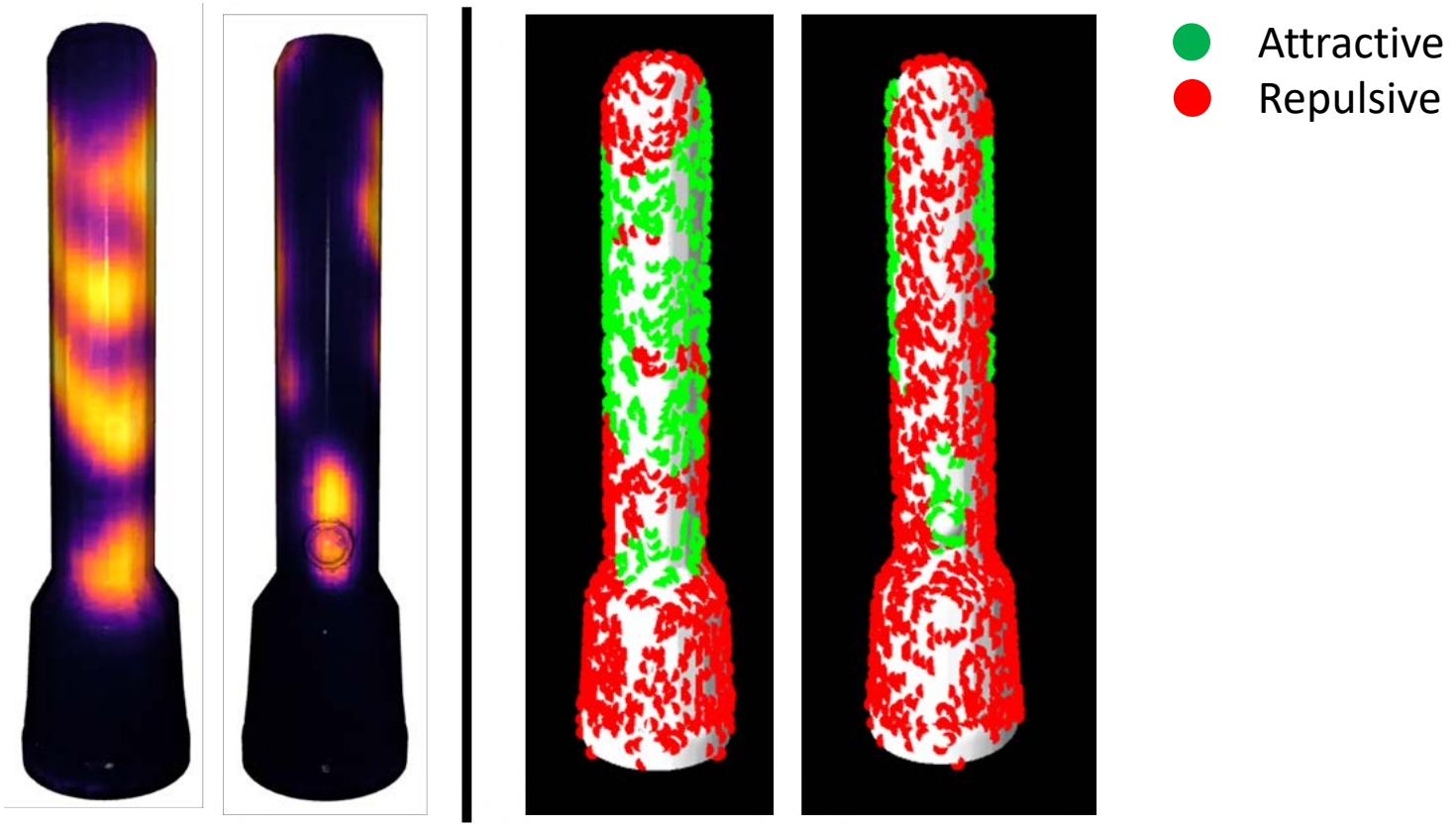


Allegro Hand grasp



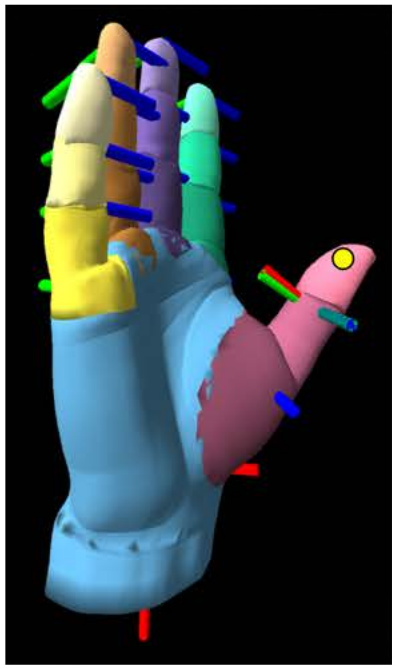
Barrett Hand grasp

Contact Model



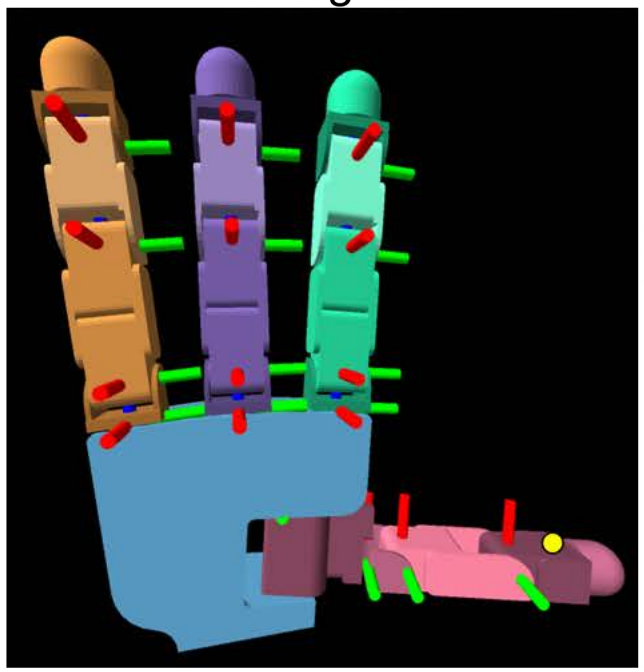
End-Effectors

Human



20 joints

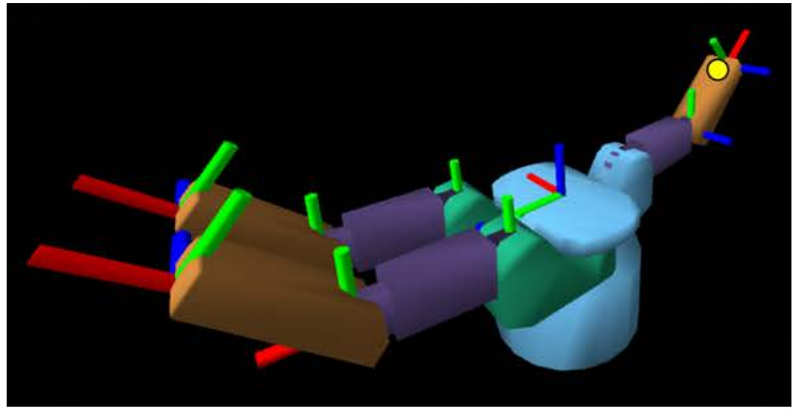
Allegro



16 joints

thumb contact point

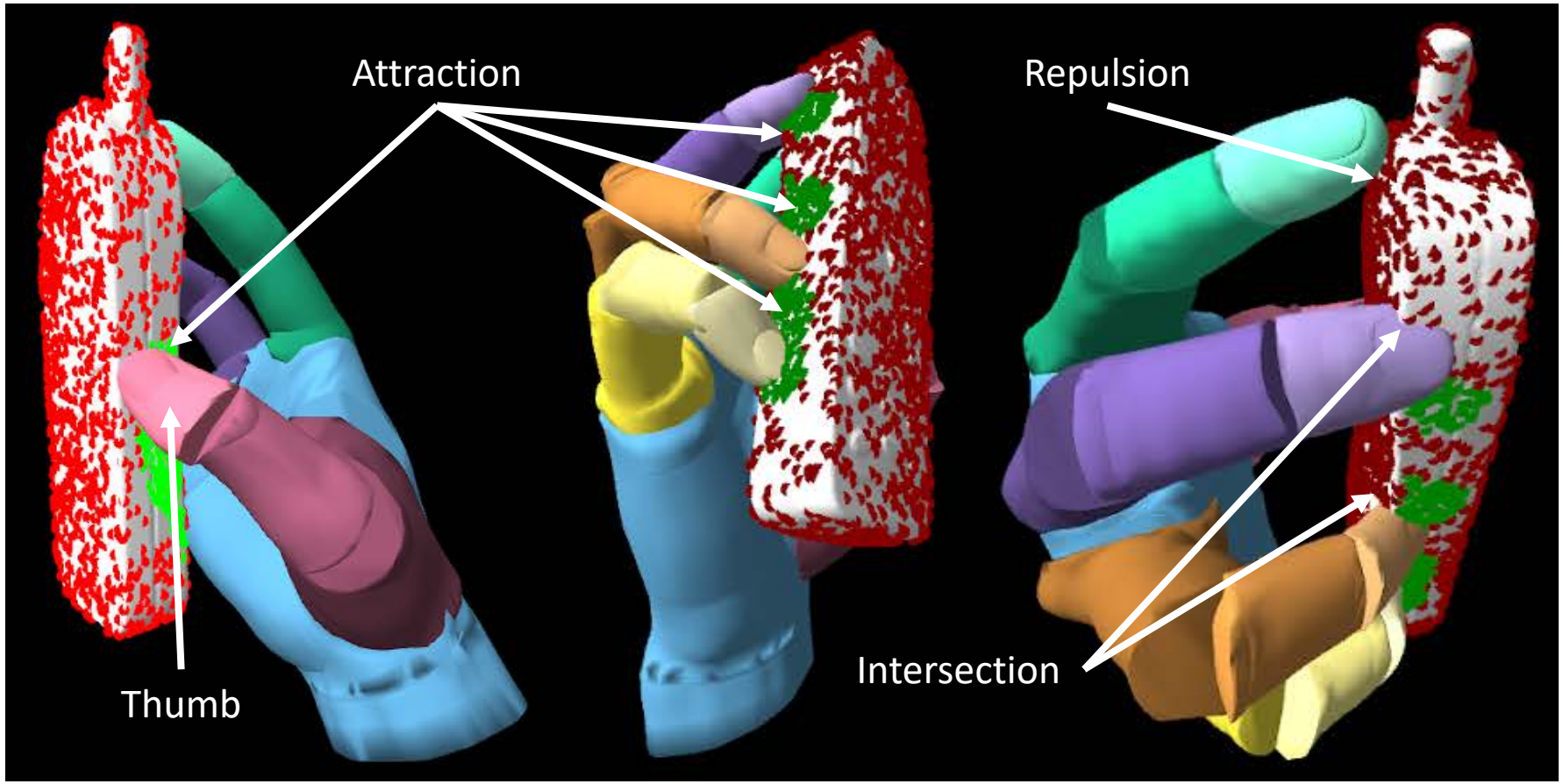
Barrett



4 joints

Hand pose Φ = (6-DOF palm pose, joint angles)

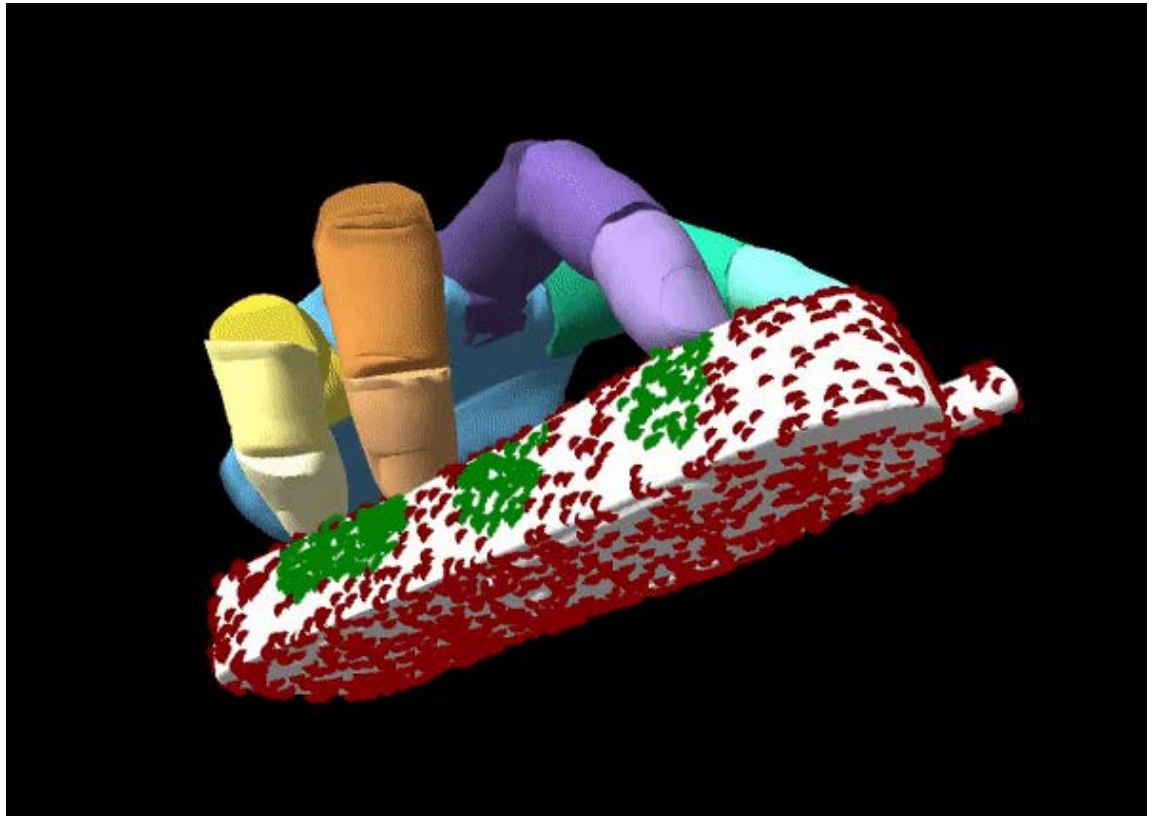
Grasp Optimization

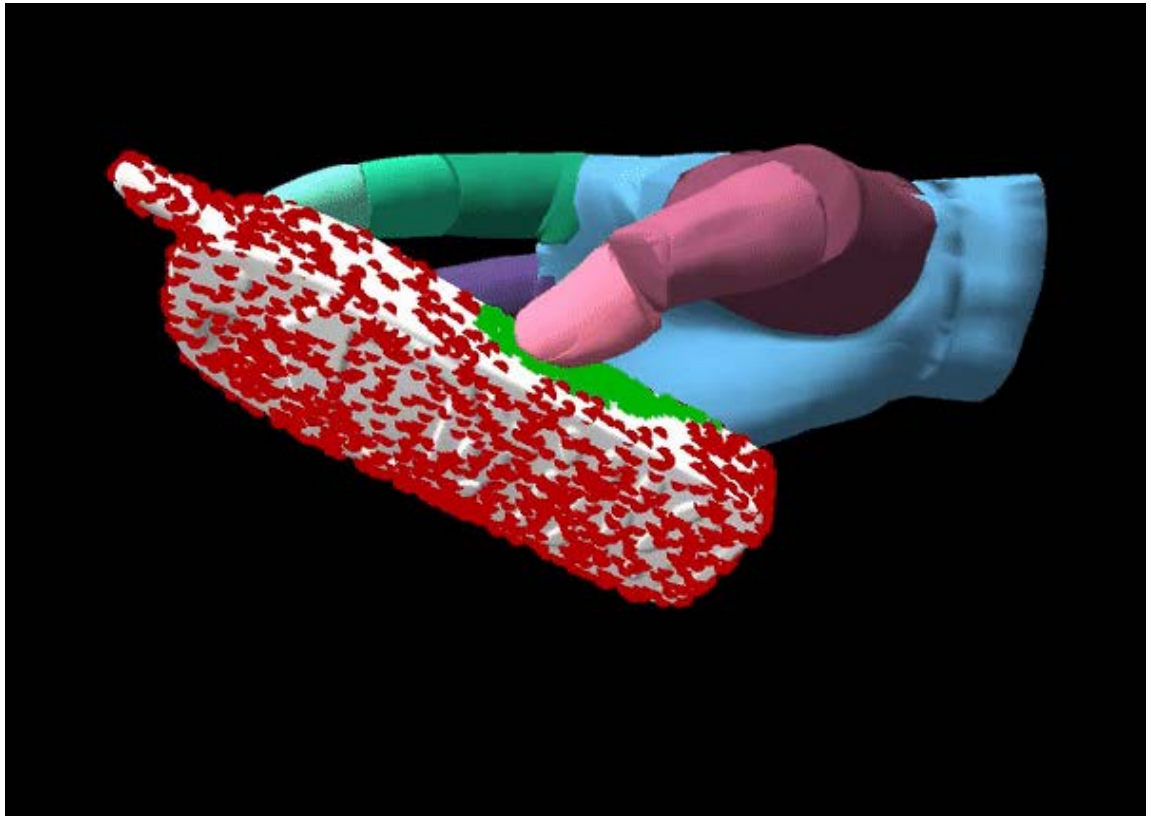


$$L(\Phi|\mathbf{c}) = L_{grasp}(\Phi|\mathbf{c}) + L_{int}(\Phi) + L_{thumb}(\Phi)$$

Φ: hand pose
c: contact map

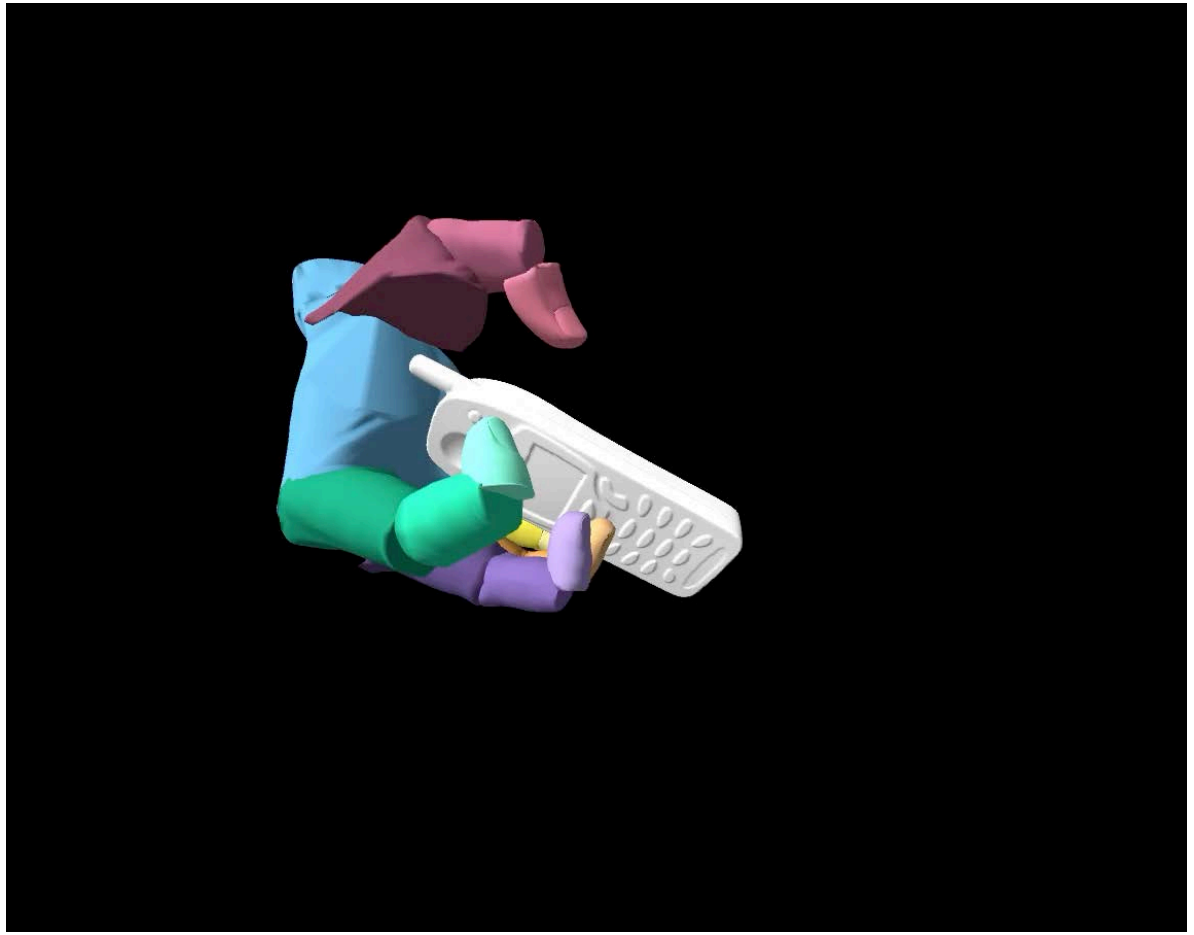
Grasp Optimization





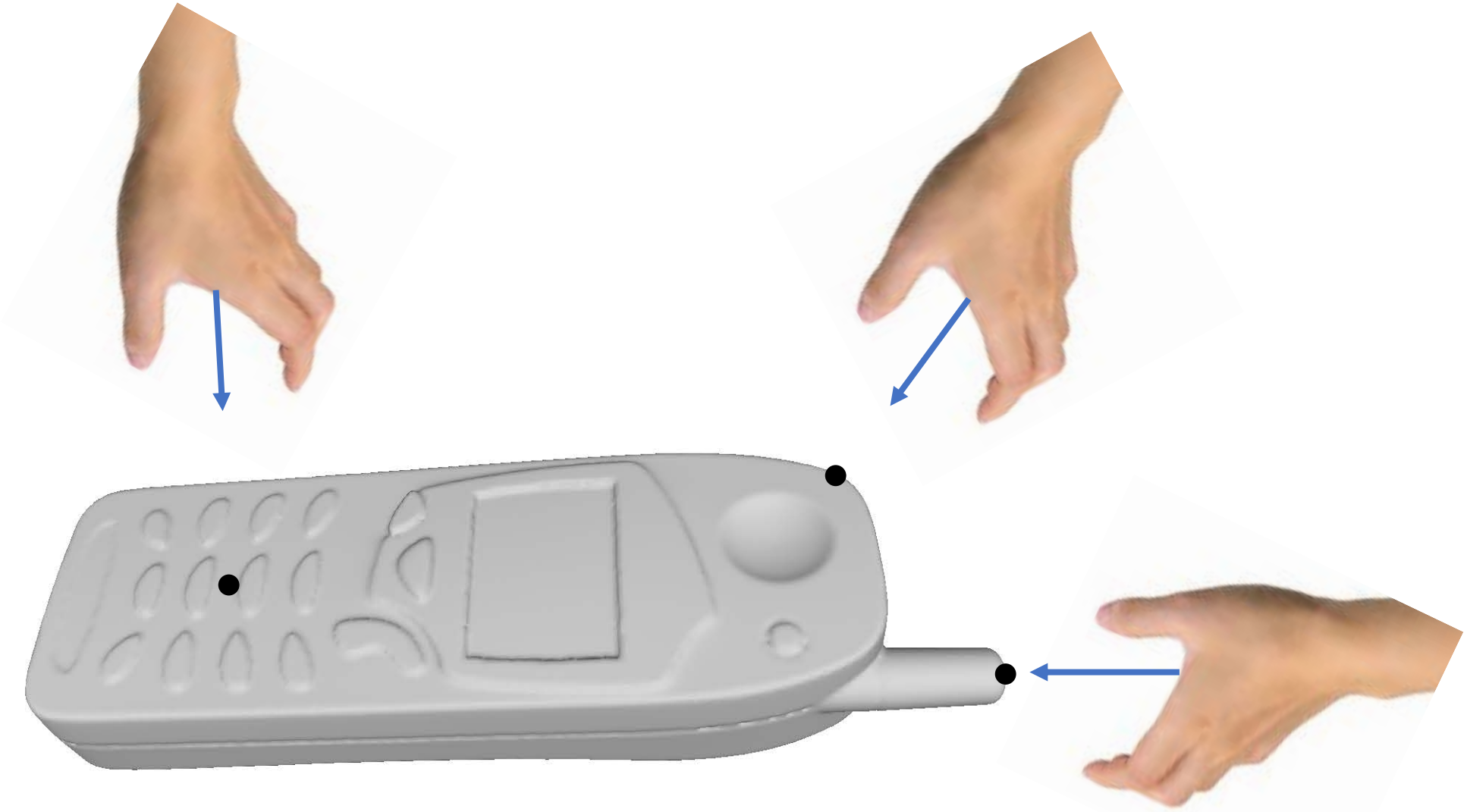
Initializing the Optimization

- Sample grasps using the GraspIt![1] Eigengrasp Planner



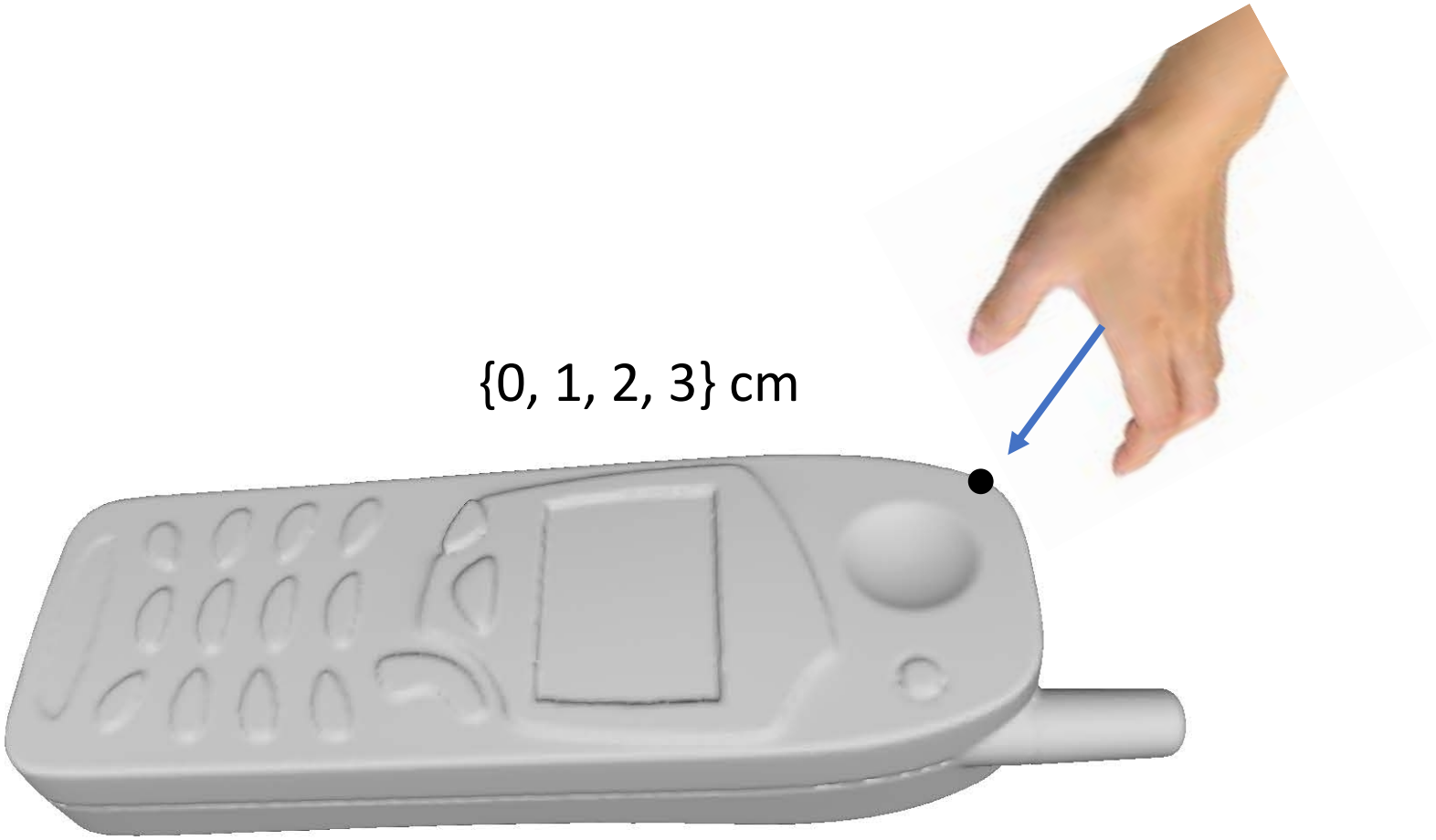
[1] “Dimensionality reduction for hand-independent dexterous robotic grasping” - Matei Ciocarlie, Corey Goldfeder, and Peter Allen – IROS ‘07

Initializing the Optimization: Approach Point and Direction

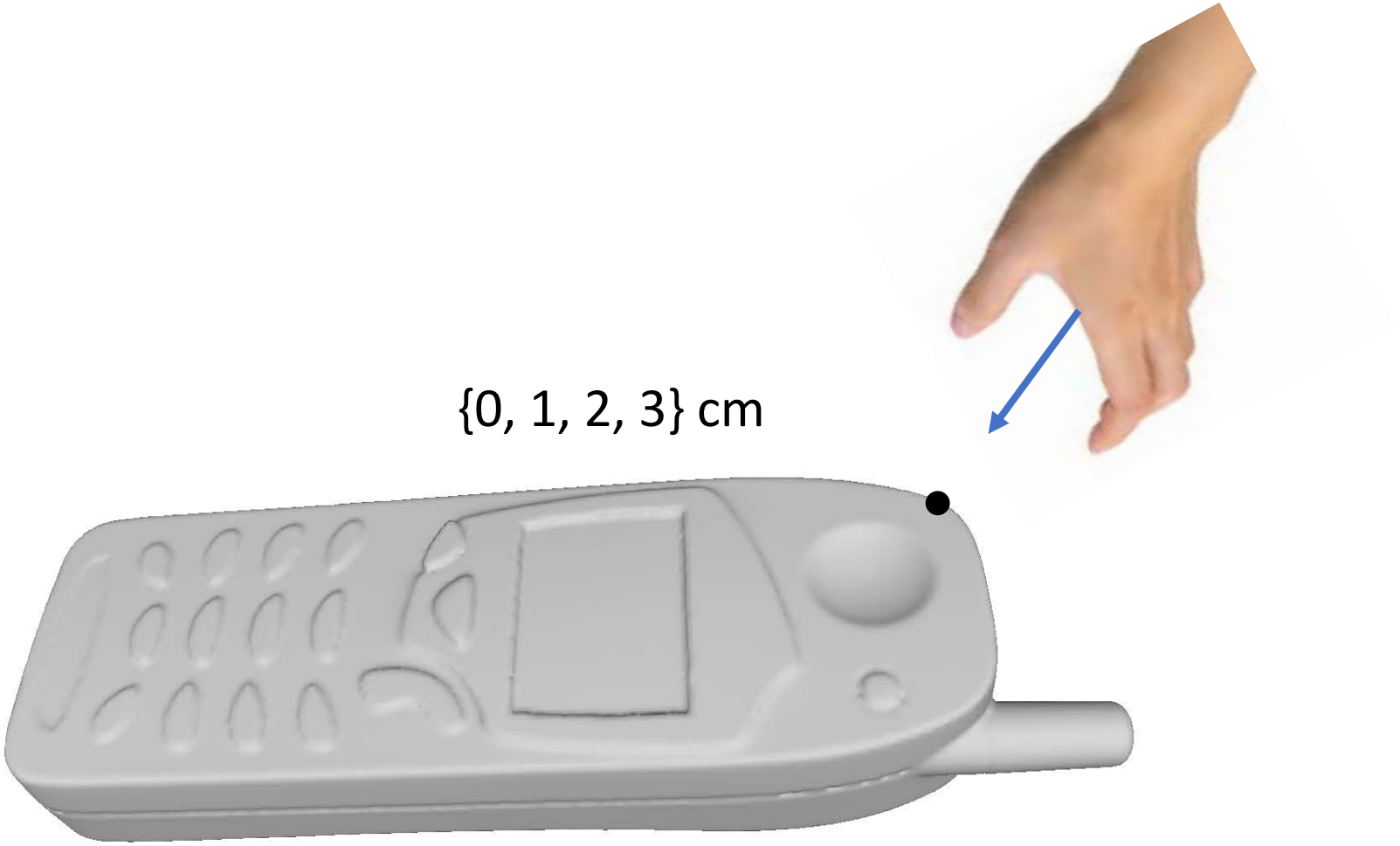


Initializing the Optimization: Approach Roll Angle

Initializing the Optimization: Approach Distance

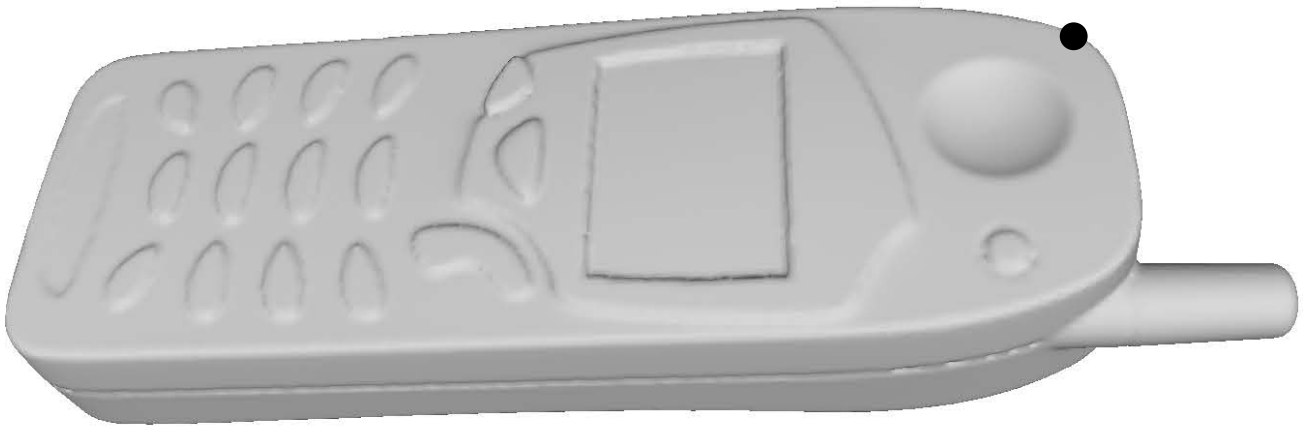


Initializing the Optimization: Approach Distance



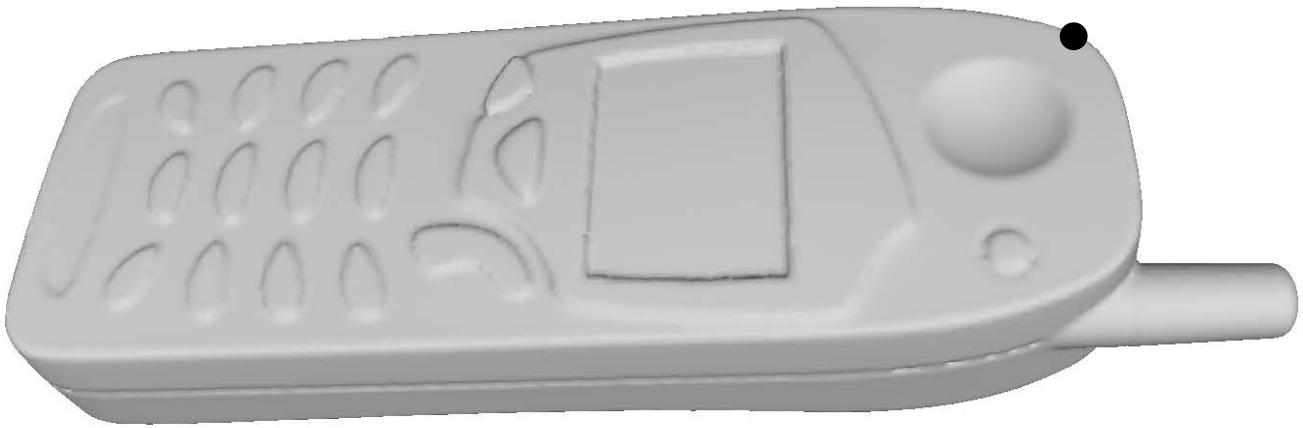
Initializing the Optimization: Approach Distance

{0, 1, 2, 3} cm

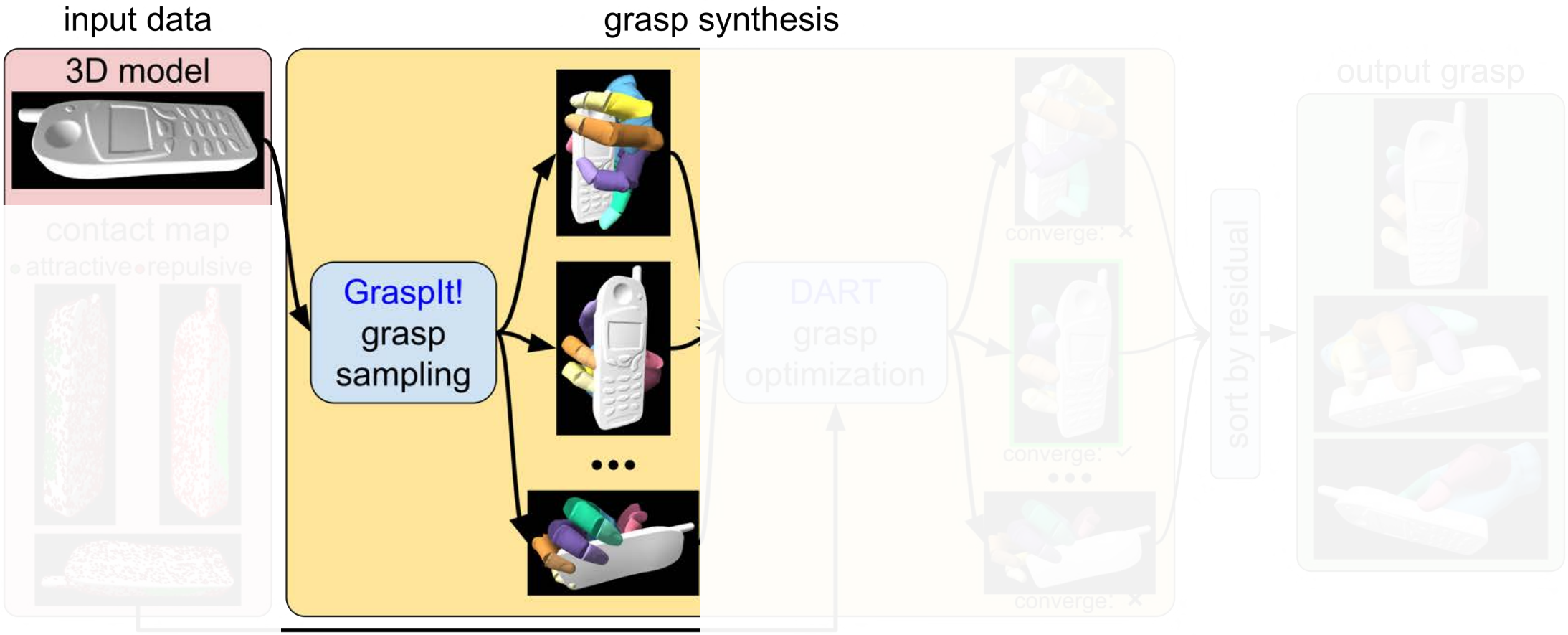


Initializing the Optimization: Approach Distance

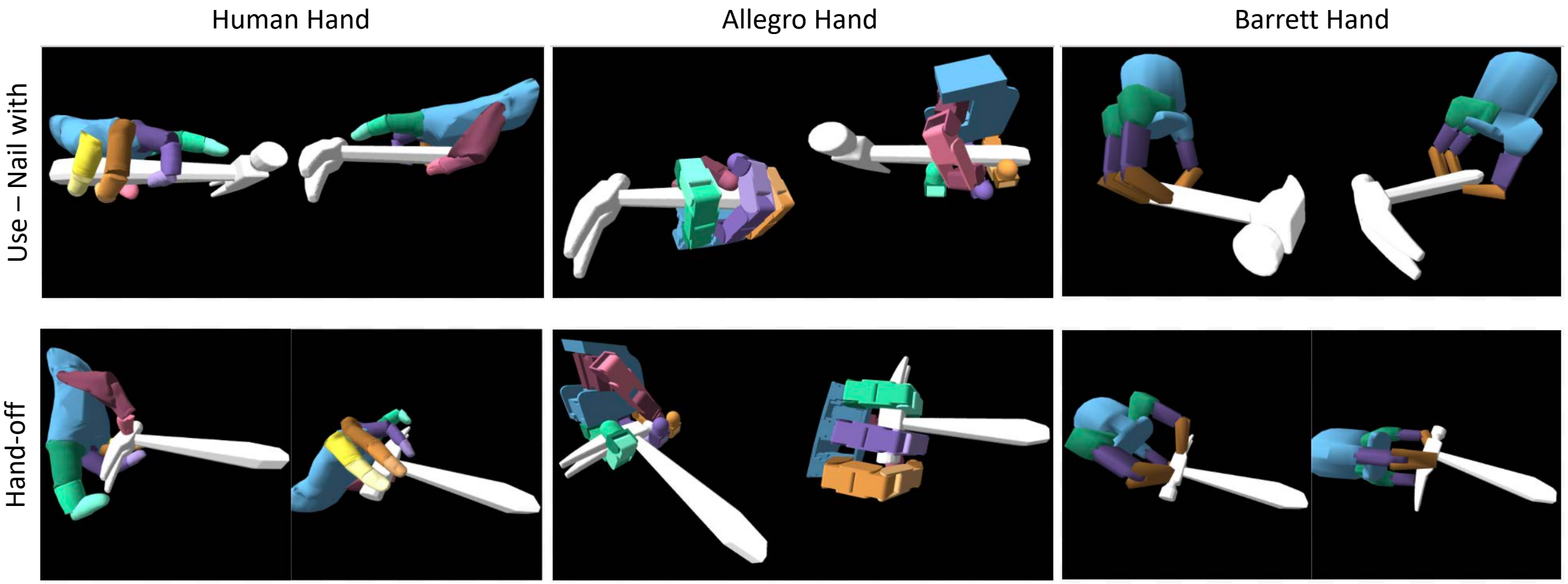
{0, 1, 2, 3} cm



ContactGrasp: Overview

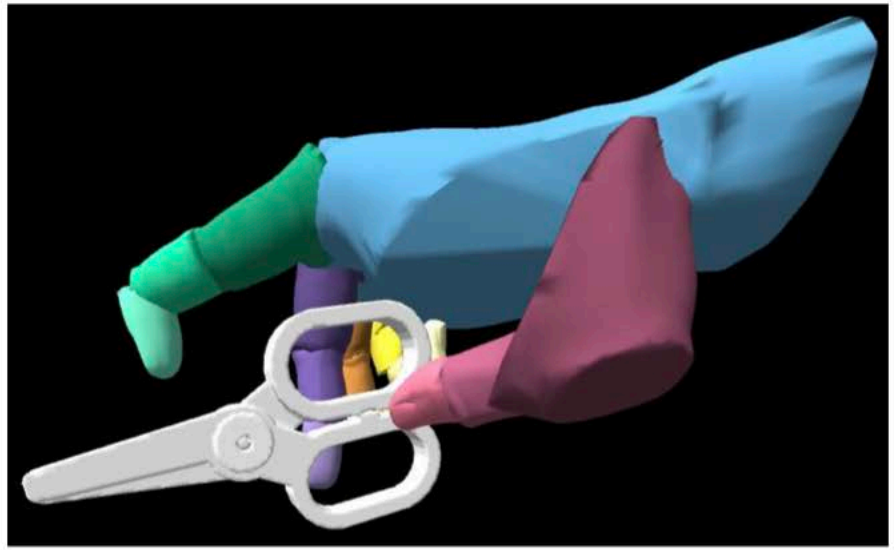


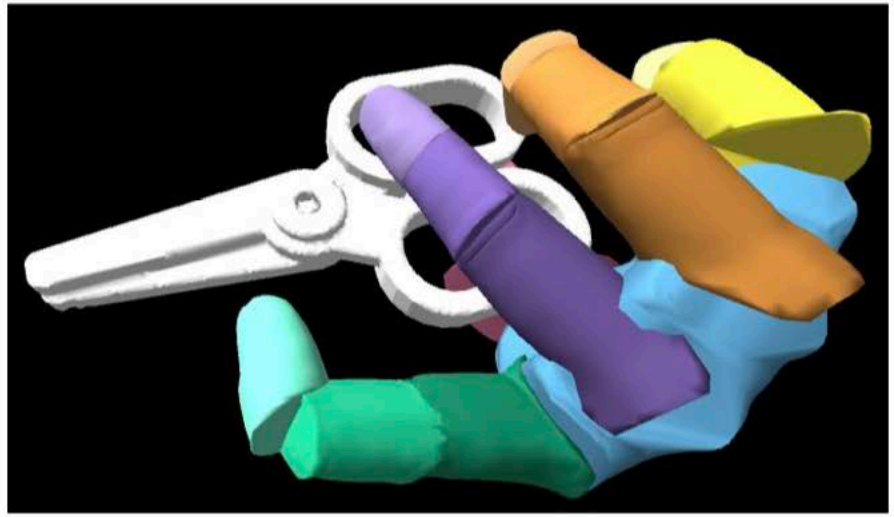
Synthesized Grasps: Hammer



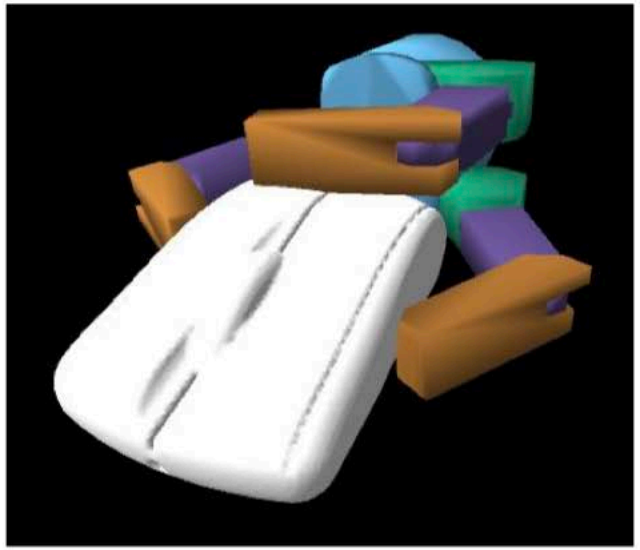
Failure Cases

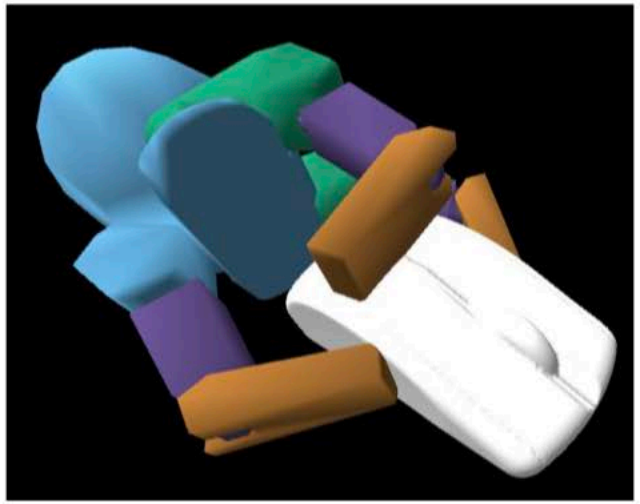
Human Hand, scissors
intent: use





Barrett Hand, mouse
intent: use



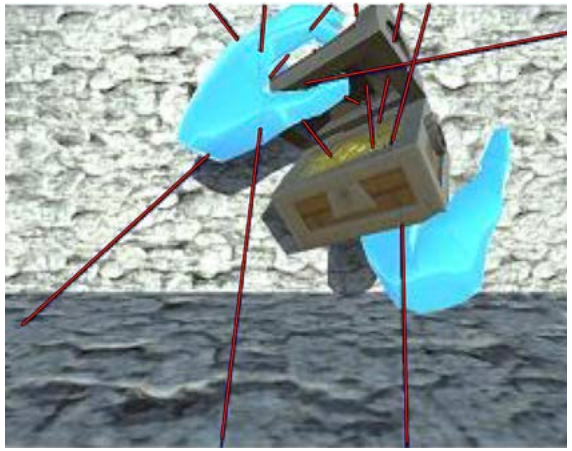


Contact Modeling – Possible Applications

Soft robotics – simulation & design

[Deimel et al, IJRR ‘16]

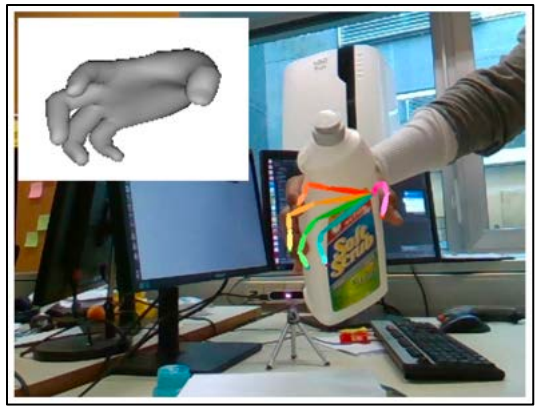
Realistic VR Experiences



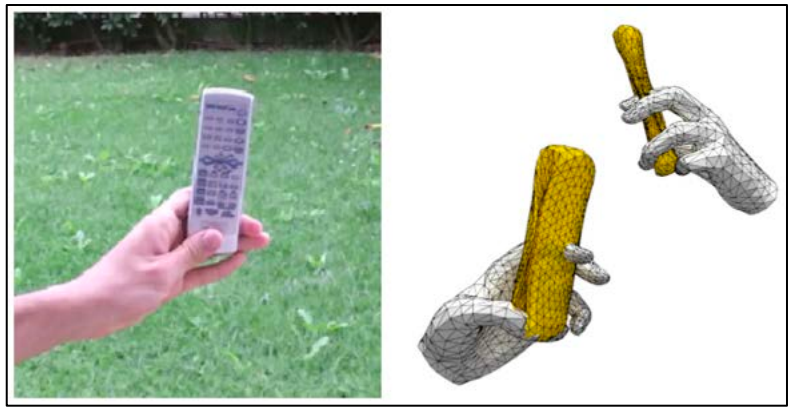
[Höll et al, VR ‘18]

Assistive robots, grasping

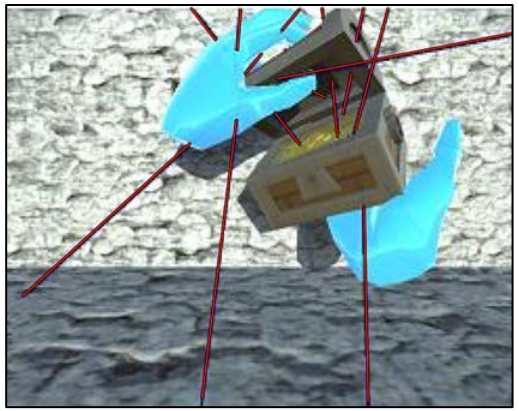
Contact Modeling – Current Status



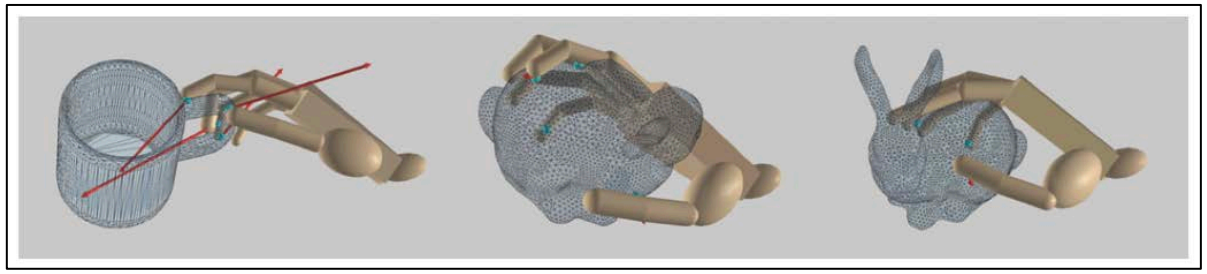
[Hampali et al, CVPR ‘20]



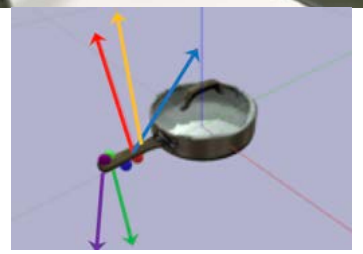
[Hasson et al, CVPR ‘19]



[Höll et al, VR ‘18]



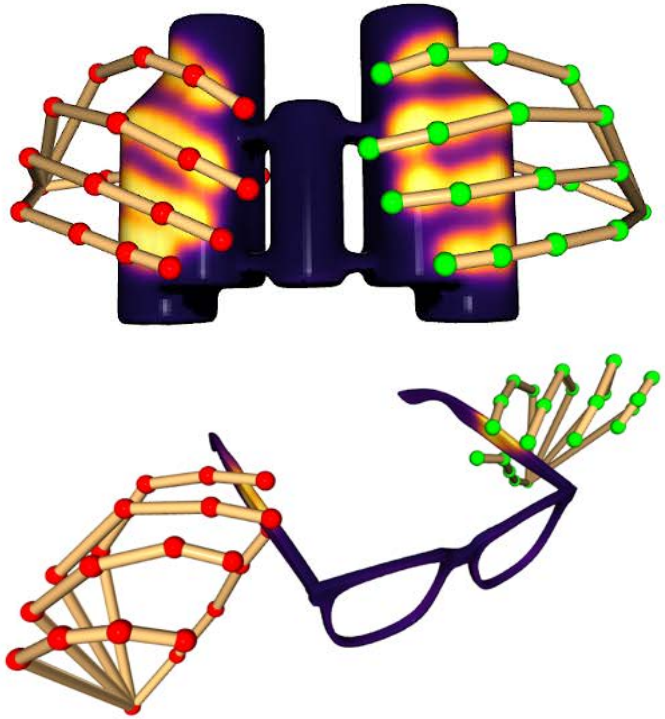
[Ye and Liu, SIGGRAPH ‘12]

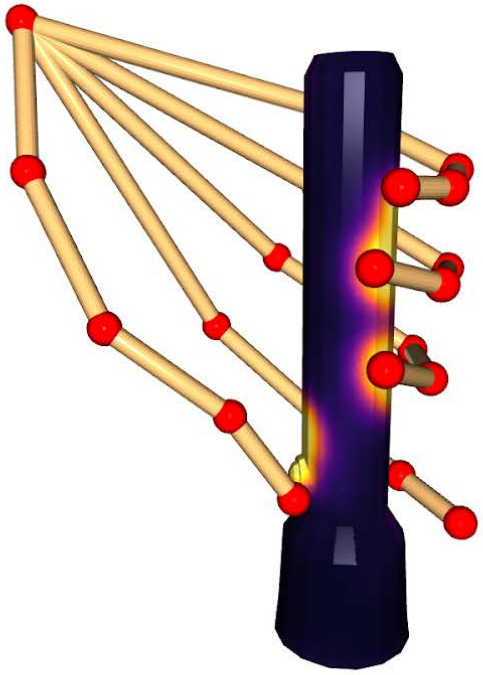


[Ehsani et al CVPR ‘20]

[Hassan et al, ICCV ‘19]

ContactPose Data - 3D





High-res Contact 3D Hand Joints MANO[1] fits

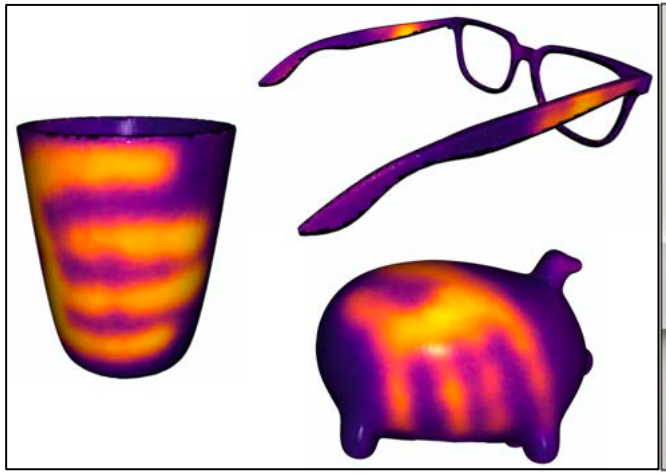
[1] Romero, Javier, Dimitrios Tzionas, and Michael J. Black. "Embodied hands: Modeling and capturing hands and bodies together." *ACM Transactions on Graphics (ToG)* 36.6 (2017): 245.

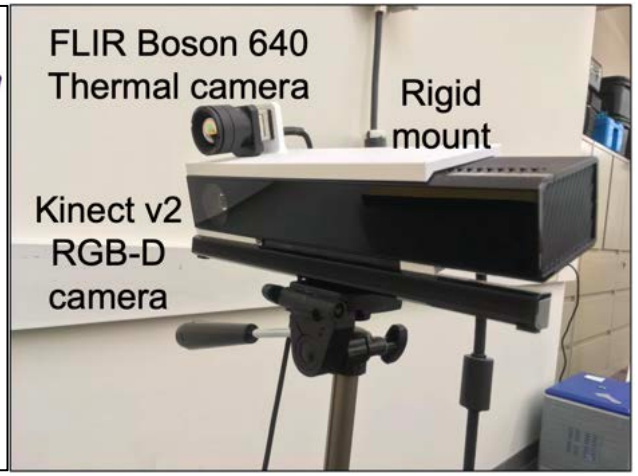
ContactPose Data - Images

Contributions

- Dataset that enables a rigorous study of contact modeling
  - Contact ground truth
  - RGB-D grasp images
  - 3D object models
  - Hand- and object- pose ground truth
  - Large scale, diversity
- Contact modeling experiments
  - Heuristic baselines
  - ML models

Capture Setup – Contact





[ContactDB: Brahmbhatt et al, CVPR ‘19]

3D printed objects

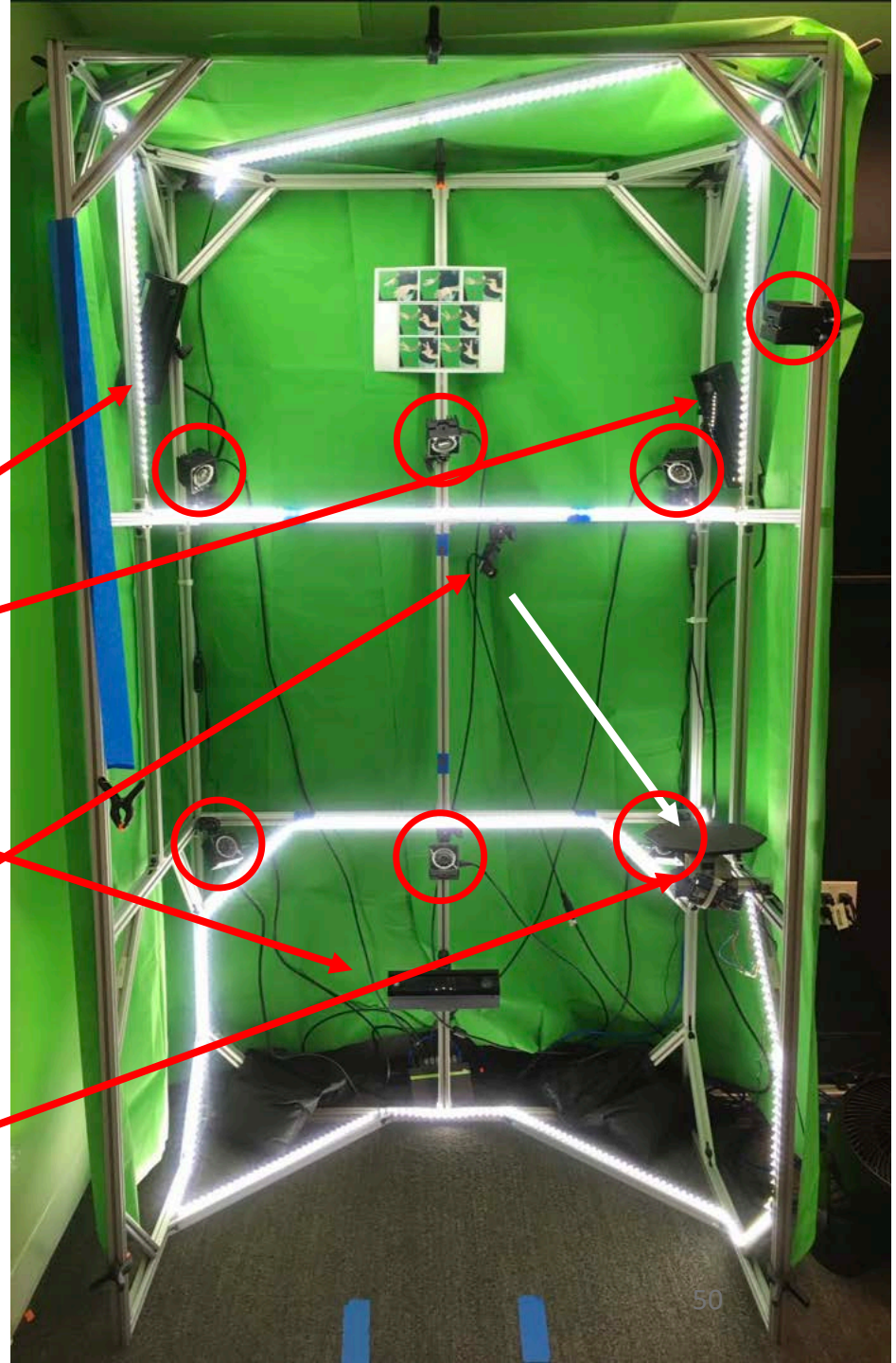
Capture Setup – Poses

7x Optitrack cameras

3x Kinects

FLIR Boson Thermal camera

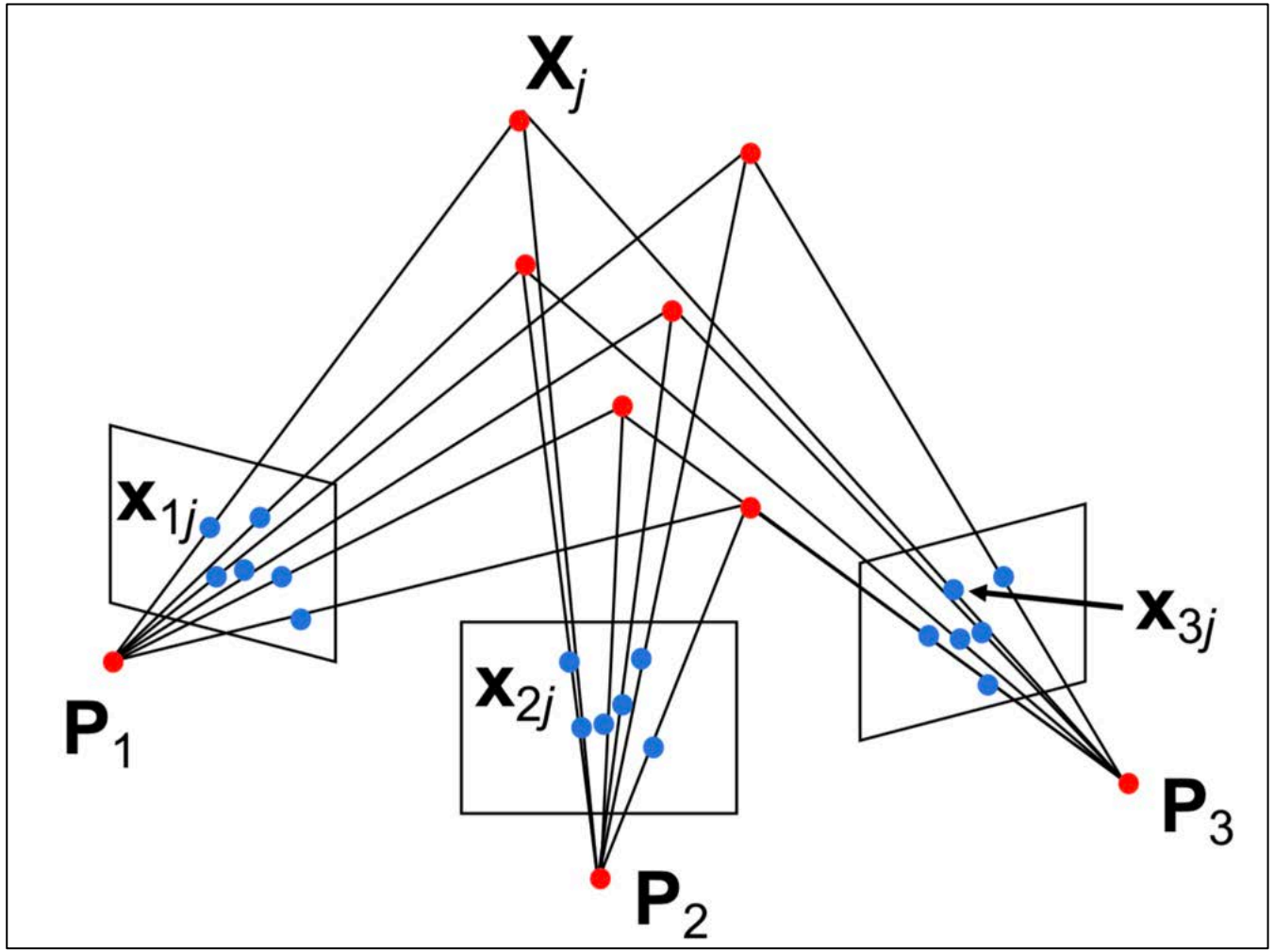
Turntable



2D Joint Detections with OpenPose[1]

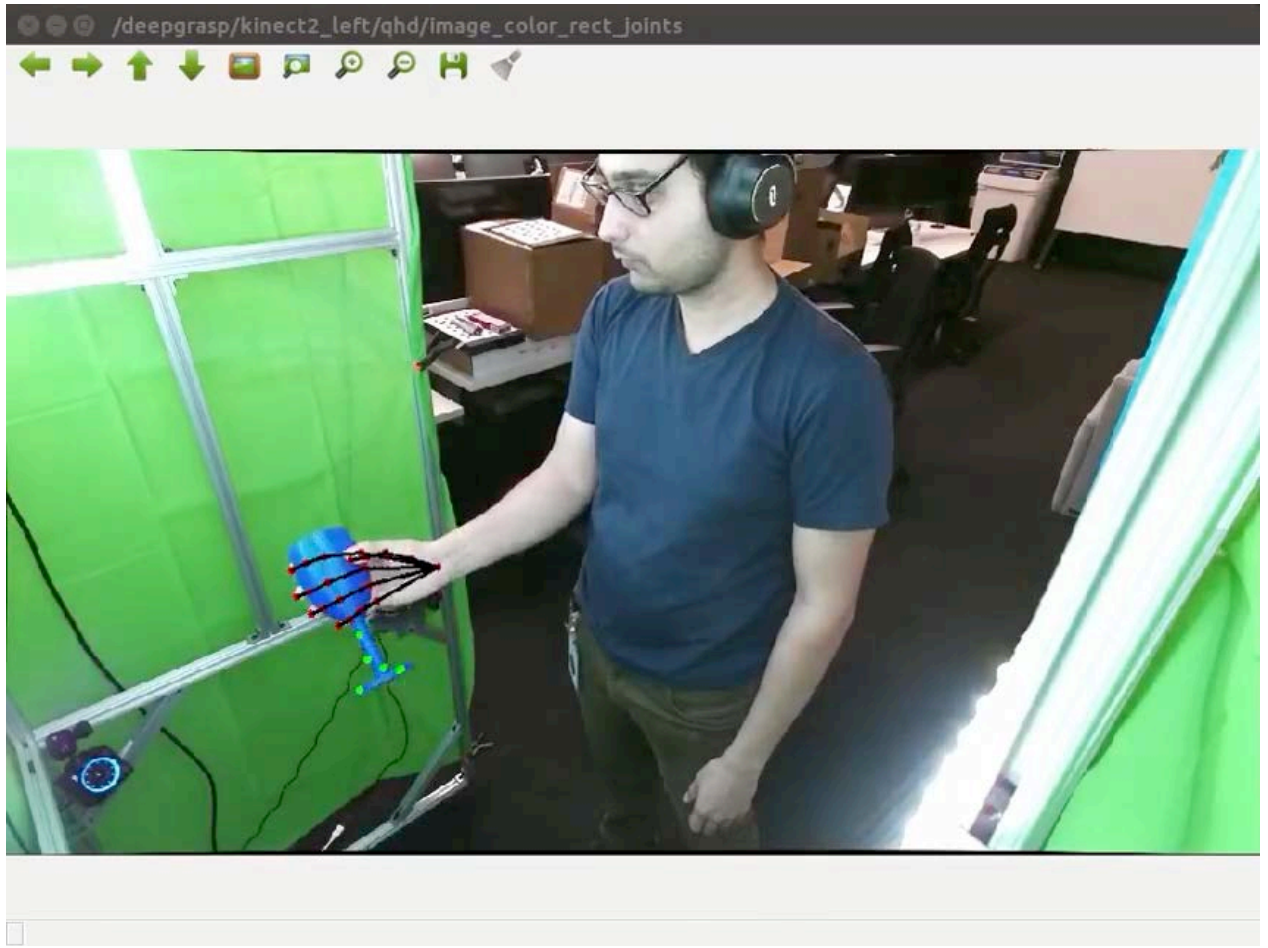
[1] “Hand Keypoint Detection in Single Images using Multiview Bootstrapping” – Tomas Simon, Hanbyul Joo, Iain Matthews, and Yaser Sheikh – CVPR 2017

Triangulating 3D Joints from Noisy 2D Observations



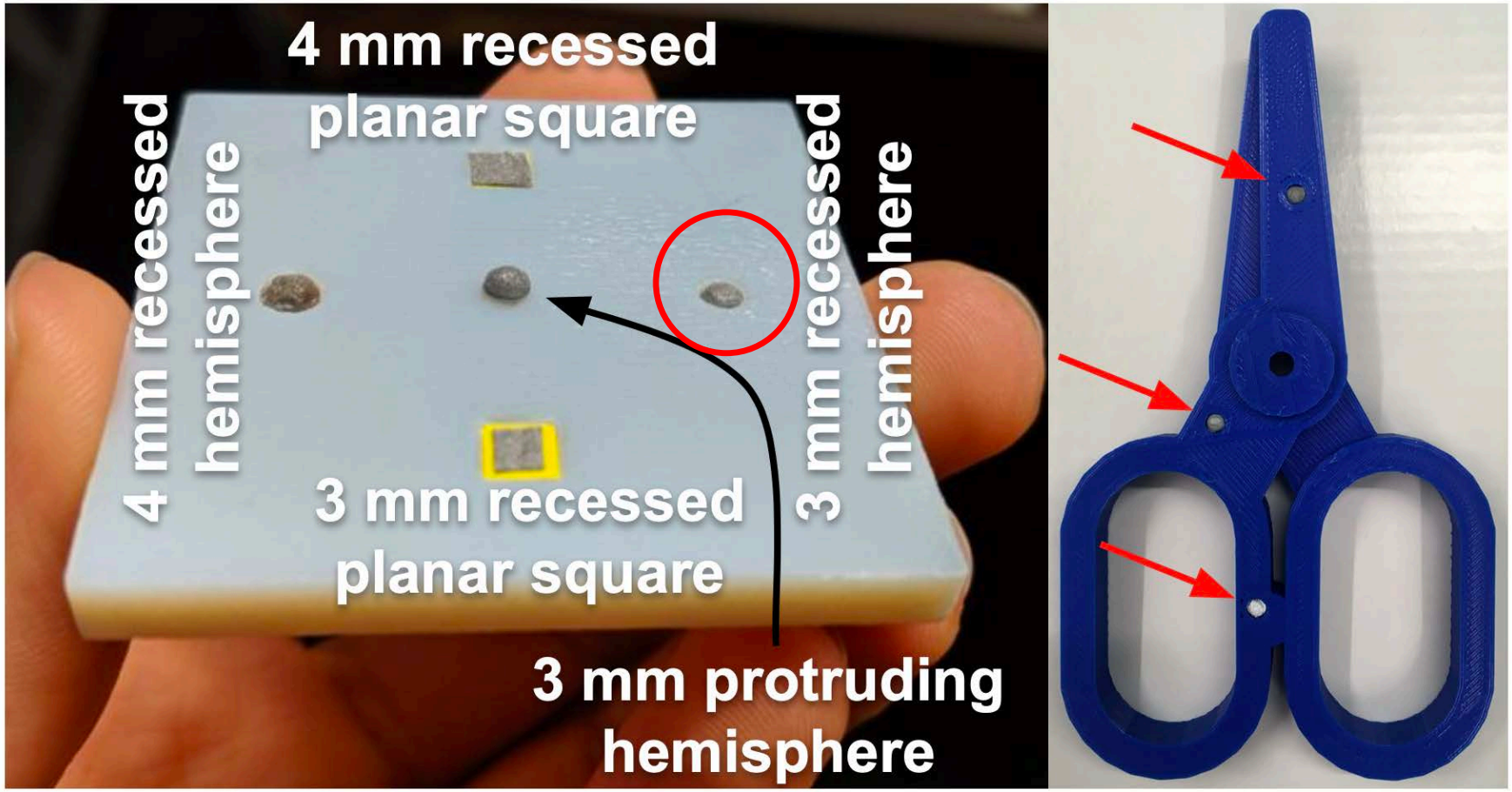
Slide by Svetlana Lazebnik

Optimization Result

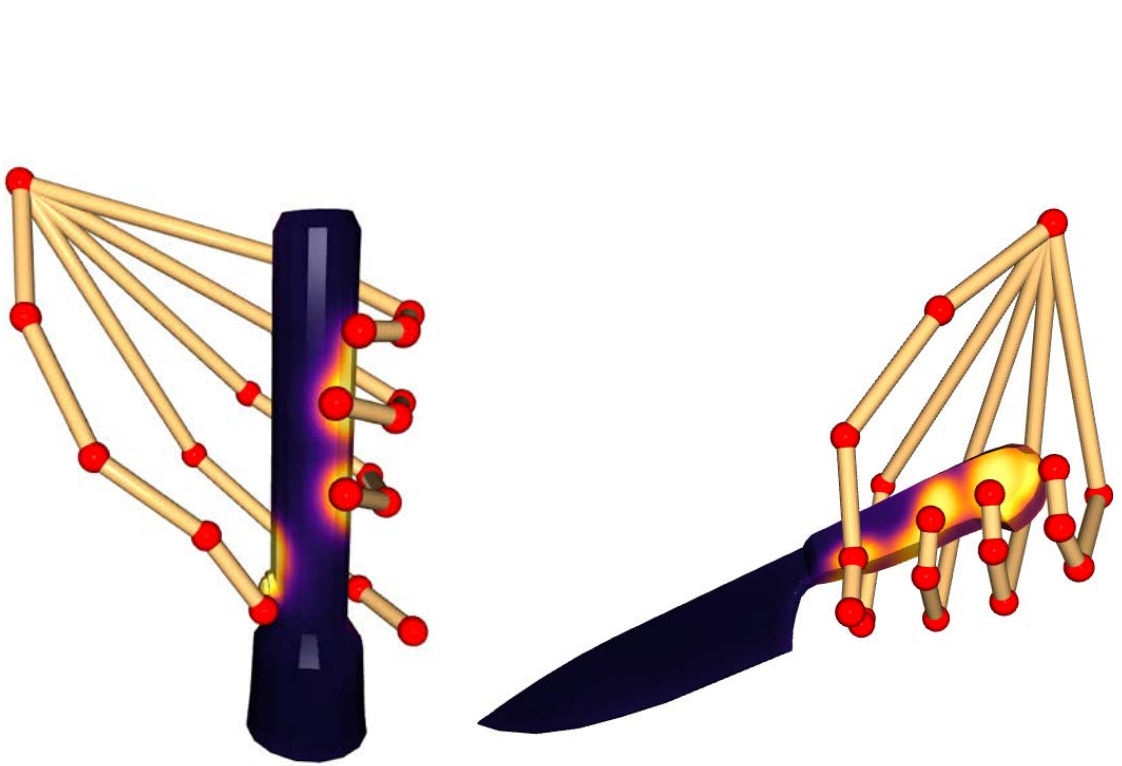


Optimization performed with GTSAM [Dellaert, Tech Report ‘12, https://gtsam.org]

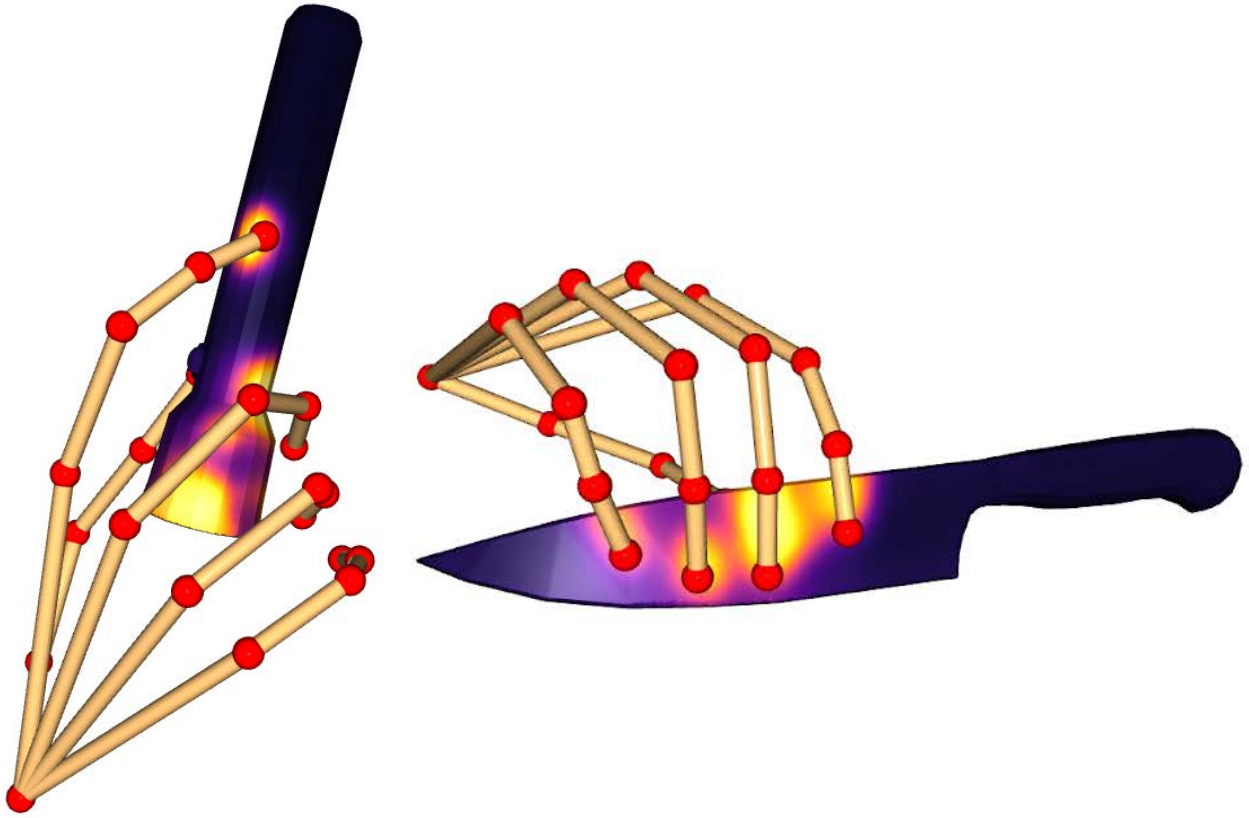
Embedded Markers for Object Tracking



Functional Intents

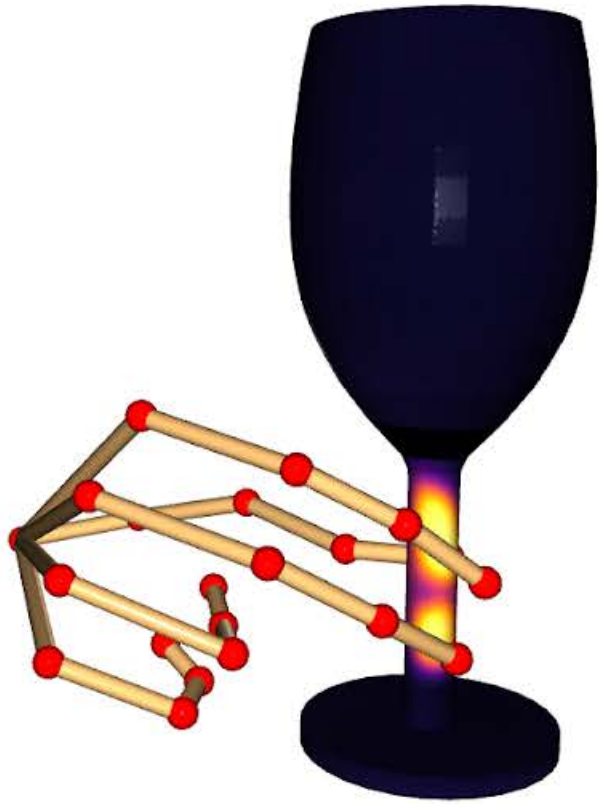


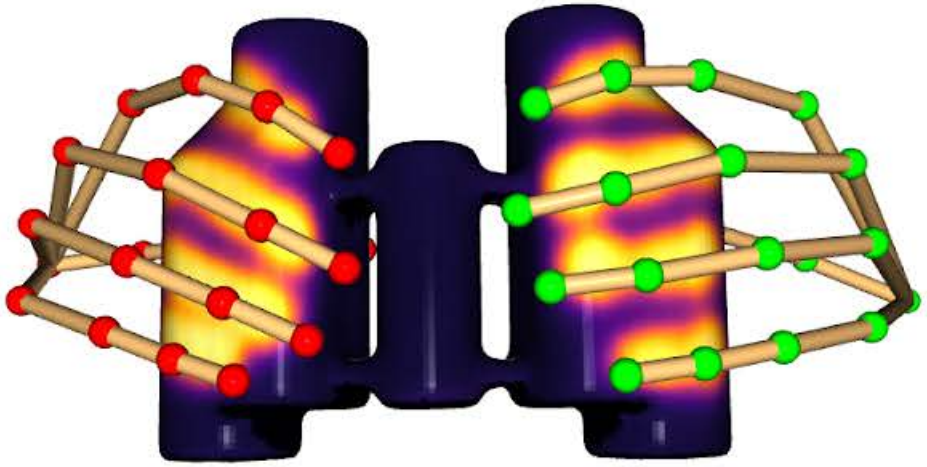
use



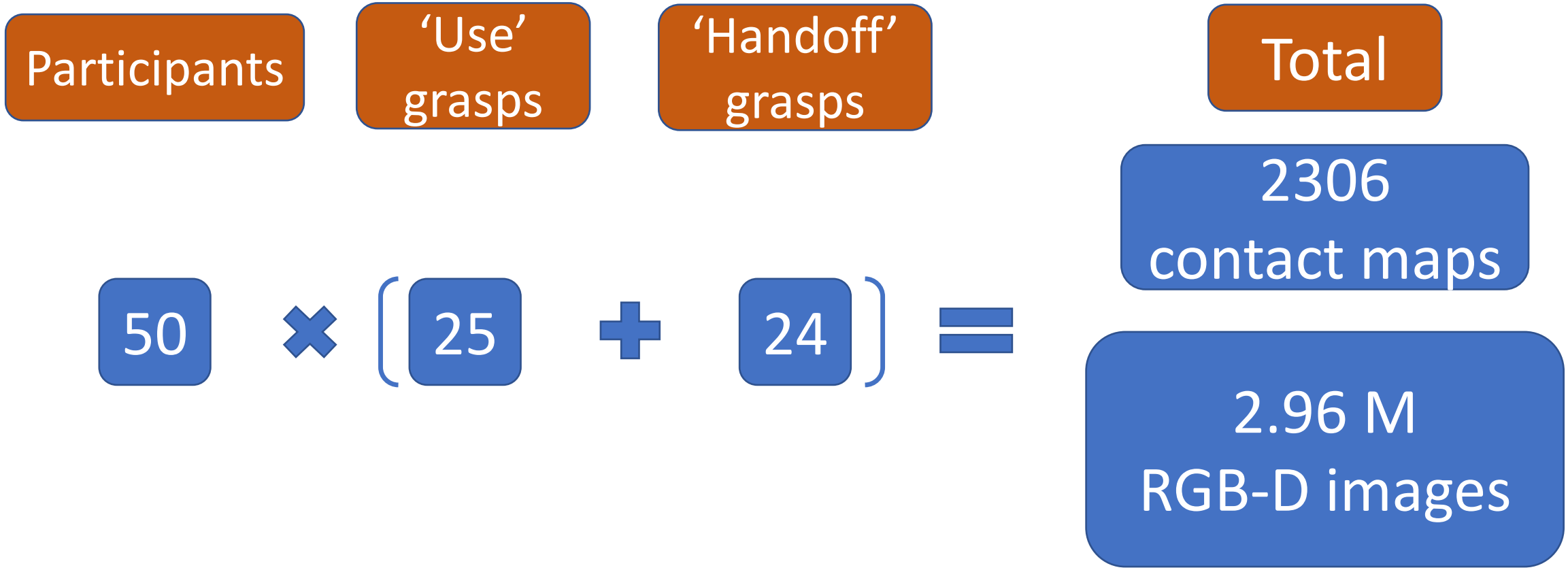
handoff

Single-handed and Bimanual Grasps





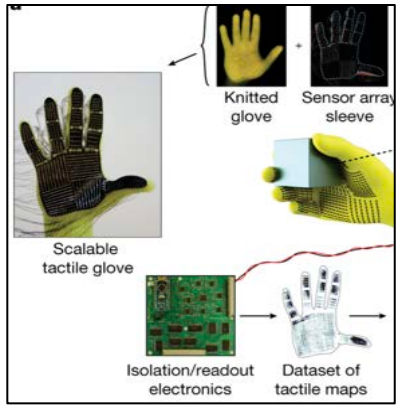
The ContactPose Dataset



Related Work

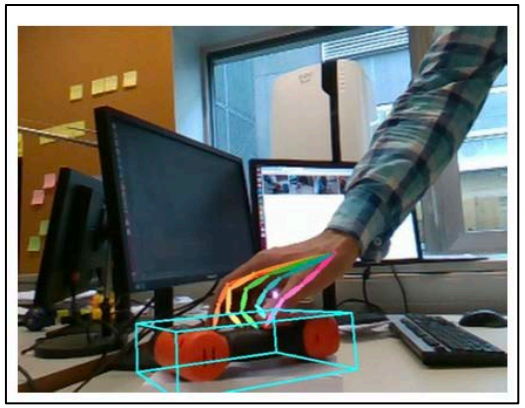
[Garcia-Hernando et al, CVPR ‘18]

object/hand pose
object texture
markerless | contact



[Sundaram et al, Nature Letters ‘19]

object/hand pose
object texture
markerless | contact

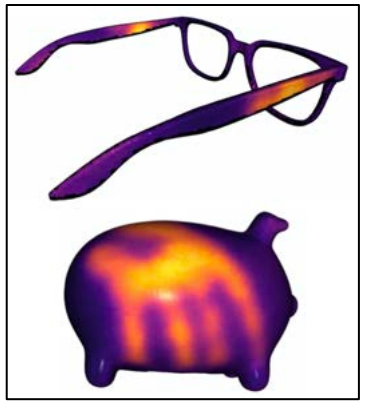


[Hampali et al, CVPR ‘20]

object/hand pose
object texture
markerless | contact

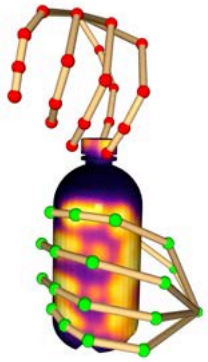
[Zimmermann et al, ICCV ‘19]

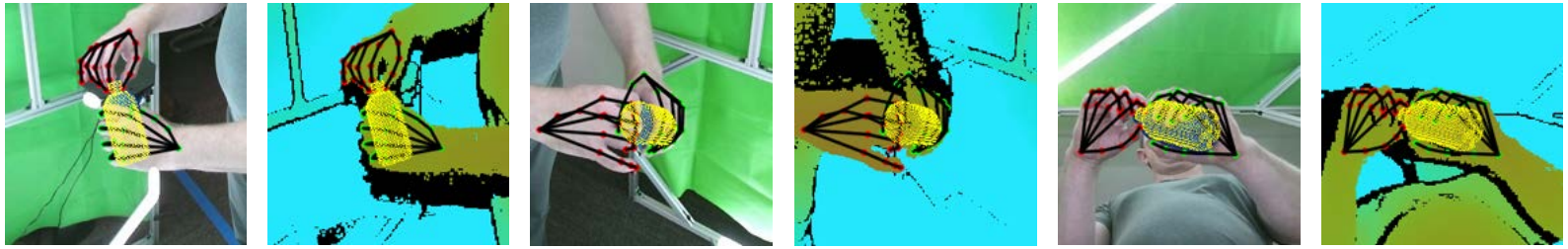
object/hand pose
object texture
markerless | contact



[Brahmbhatt et al, CVPR ‘19]

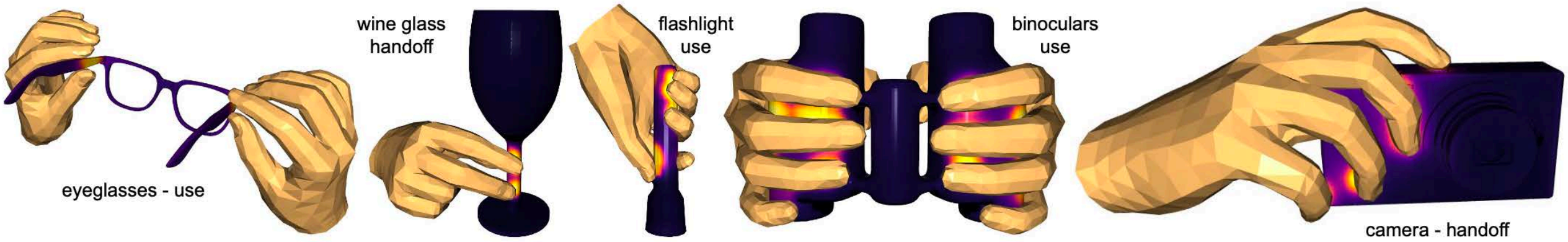
object/hand pose
object texture
markerless | contact





object/hand pose | object texture
markerless | contact

Parametric Hand Mesh Models (e.g. MANO[1])



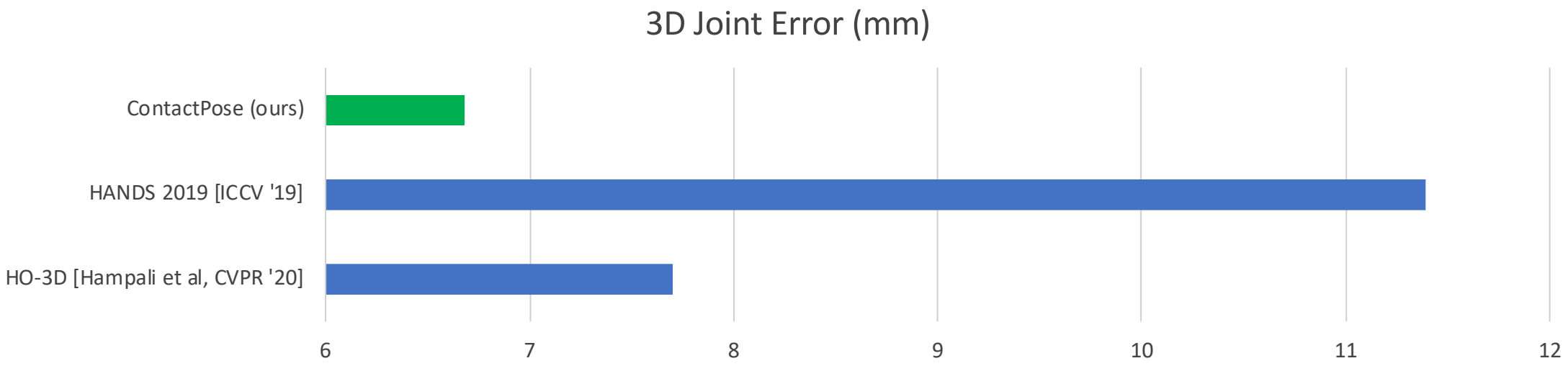
$$\beta^*, \theta^* = \arg min_{\beta,\theta} ||J(\beta, \theta) - J^*|| + \frac{1}{\sigma}||\beta||$$

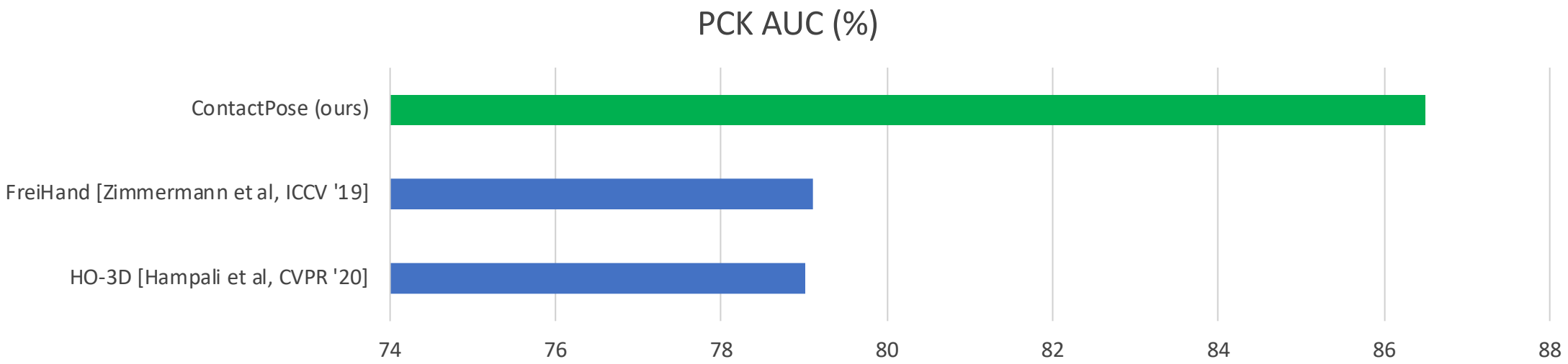
Hand shape

Hand pose

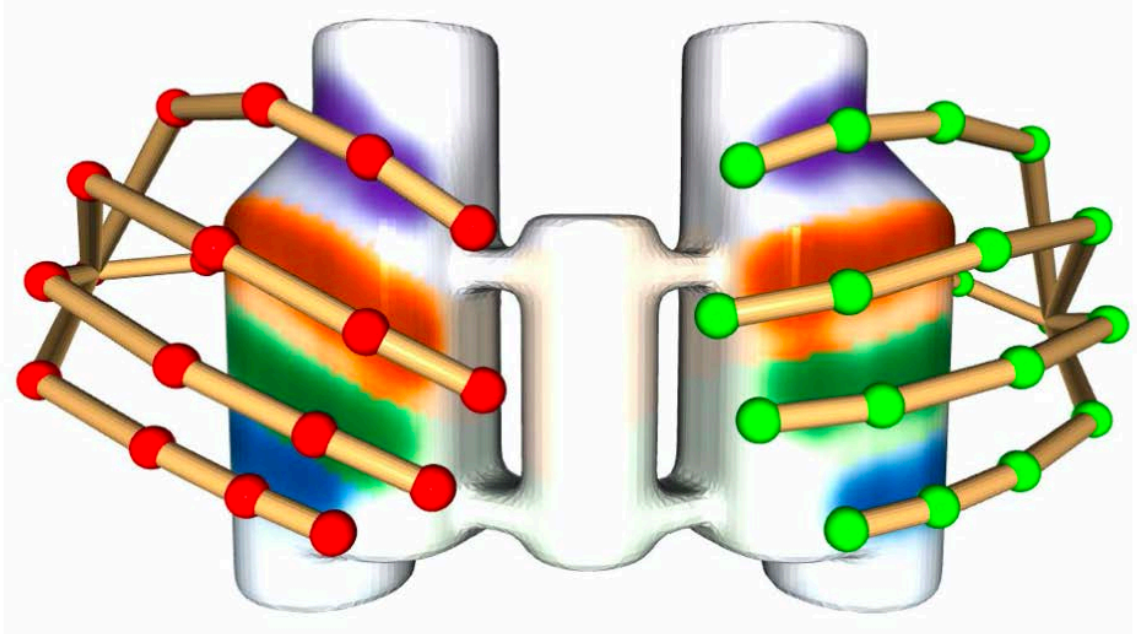
[1] Romero, Javier, Dimitrios Tzionas, and Michael J. Black. "Embodied hands: Modeling and capturing hands and bodies together." *ACM Transactions on Graphics (ToG)* 36.6 (2017): 245.

MANO Fitting Accuracy

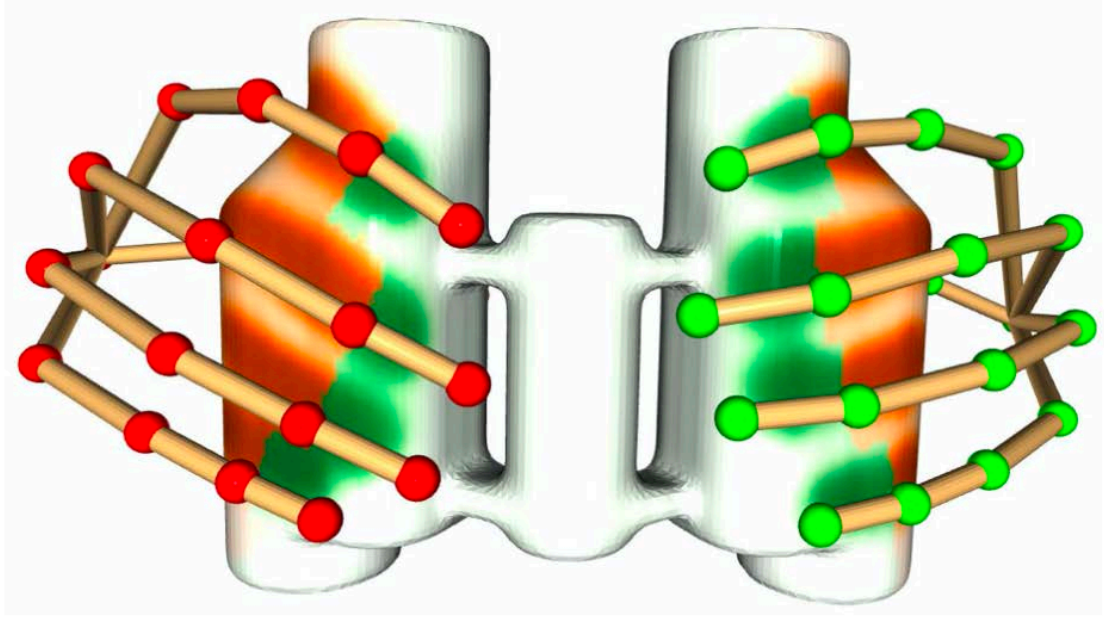




Association of Contact to Hand Parts

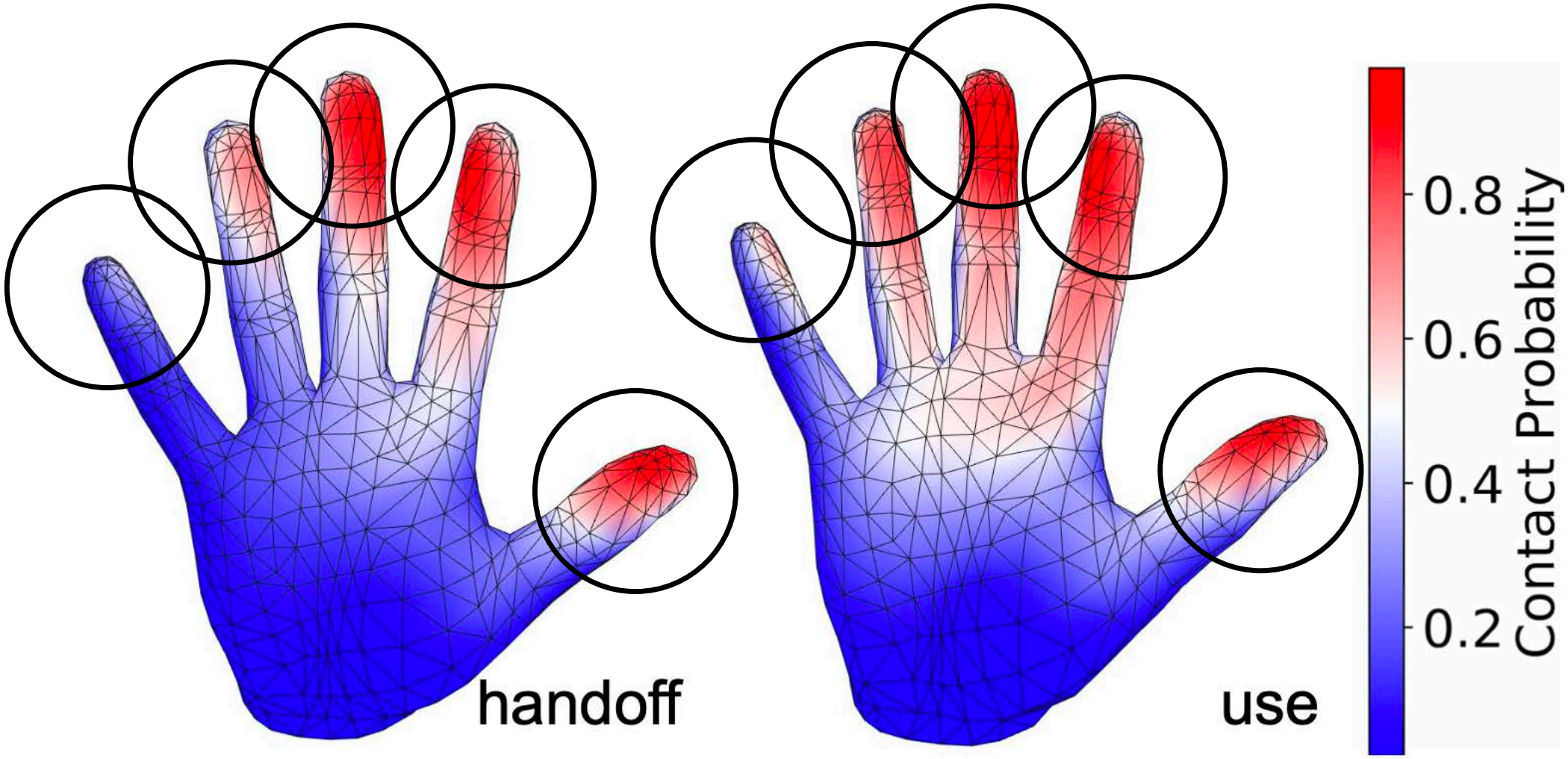


Association to fingers

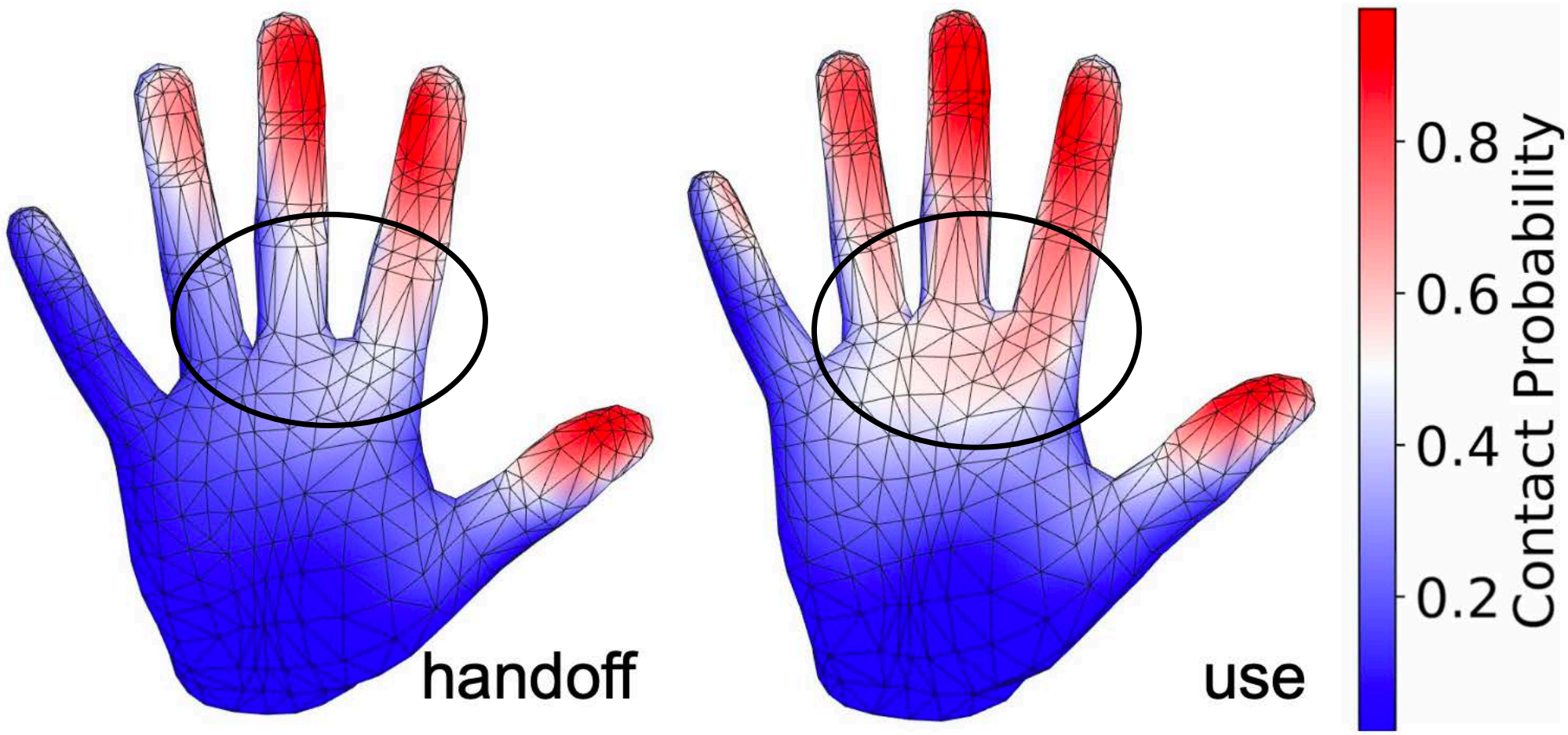


Association to phalanges

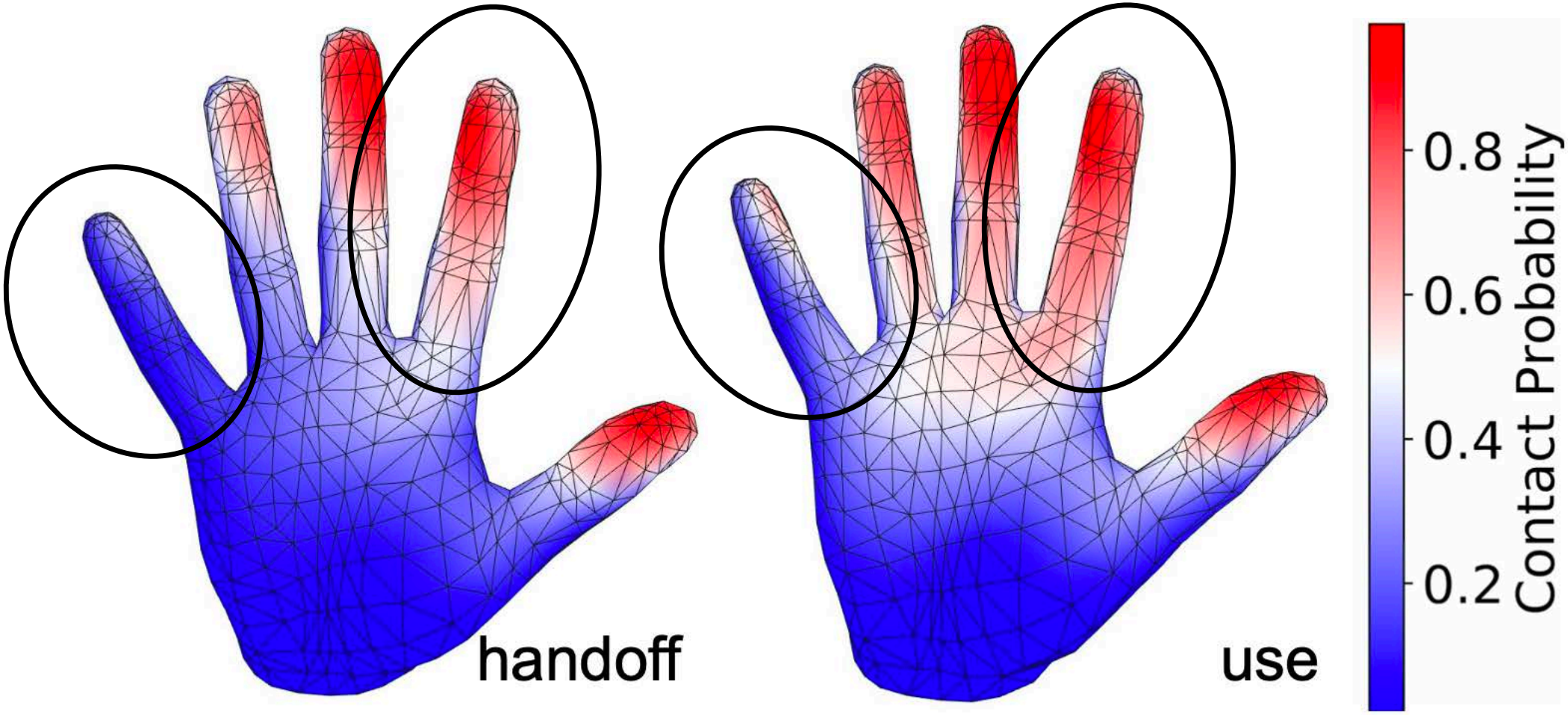
Hand Contact Probability



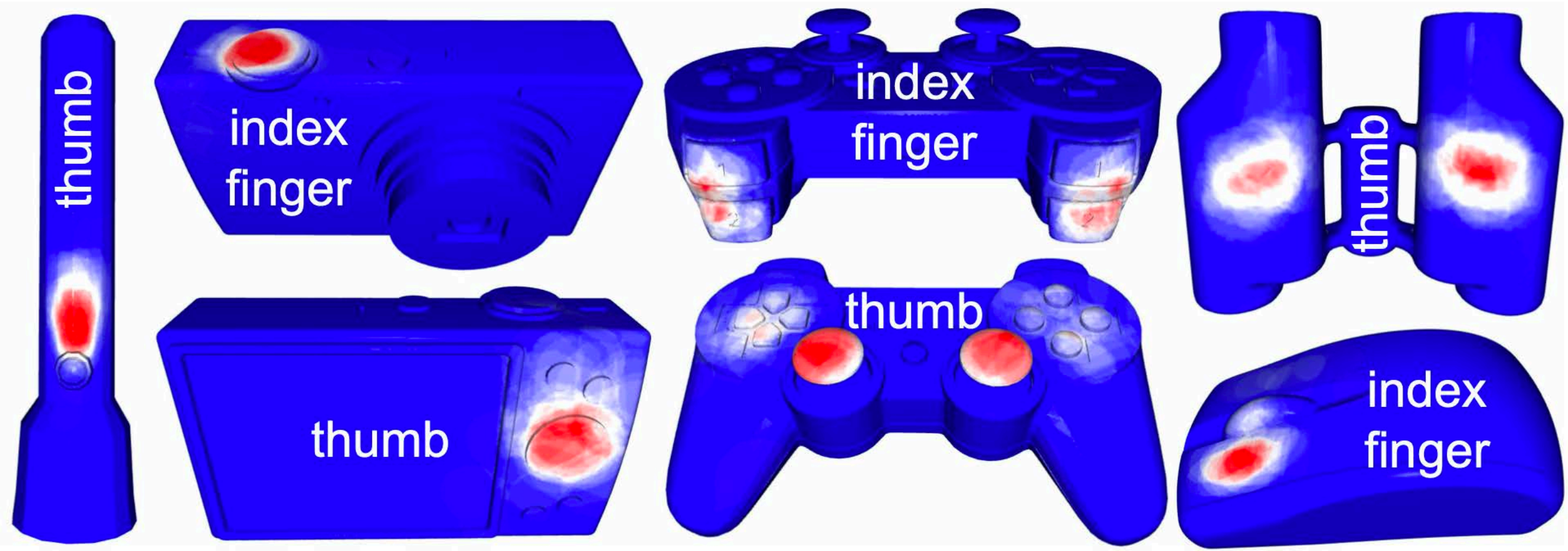
Hand Contact Probability



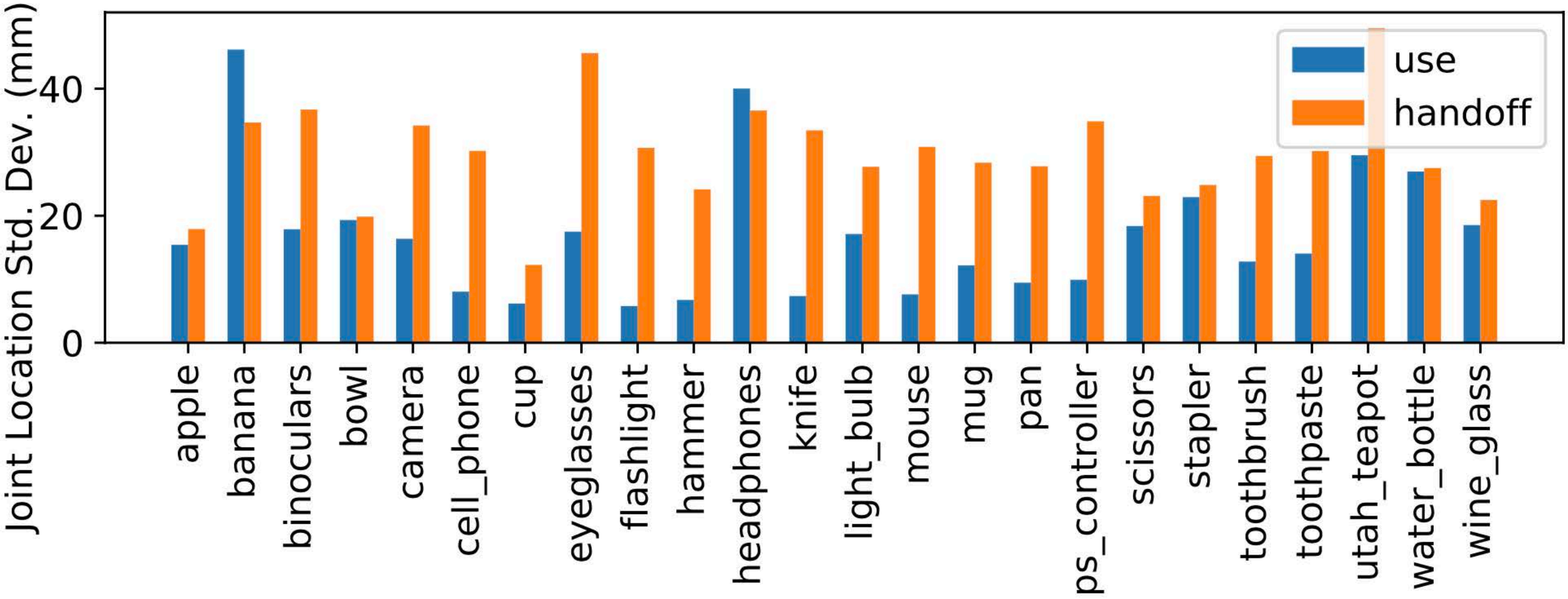
Hand Contact Probability



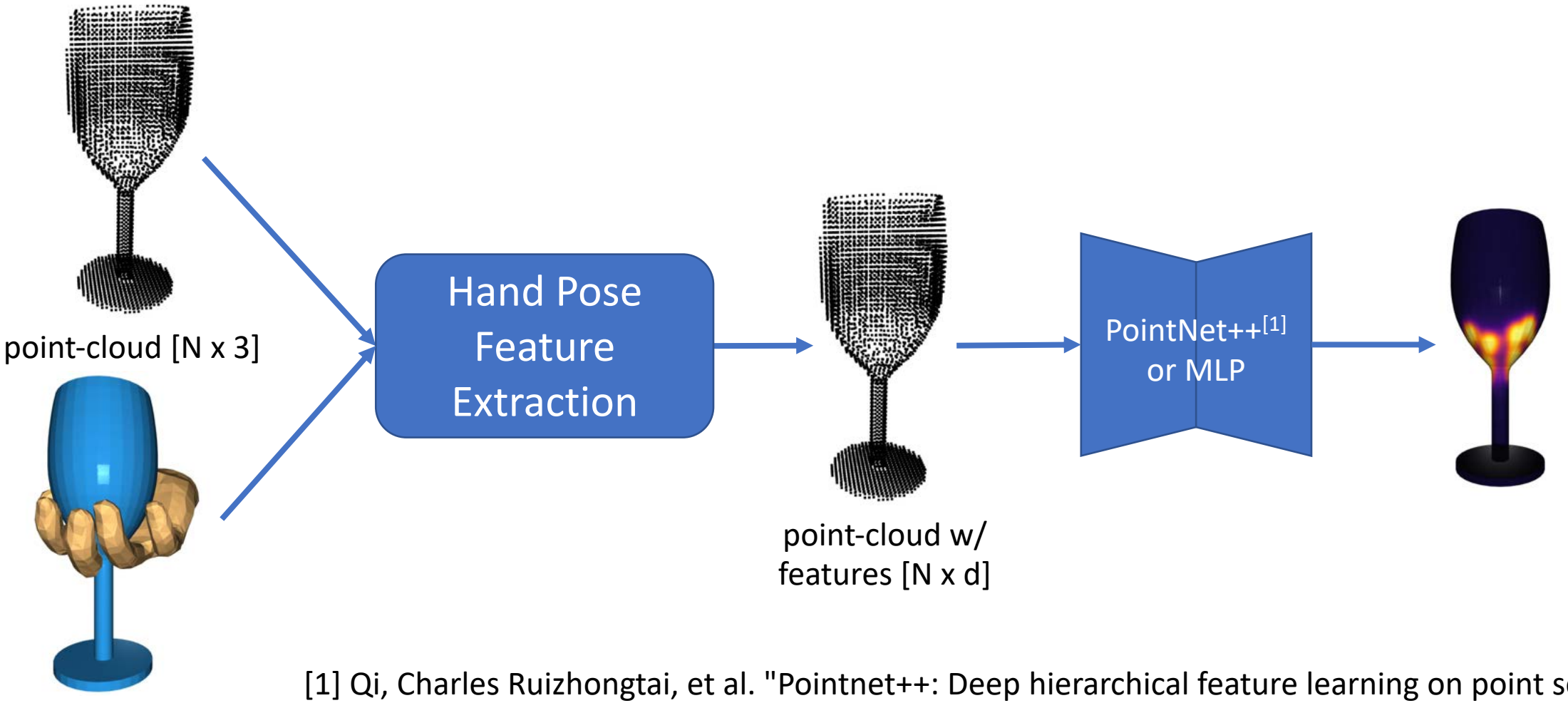
“Active Area” Discovery



Effect of Functional Intent on Hand Pose Diversity



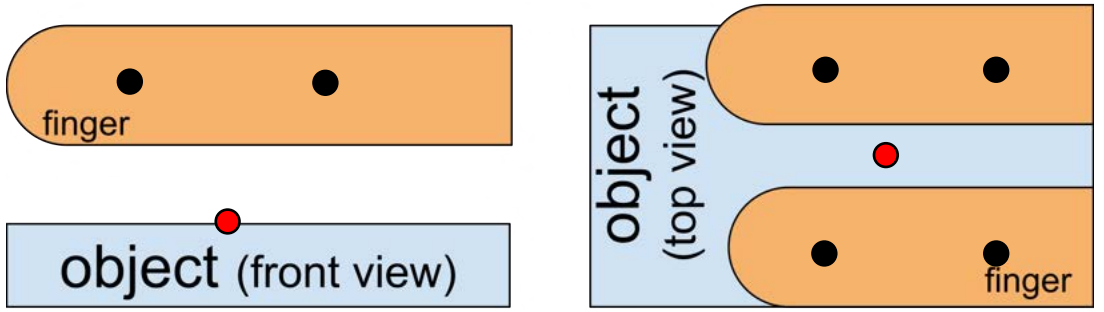
Learning Contact Modeling



[1] Qi, Charles Ruizhongtai, et al. "Pointnet++: Deep hierarchical feature learning on point sets in a metric space." *Advances in neural information processing systems*. 2017.

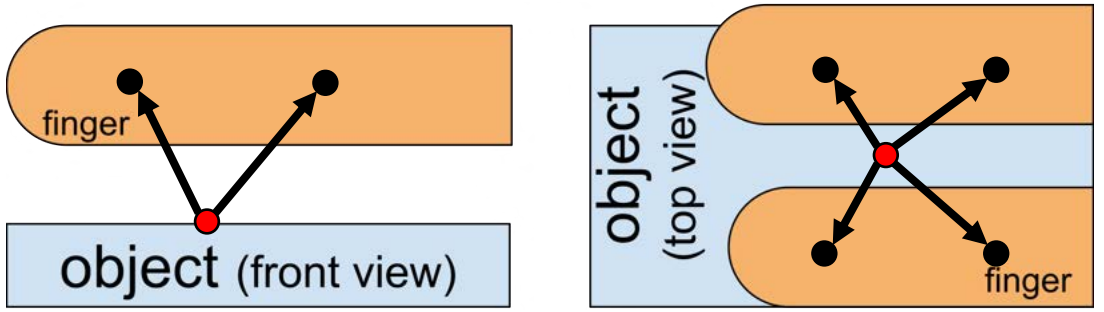
Hand Pose Features

- `simple-joints`



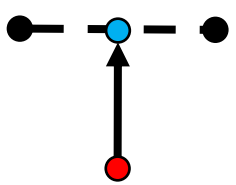
Hand Pose Features

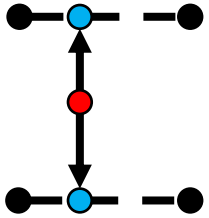
- `simple-joints`
- `relative-joints`



Hand Pose Features

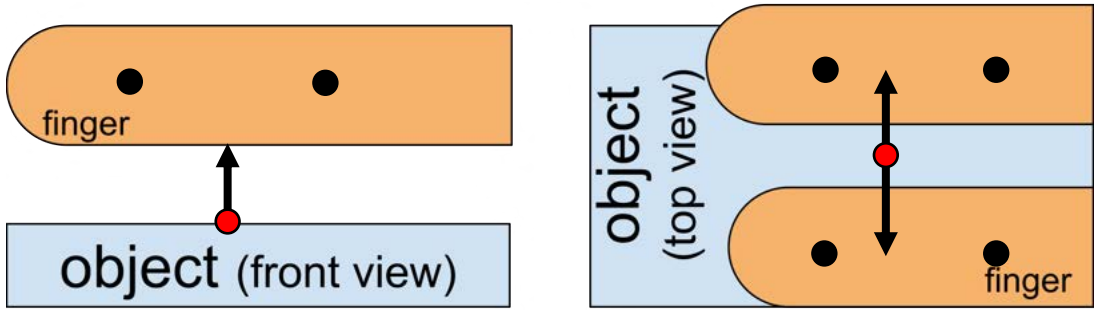
- `simple-joints`
- `relative-joints`
- `skeleton`



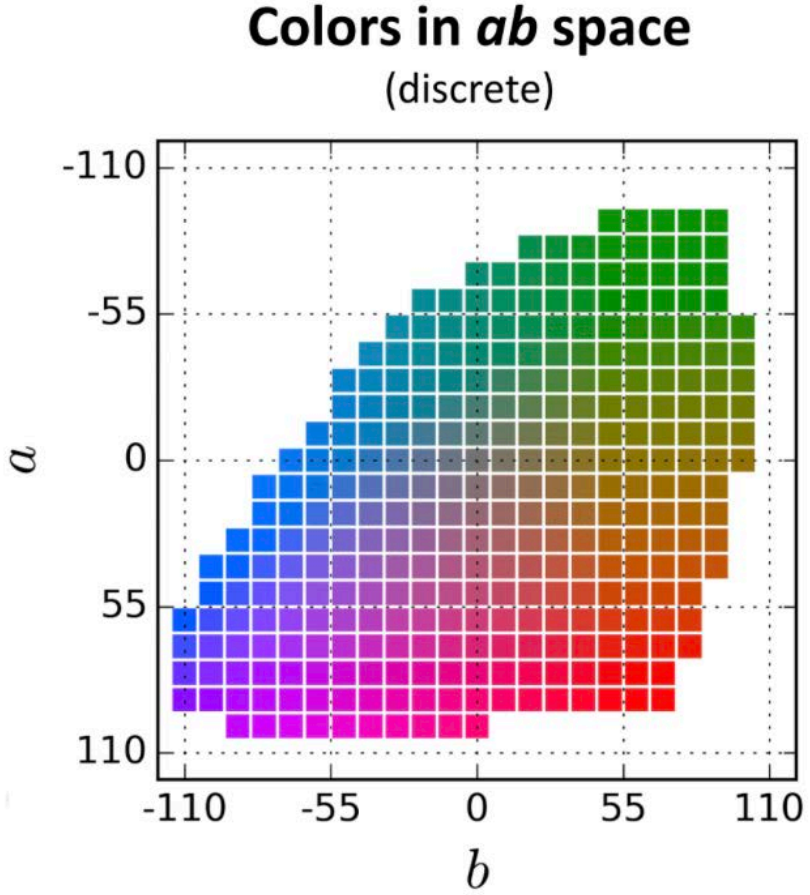


Hand Pose Features

- `simple-joints`
- `relative-joints`
- `skeleton`
- `mesh`



Contact Representation



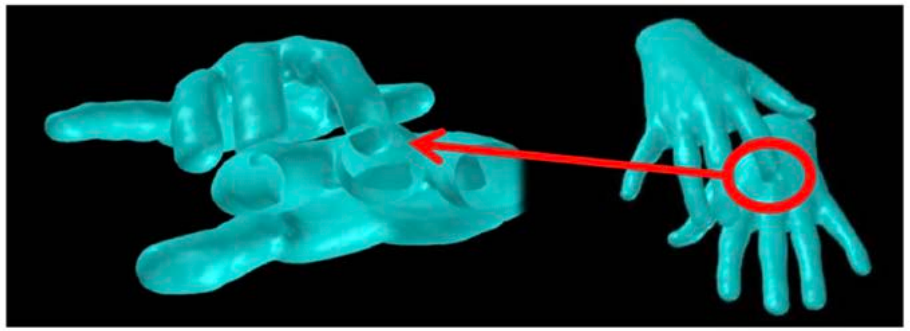
"Colorful Image Colorization" – Zhang, Isola, and Efros – ECCV 2016

- Discretize contact values into 10 bins
- Classification problem
- Loss weight inversely proportional to occurrence frequency
- "Annealed Mean" for continuous prediction

$$f_T(\mathbf{z}) = \frac{\exp(\log(\mathbf{z})/T)}{\sum_q \exp(\log(\mathbf{z}_q)/T)}$$

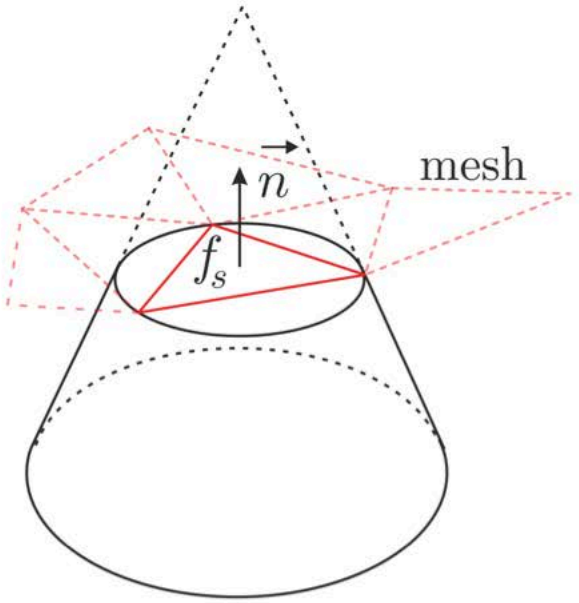
$$\mathcal{H}(\mathbf{Z}_{h,w}) = \mathbb{E}\big[f_T(\mathbf{Z}_{h,w})\big]$$

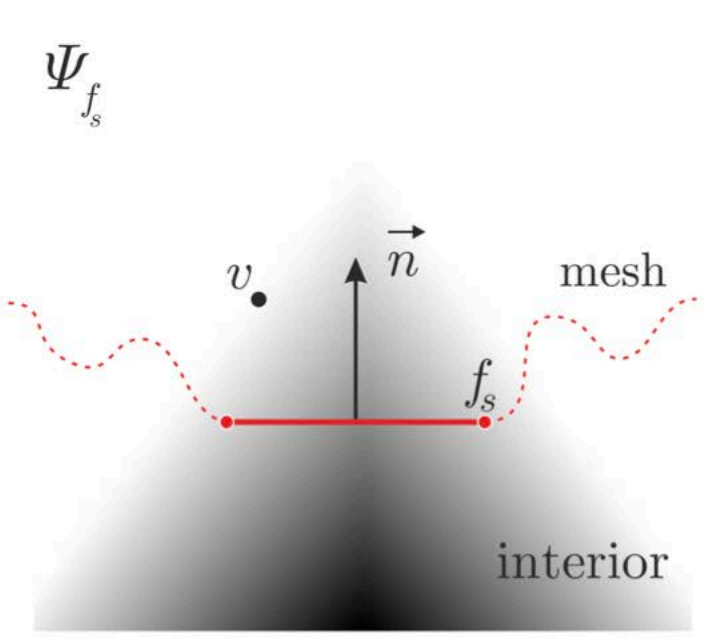
Contact Modeling – Heuristics



[Tzionas et al., IJCV ‘16]

Conic distance field

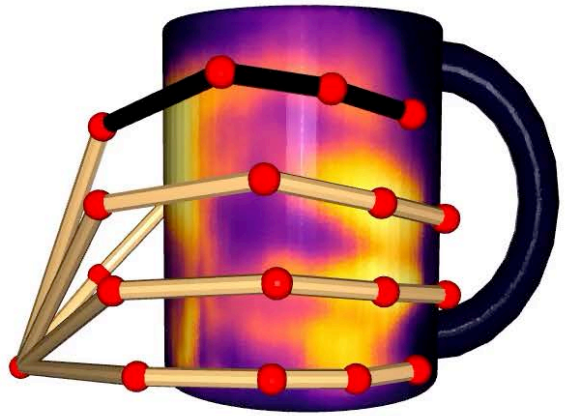




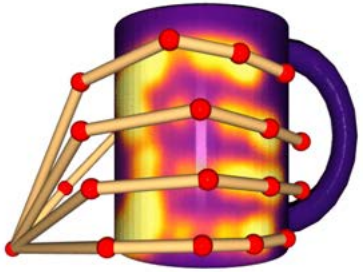
[Tzionas et al., IJCV ’16, Ballan et al., ECCV ‘12]

Contact Modeling from Hand Pose

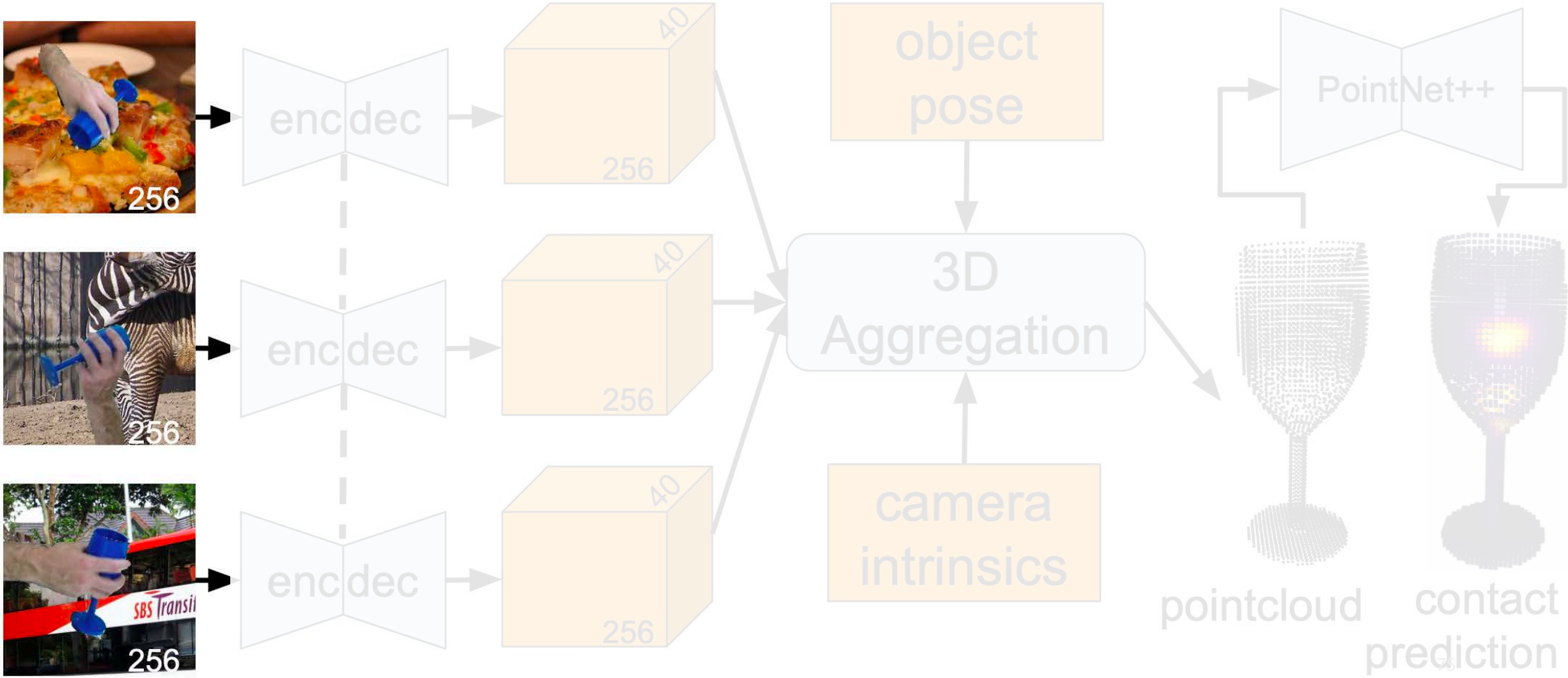
Prediction (unseen object “mug”)



ground truth



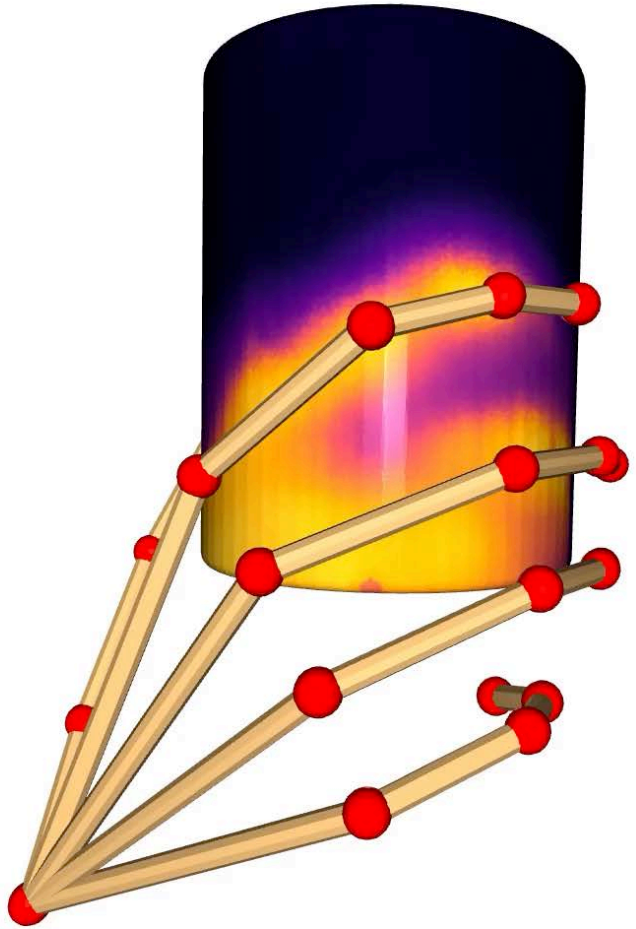
Contact Modelling – Features From Images



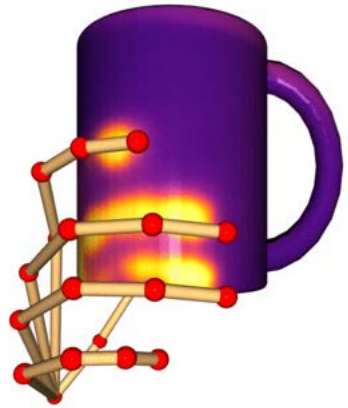
Contact Modeling from Grasp Images

Prediction (unseen object “mug”)

input images

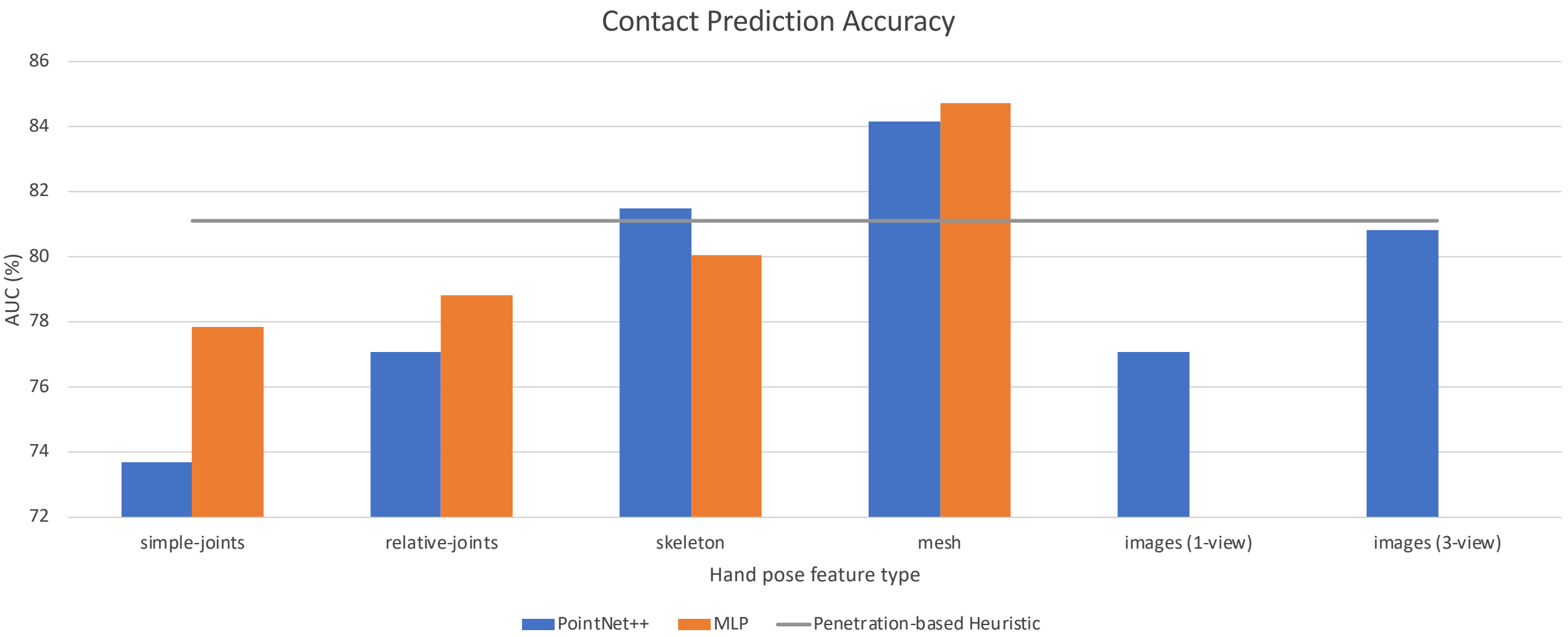


ground truth

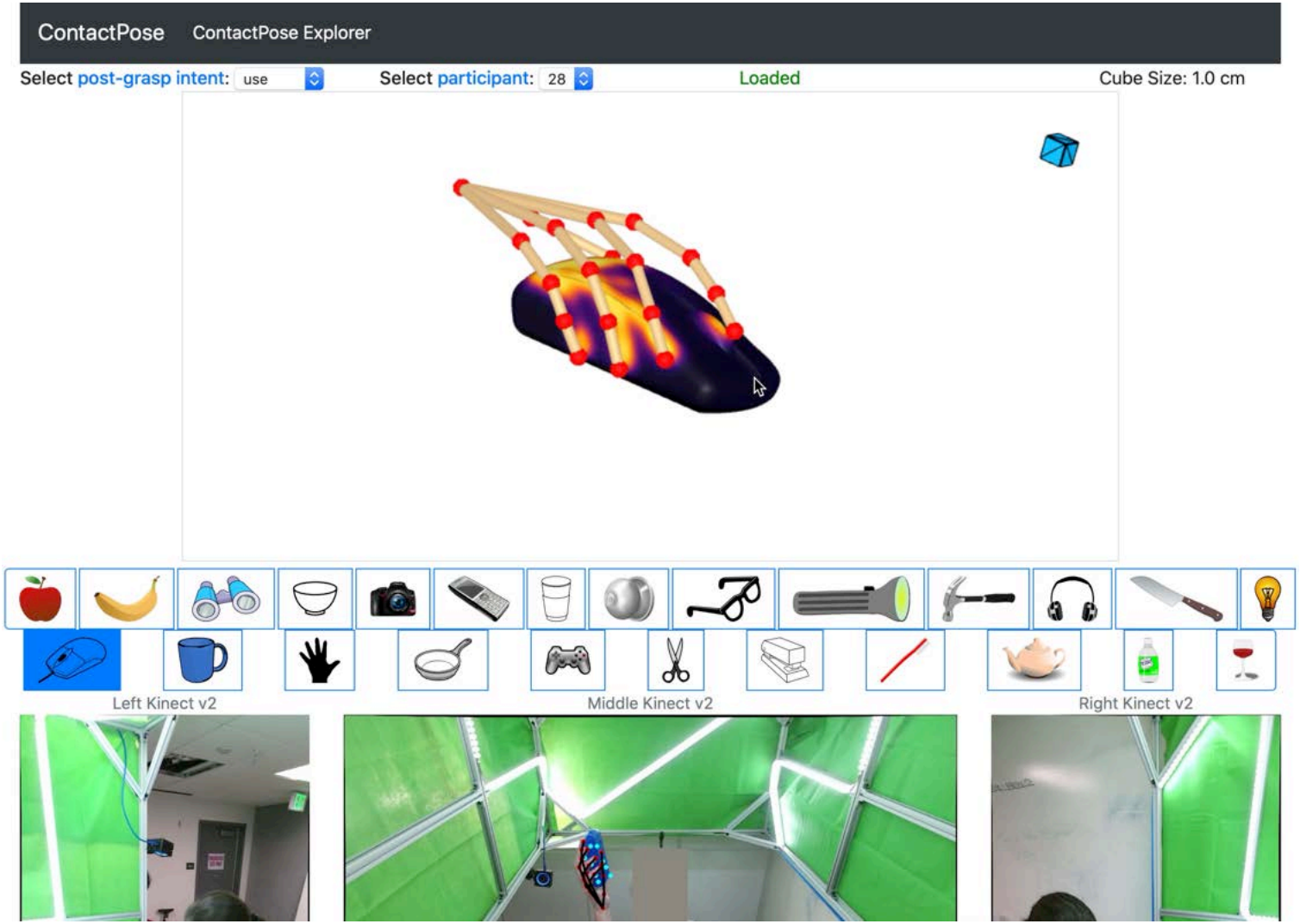


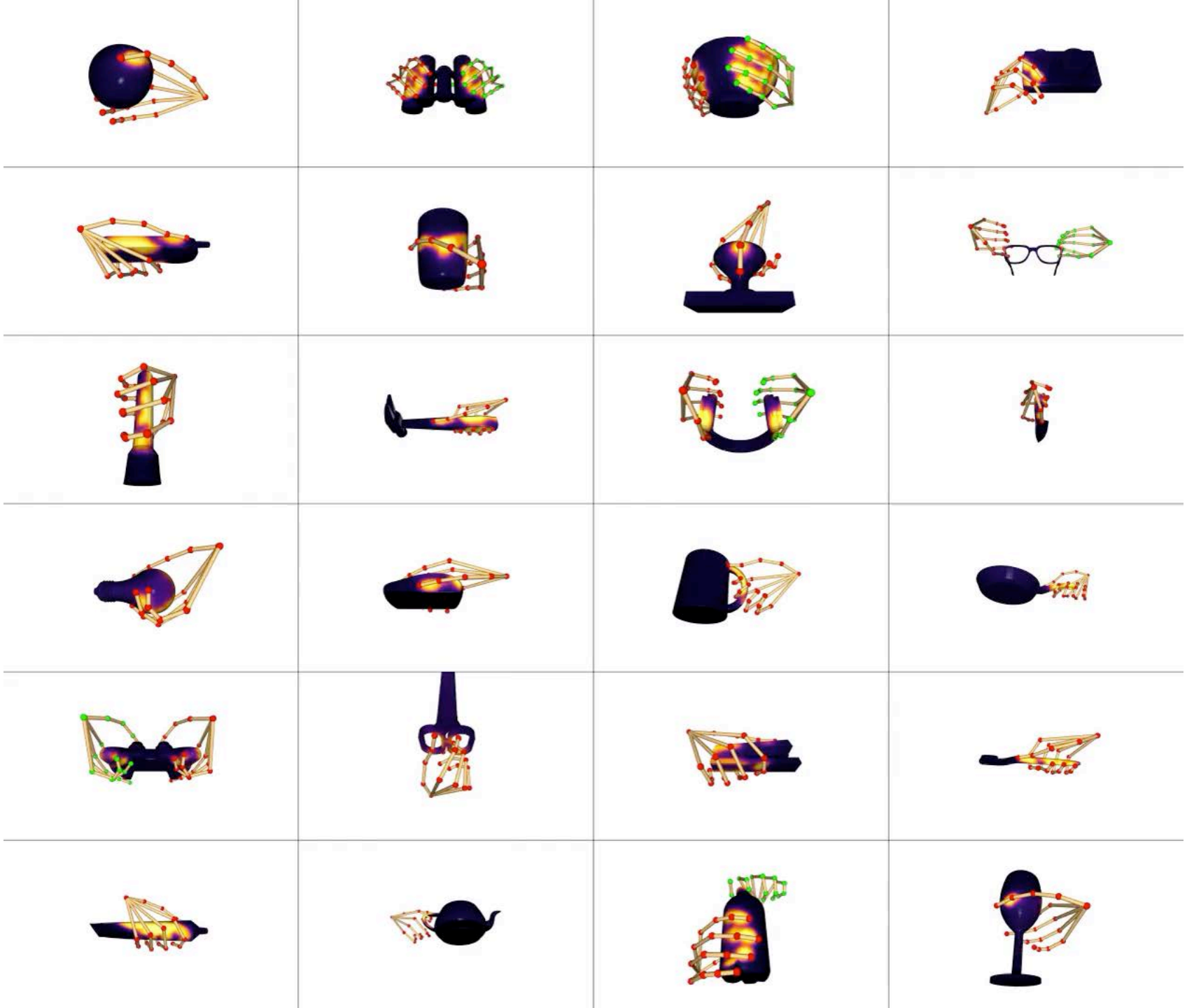
Hand Pose not used for prediction, shown for reference.

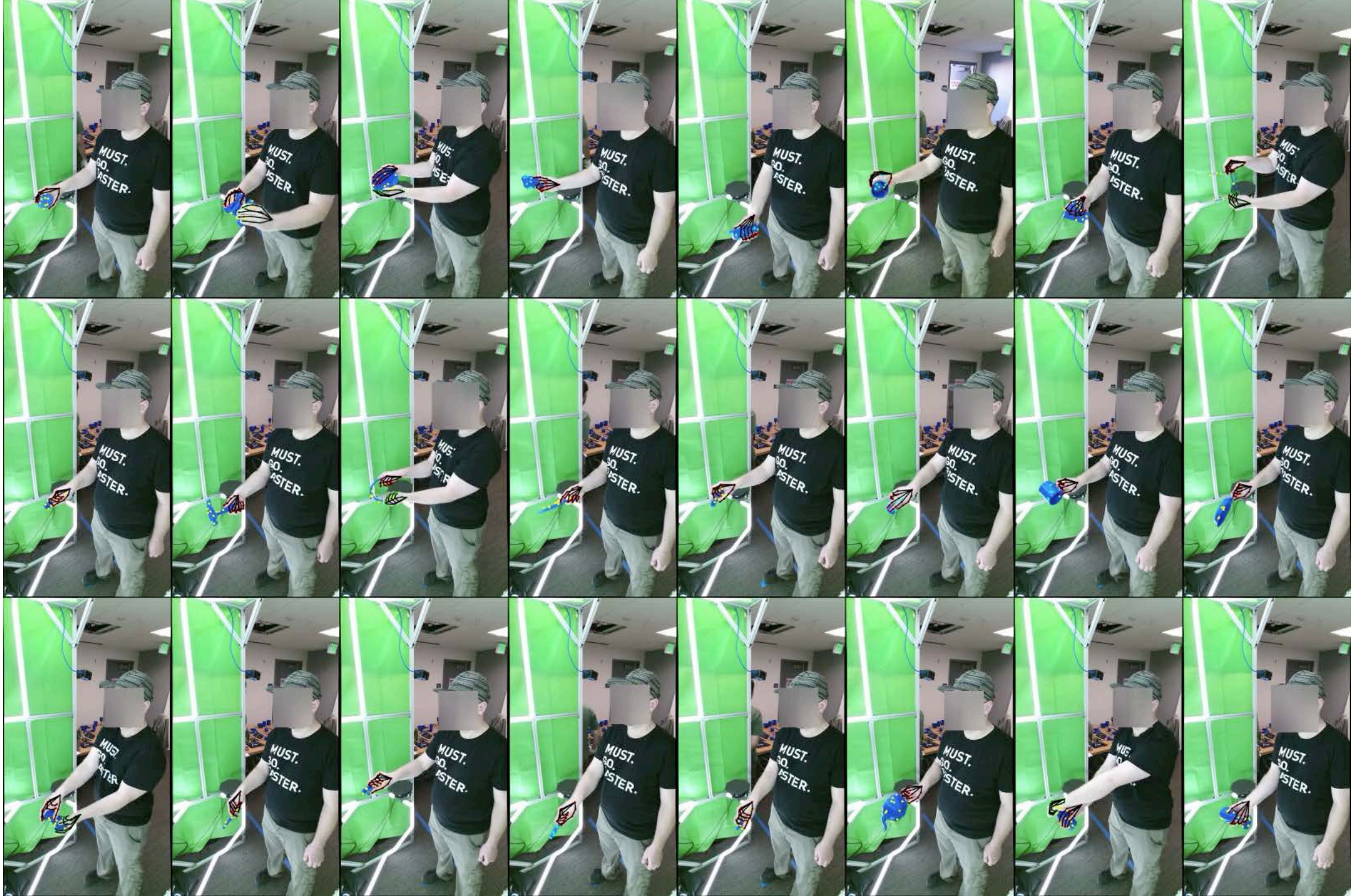
Contact Modeling Quantitative Results

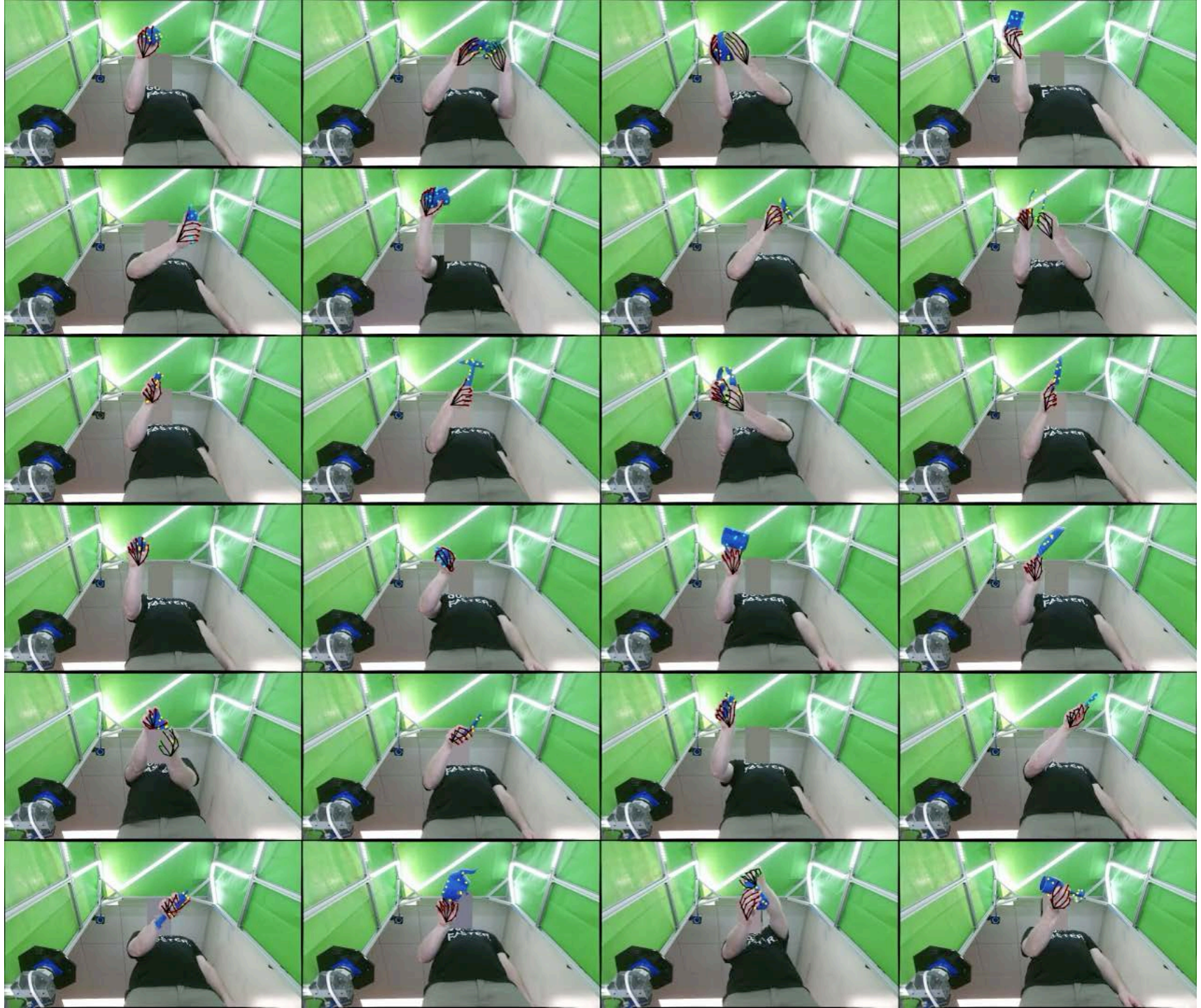


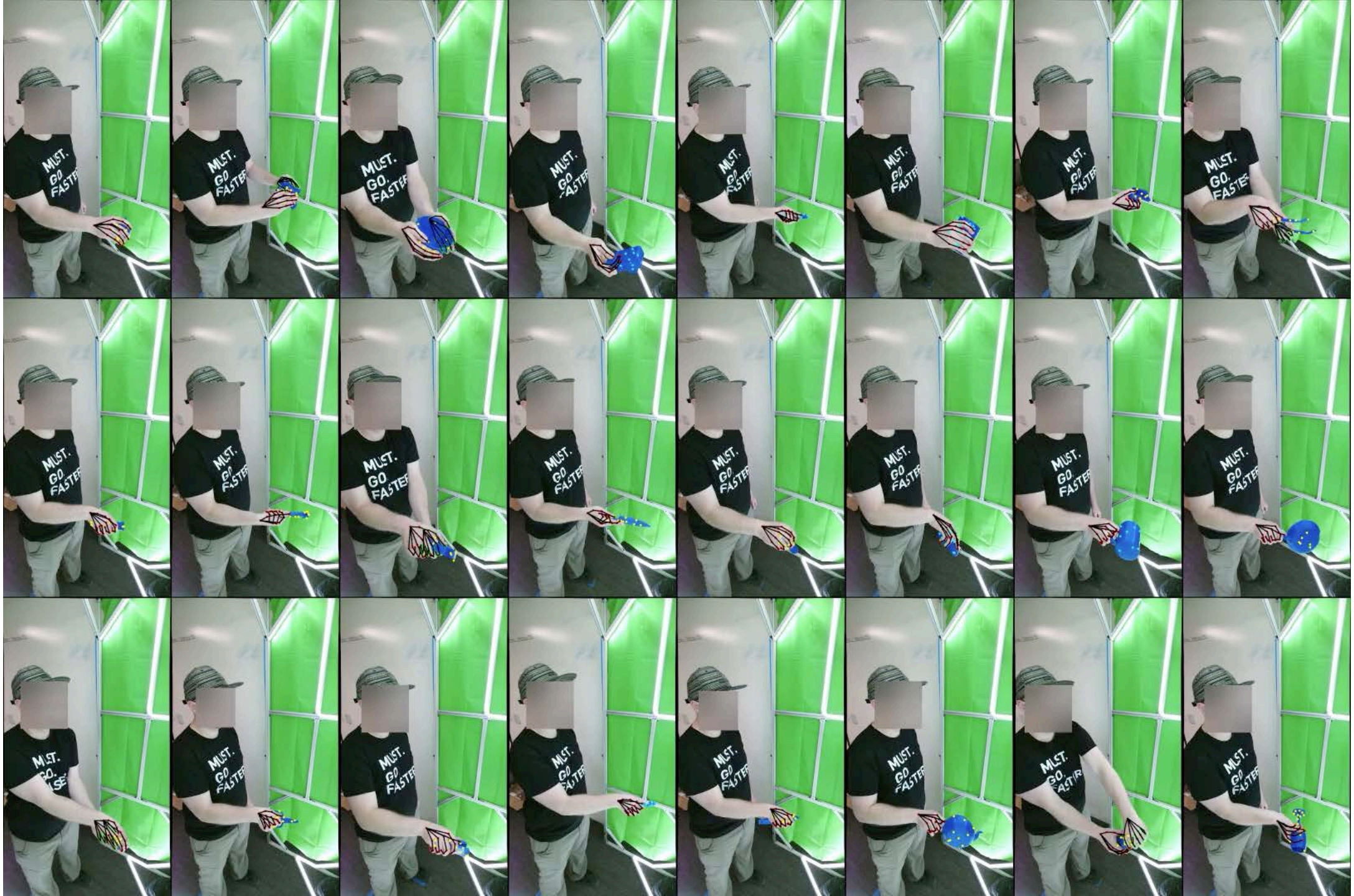
Data, Code and Models:
https://contactpose.cc.gatech.edu






MUST.
GO.
FASTER.

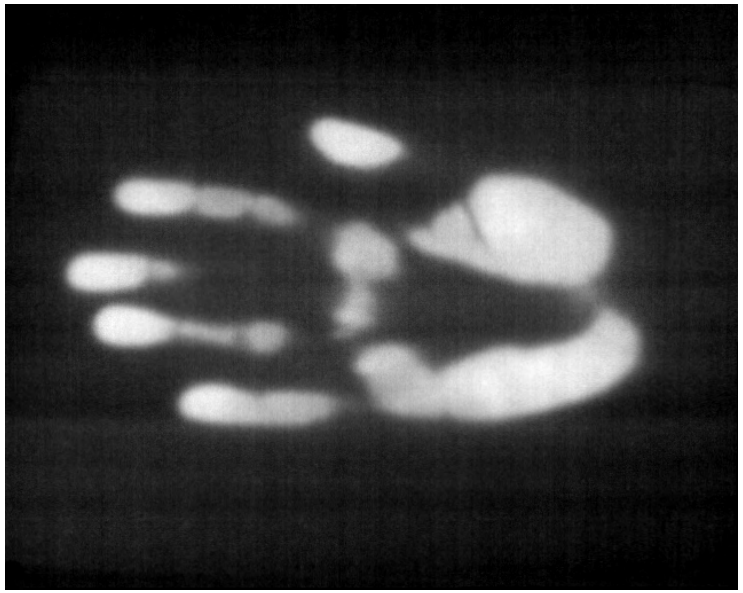



MUST.
GO
FASTER

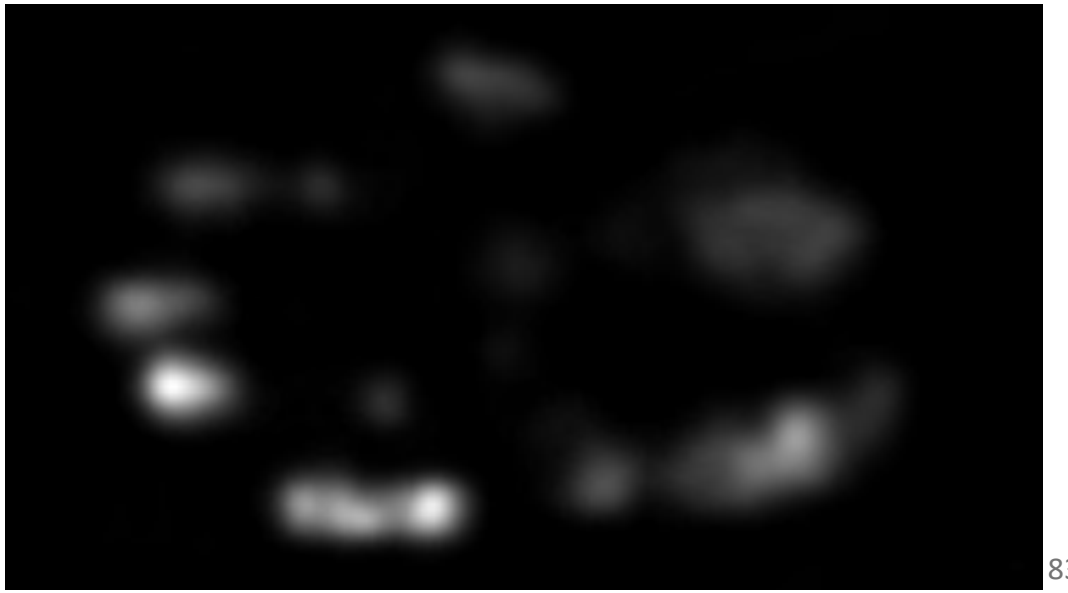
Capturing Contact

- Pressure is exerted
- Heat is transferred

Higher spatial resolution
Works for arbitrary surface shapes
No surface instrumentation

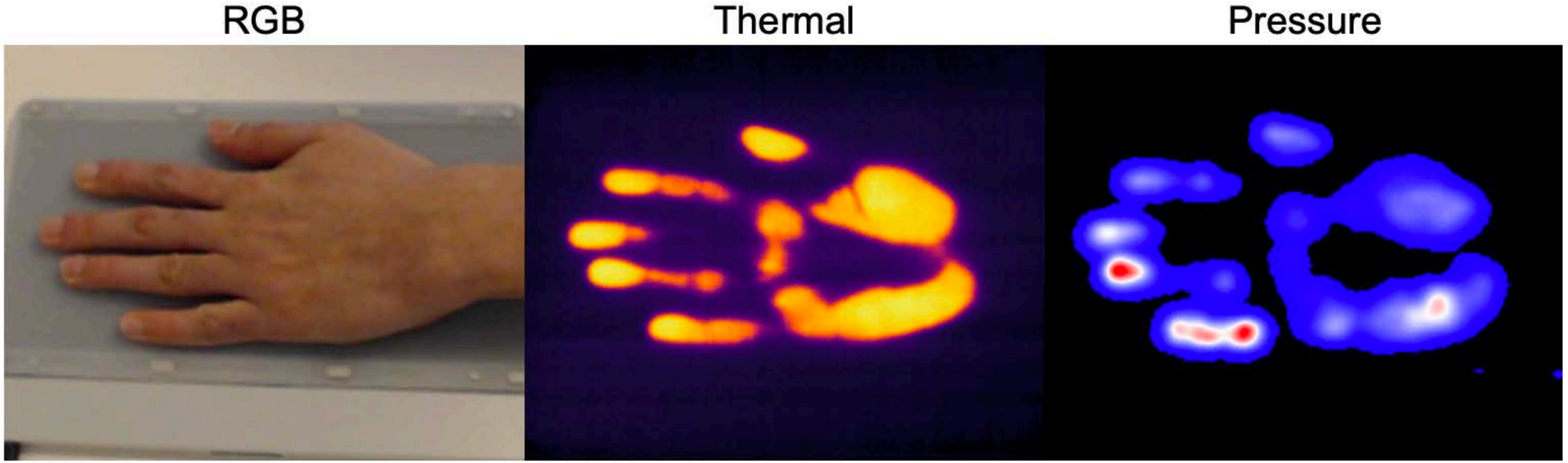


Thermal image

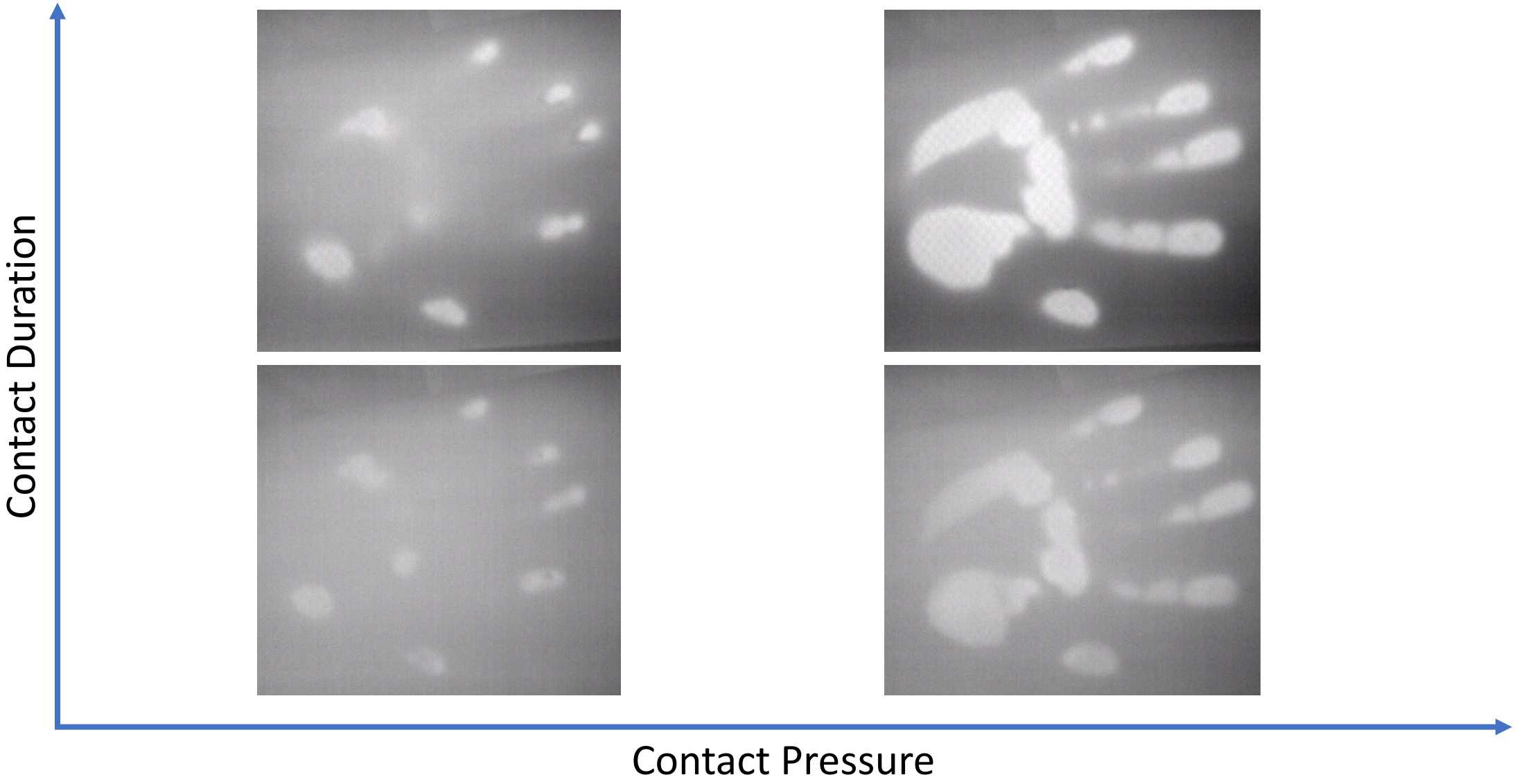


Pressure image from a Sensel Morph

Thermal Cameras: Contact Pressure Sensors?



Thermal Cameras: Contact Pressure Sensors?



Thank You

https://samarth-robo.github.io