Mid-term Project Presentation:

Improvement on Bimanual Grasp Pose Synthesis

Team 3

Seungwan Kang, Hajun Park

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1. Introduction & Motivation : Bimanual Dexterous Grasping

1.1. Introduction to Dexterous Grasping

1.2. Unimanual to Bimanual

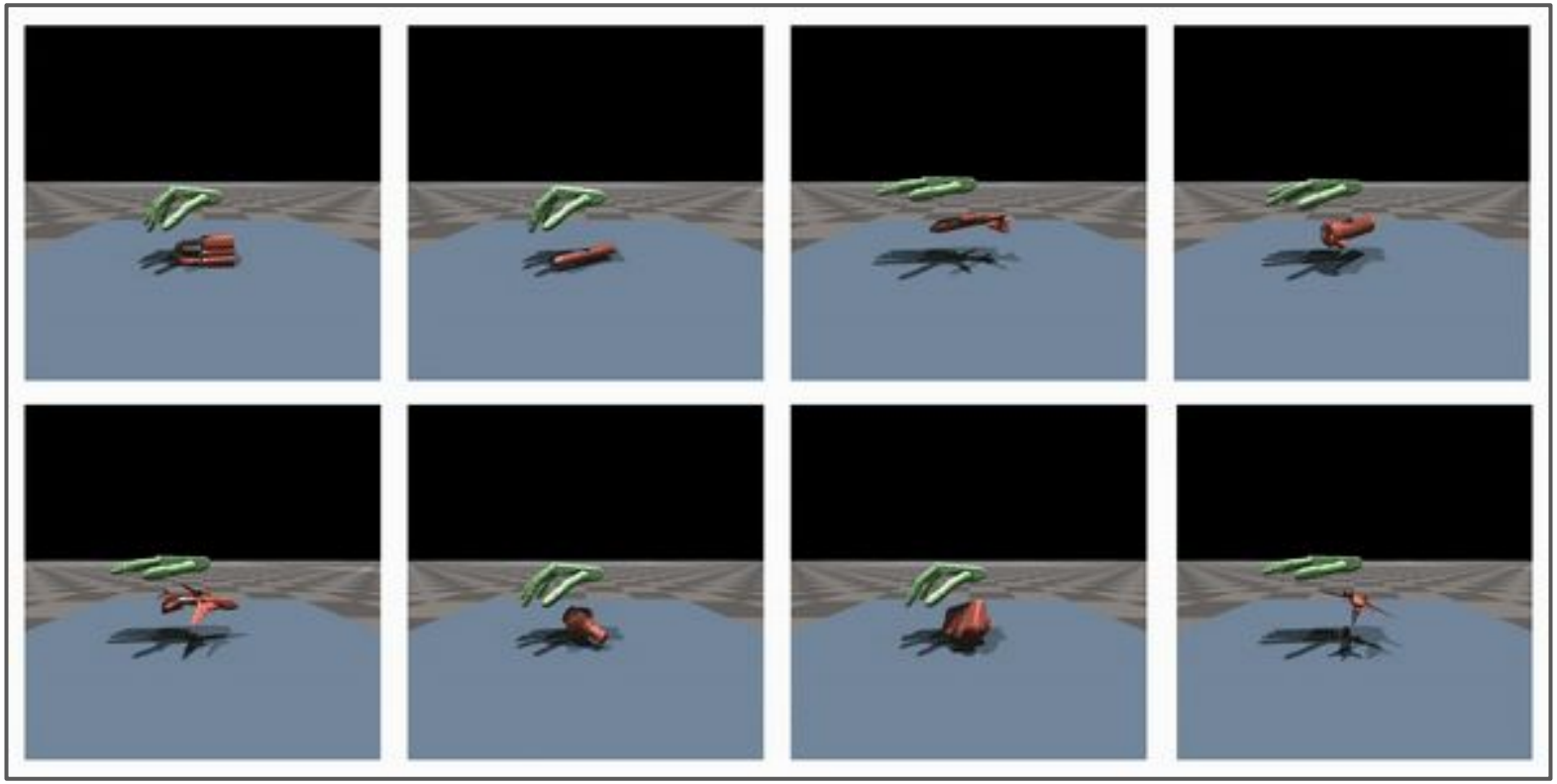
1.1. Introduction to Dexterous Grasping

Emergence of dexterous hands alongside the evolution of humanoid robots

- Image from Unitree, Dex5

1.1. Introduction to Dexterous Grasping

Significant progress has been made in one-hand dexterous grasping

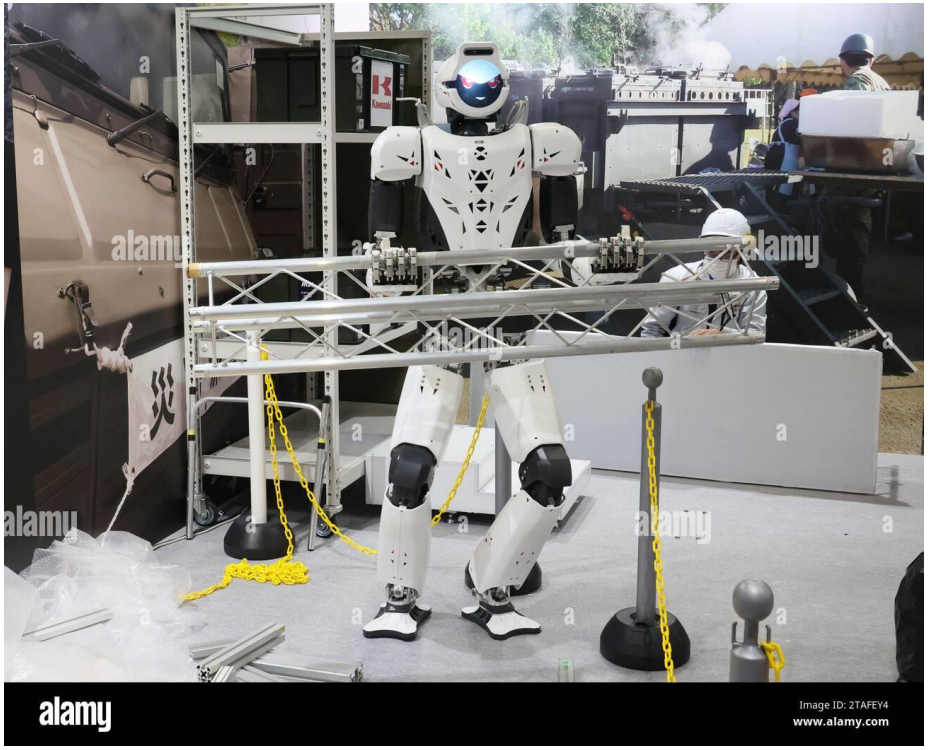


- Image from UniDexGrasp++ (W. Wan, et al)

1.2. Unimanual to Bimanual

A consideration in unimanual grasping

- Always graspable object in size and weight….
- How about bigger and heavier object?



- Image from alamy

1.2. Unimanual to Bimanual

Why do we have to consider Two Hands?

① Objects in the real world vary in size and weight.

② Humans and humanoid robots are equipped with two hands - we should leverage this capability.

③ Using both hands can also improve abilities(speed, efficiency) and reliability in performing sequential tasks.

Prehensile Manipulation (grasping)

Non-Prehensile Manipulation (in-hand, pushing, …)

1.2. Unimanual to Bimanual

Why should we develop different strategies for bimanual grasping?

Method	$\rho = 5000$	$\rho = 2500$	$\rho = 500$
Both Hands (Optimization)	**41.02%**	**54.03%**	**71.42%**
Uni2Bim (opt)	32.87%	45.26%	56.69%
Left Hand Only	23.38%	41.48%	68.42%
Right Hand Only	21.85%	41.95%	68.48%
Both Hands (Diffusion)	**42.39%**	**54.06%**	**69.87%**

- Unimanual grasp policy and synthesis method does not consider the **interaction & cooperation** between two hands.

- We need integrated policy and dedicated large-scale datasets for the bimanual grasping!

[1] Bimanual Grasp Synthesis for Dexterous Robot Hands (ICRA, 2025)

2. Overview of Related Works

2.1. Unimanual Dexterous Grasping

2.2. Bimanual Dexterous Grasping

2.1. Unimanual Paper (1)

DexGraspNet: A Large-Scale Robotic Dexterous Grasp Dataset for General Objects Based on Simulation (ICRA 2023)

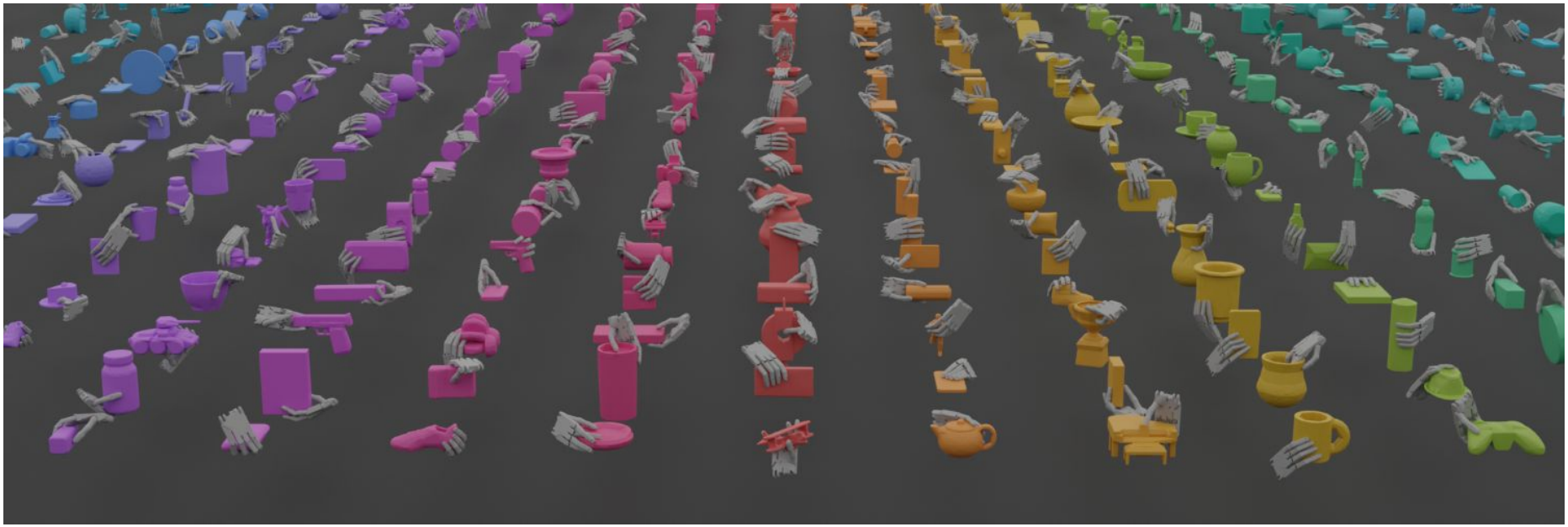


TABLE I: Dexterous Grasp Dataset Comparison

Dataset	Hand	Observations	Sim./Real	Grasps	Obj.(Cat.)	Grasps per Obj.	Method
ObMan [14]	MANO	-	Sim.	27k	2772(8)	10	*GraspIt!*
HO3D [15]	MANO	RGBD	Real	77k	10	>7k	Estimation
DexYCB [16]	MANO	RGBD	Real	582K	20	**>29k**	Human annotation
ContactDB [17]	MANO	RGBD+thermal	Real	3750	50	75	Capture
ContactPose [18]	MANO	RGBD	Real	2306	25	92	Capture
DDGdata [9]	ShadowHand	-	Sim.	6.9k	565	>100	*GraspIt!*
DexGraspNet (Ours)	ShadowHand	-	Sim.	**1.32M**	**5355(133)**	>200	Optimization

2.1. Unimanual Paper (1)

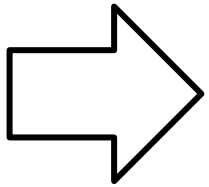
DexGraspNet: A Large-Scale Robotic Dexterous Grasp Dataset for General Objects Based on Simulation (ICRA 2023)

Method: Differentiable Force Closure [2]

→ Optimization with differentiable force closure estimator as an energy term

- **Energy terms**

E_fc: force closure estimation
E_dis: ensure contact
E_pen: prevent penetration
E_spen: penalize self-penetration
E_joints: penalize out-of-limit joint angles



$$E_{fc} + w_{dis}E_{dis} + w_{pen}E_{pen} + w_{spen}E_{spen} + w_{joints}E_{joiints}$$

→ Optimized with MALA optimizer
: MALA is basically gradient- guided exploration with correction

[2] Synthesizing diverse and physically stable grasps with arbitrary hand structures using differentiable force closure estimator (RA-L, 2021)

2.1. Unimanual Paper (2,review)
DexGrasp Anything

- Generate pose using **DDPM based diffusion model**
- Achieved SOTA performance in unimanual grasping

2.2. Bimanual Paper (base paper)

Bimanual Grasp Synthesis for Dexterous Robot Hands (ICRA 25)

Goal

- **Generate bimanual grasping pose**
  which can also grasp big and heavy objects

Problems

- No previous work and dataset
- Much higher DoF: (22+6) × 2 = 56 dim

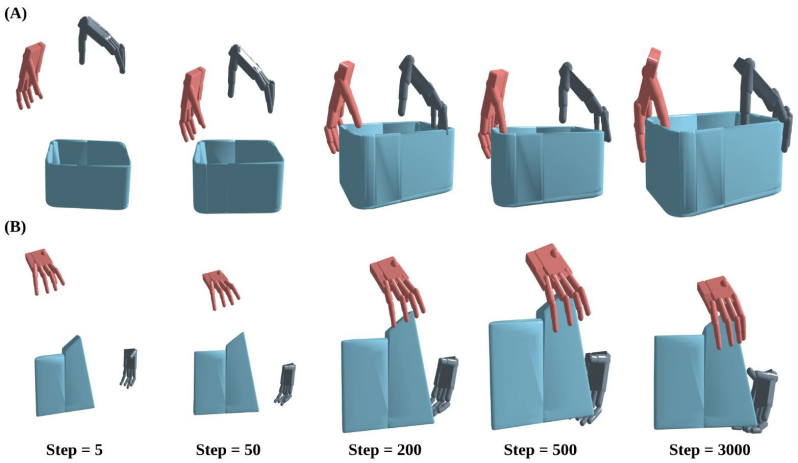
Solution: BimanGrasp-DDPM Algorithm

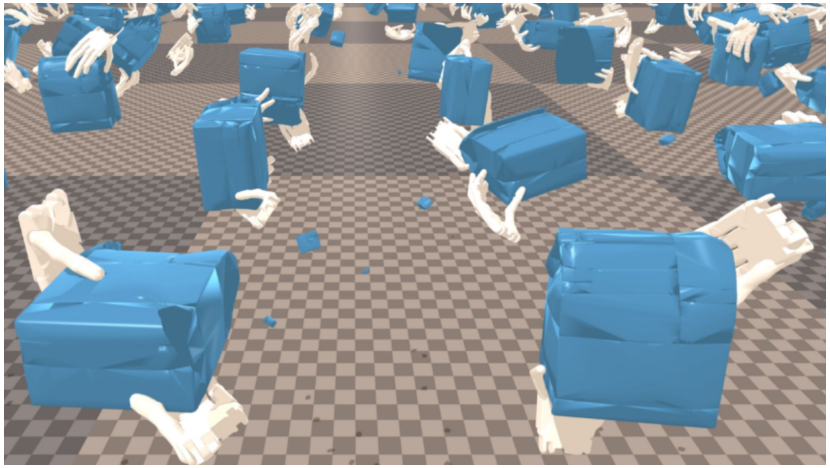
2.2. Bimanual Paper (base paper)

Bimanual Grasp Synthesis for Dexterous Robot Hands (ICRA 25)

BimanGrasp Algorithm

- Generate Dataset considering Energy term of
  Hand-Object Distance, **Force Closure** and **Penetration**





DDPM Algorithm

- Generate pose using diffusion model and
  execute few optimization to avoid penetration

2.2. Bimanual Paper (base paper)

Bimanual Grasp Synthesis for Dexterous Robot Hands (ICRA 25)

Result

Method	$\rho = 5000$	$\rho = 2500$	$\rho = 500$
Both Hands (Optimization)	**41.02%**	**54.03%**	**71.42%**
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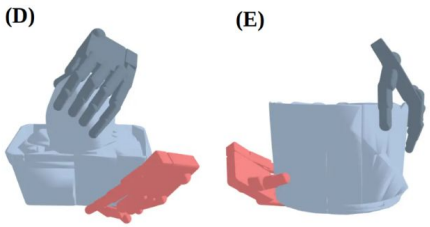


Limitation

- Low performance as it is first trial paper
- Penetration is not considered in DDPM model

3. Problems & How to Improve

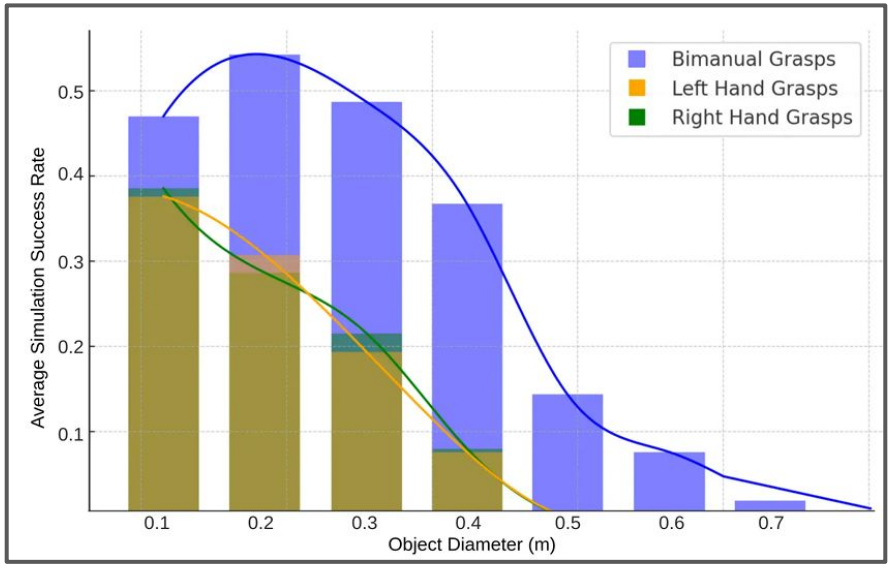
3.1. Optimization-Based: Problems

3.2. Optimization-Based:
Initialize with candidate force closure area pair

3.3. Diffusion-Based: Weight maximum density

3.1. Optimization-Based: Problems

Recap: Energy terms in Bimanual Grasp Synthesis for Dexterous Robot Hands (ICRA 25)



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3.1. Optimization-Based: Problems

Recap: Energy terms in Bimanual Grasp Synthesis for Dexterous Robot Hands (ICRA 25)

TABLE I: Energy function for grasp search problem. The minimization objective of the algorithm is the weighted sum of all terms.

Term	Formulation
E_{dis}: Hand-object distance	$\sum_{a=1}^{n} d(x_a, O)$
E_{fc}: Force Closure	$\|\|\boldsymbol{Gc}\|\|_2$
E_{vew}: Wrench Ellipse Volume	$\left(\det\left(\mathbf{G}\mathbf{G}^T\right)\right)^{-\frac{1}{2}}$
E_{objpen}: Hand-Object Penetration	$\sum_{l\in\{1,2\}} \sum_{p_l\in P(H_l)} \max(\delta - d(p_l, O), 0)$
E_{selfpen}: Hand Self-Penetration	$\sum_{l\in\{1,2\}} \sum_{p,q\in P(H_l)} \max(\delta - d(p, q), 0)$
E_{bimpen}: Inter-Hands Penetration	$\sum_{p\in P(H_1), q\in P(H_2)} \max(\delta - d(p, q), 0)$
E_{joint}: Violation of Joint Limits	$\sum_{i=1}^{44} (\max(\theta_i - \theta_i^{max}, 0) + \max(\theta^{min} - \theta_i, 0))$

3.1. Optimization-Based: Problems

Recap: Energy terms in Bimanual Grasp Synthesis for Dexterous Robot Hands (ICRA 25)

E_{bimpen}: Inter-Hands Penetration $\sum_{p \in P(H_1), q \in P(H_2)} \max(\delta - d(p, q), 0)$

Problems of E_bimpen

- Adding only inter-hands penetration energy term may not be sufficient to reflect interaction b/w two hands
- May overlap with or weaken other penetration terms

Problems of utilizing similar method with DexGraspNet

- It might not works well for exploiting two hands
- Low performance in small size objects
- Originally, DexGraspNet(dataset for unimanual) have its flaw on that it always gets contact-rich and power-grasp
  - it means that it does not explicit its dexterity
  - so, may struggle in generating functional grasps

3.2. Optimization-Based:

Initialize with candidate force closure area pair

Problem

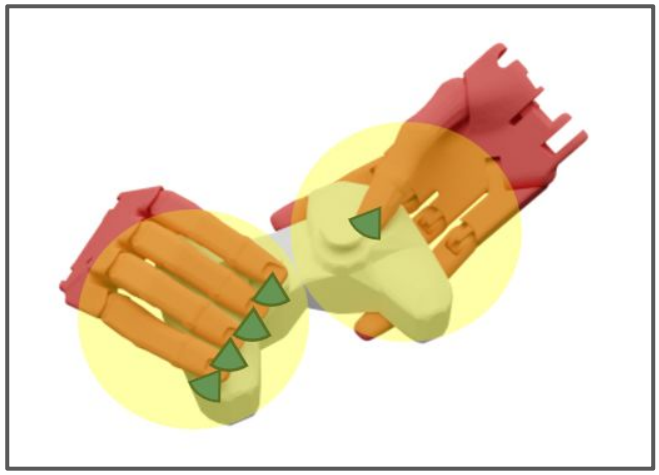
- Initial state doesn't consider geometric information
- Only 33% can pass criteria for dataset (2 second grasping)

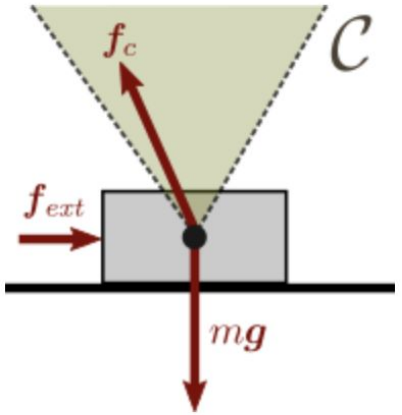
Ideation

- Select candidate pair that can make grasp stable

Planning Trial

- Make integration of **Friction Cone** in two area cover whole direction





- figure of friction cone

3.3. Diffusion-Based:

Weight maximum density

Problem

- Generated Poses are successful in fixed density
- All data are weighted same

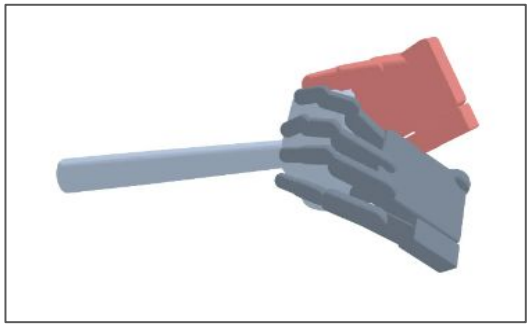
Ideation

- Add row about stability of each dataset
- Weight each stability while training DDPM

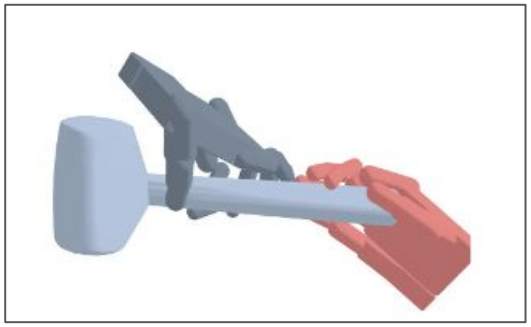
Planning Trial

- Add CFG term in DDPM
  give maximum success density as guidance

Example



weight: 2500 $kg \cdot m^{-3}$



weight: 7500 $kg \cdot m^{-3}$

4. Our Progress

4.1. Progress on Code

4.1. Our Progress

What we need to develop and test our idea…

- Codes
  - grasp generator
  - grasp validation
  - energy calculation, point sampling, optimizer, …
- Files
  - 3D objects meshes
  - Hand meshes

We are currently working based on DexGraspNet code:
https://github.com/PKU-EPIC/DexGraspNet.git

You can find our progress and development at:
https://github.com/dareumHJ/cs586.git

Thank you

Q&A