SIGGRAPH ASIA 2020 VIRTUAL
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Learning 3D Functionality Representations

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Speakers

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Learning 3D Functionality Representations

- What is this course about?
  - Cover recent developments that incorporate **functionality** considerations into **shape analysis** in **computer graphics**
  - For the analysis of **3D objects** and **scenes**
  - Discuss work **in learning 3D representations for functionality** and its connections to **deep learning, computer vision, and robotics**
  - Course targeted at **researchers** and **students**

Learning 3D Functionality Representations

- Differences to our SIGGRAPH Asia 2016 course on *Directions in Shape Analysis towards Functionality*:
  - We provide an **organizational framework** to classify prior work
  - We connect functionality to recent works **on learned 3D representations**, especially to connect it to deep learning, computer vision, and robotics

Outline

- Introduction
  - Concept of functionality
  - Motivation: semantics versus functionality in shape analysis
  - Example applications

- Overview of the remaining sections of the course

Course material

- The course material is available at our course Web page:

  https://learn3dfunc.github.io/

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Introduction

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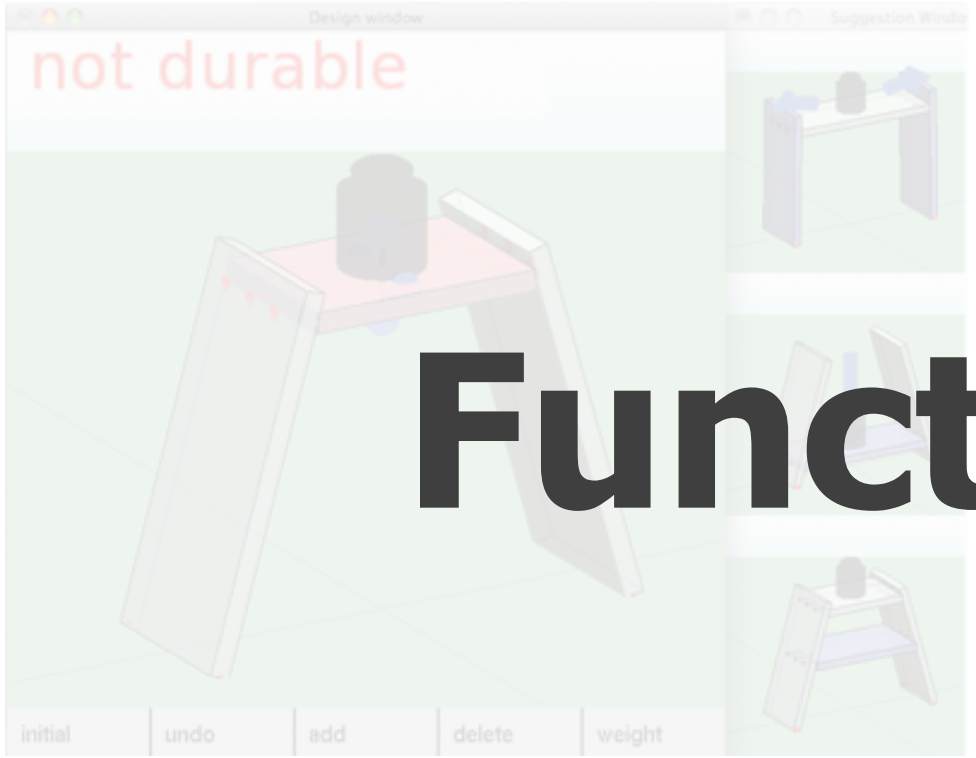
Shape design and simulation



Functionality

Furniture Design
[UIM12]

Motion simulation
[HLK*17]

What is functionality?

- "The particular use for which an object is designed"

-- [Merriam-Webster dictionary]

What is functionality?

- "The application of an object in a specific context for the accomplishment of a particular purpose" [BB95]

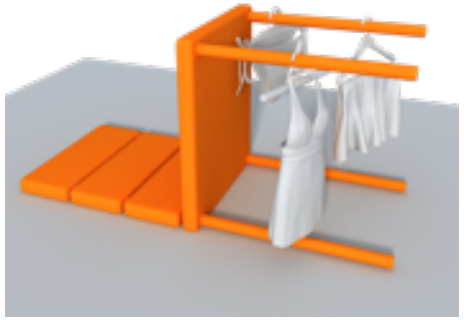
Object recognition vs. functionality recognition

What is this? ➡ Chair

What can we do with this?

Chair

Handcart



Drying Rack

...

Object recognition vs. functionality recognition

- "The essential definition of object classes is functional"

Handcart

Table

Shape analysis and semantics

Several approaches related to **shape understanding**

- Structure-aware shape processing
- Symmetry detection
- Data-driven shape analysis
- Generative models

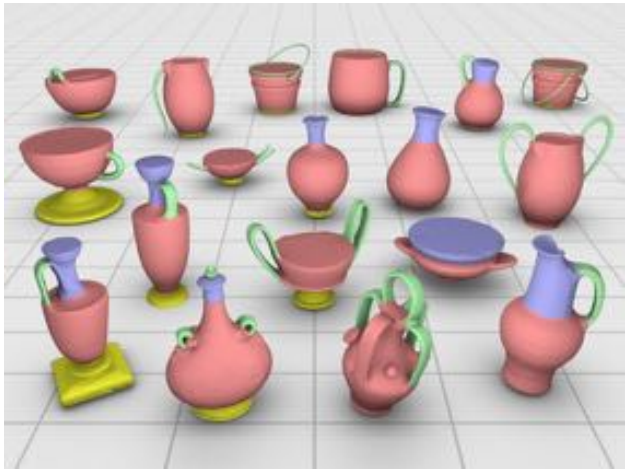
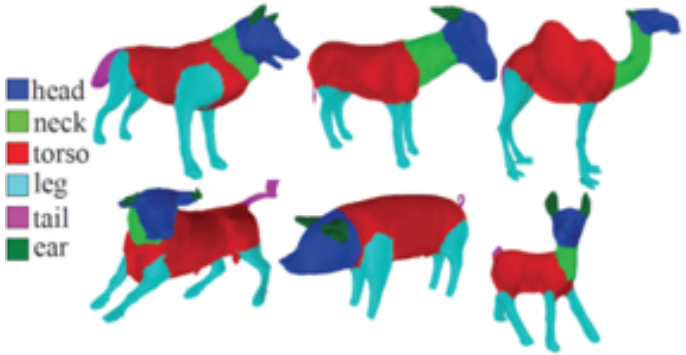
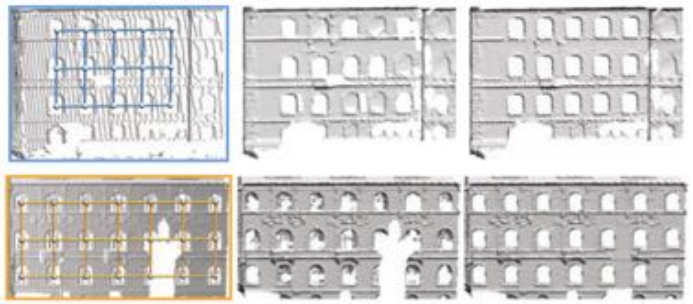
Shape analysis and semantics

Methods covered in **previous** courses, tutorials, and STARs:

- Symmetry in 3D geometry: Extraction and applications [MPWC12]
- Structure-aware shape processing [MWZ*13]
- Data-driven shape analysis and processing [XKHK17]
- Modeling and remodeling 3D worlds [YYAZ17]
- Learning generative models of 3D structures [CXRZ19]

Shape analysis and semantics

Three general **problems** related to **functionality** analysis:

Unsupervised segmentation	Supervised segmentation	Symmetry detection
		
[SvKK*11]	[KHS10]	[PMW*08]

Discussion

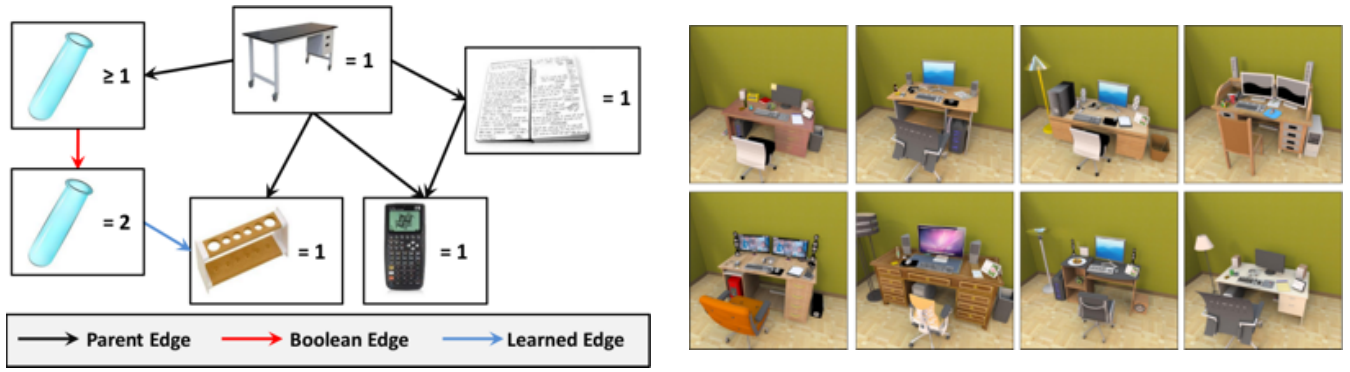
- Co-segmentation, symmetry analysis, and classification provide **part labels** and/or **correspondences** among shape **parts**
- Corresponding parts *likely* possess the same **functionality**
- There is some **relation** between **labels** and certain types of **functionality**, e.g., *chair seat* versus *sitting*
- Can constitute a **preliminary analysis** of functionality

Discussion

- Difficult to infer the true **functional similarity**
- Analysis based only on **geometry** and **structural** similarity
- The **functionality** is not directly **named** or **categorized**

Learning generative models of 3D structures

[LXC*17]



[FRS*12]

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Discussion

- Synthesis performed based on **geometric** and/or **structural** similarity of the shapes
- Synthesized shapes **resemble** exemplars in the training data
- Functionality preservation is **not** enforced nor guaranteed

Functionality vs. geometry

- Difference between “geometric appearance” and “functionality”

Challenges in functionality analysis

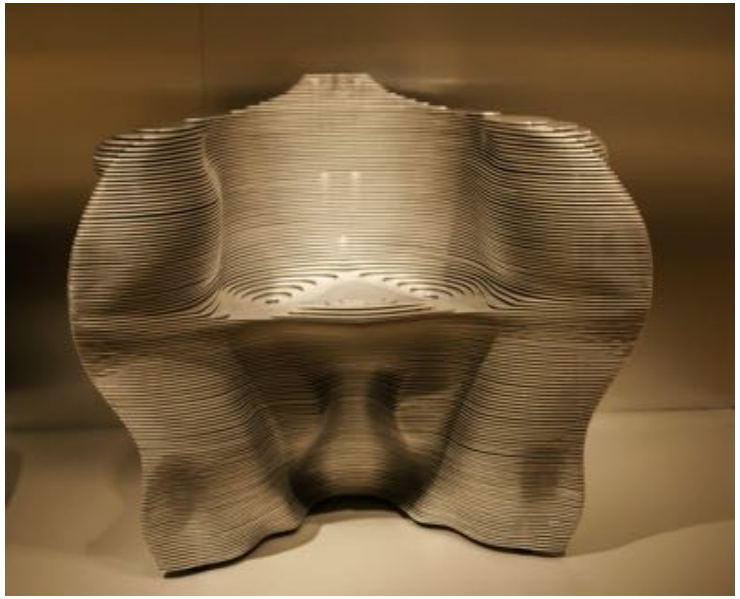
- Hard to handle large structural variations

Handcart

Table

Challenges in functionality analysis

- Hard to handle large **structural variations**
- Hard to establish the **connection** between **structure** and **functionality**



Modern chair by Valerie Everett

Halo modern chair by Michael Sodeau

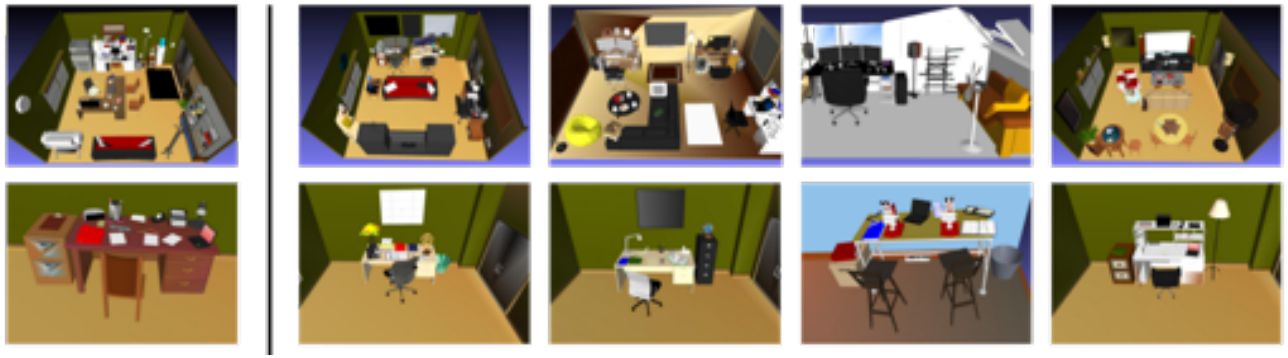
Functionality-aware processing

- **Shape analysis can benefit from functionality**
  - Incorporate a model of shape functionality to analyze and process 3D objects and scenes

- **Why?**
  - Several applications motivate this goal...

Functionality-aware applications

- **Object and scene retrieval**
- Scene synthesis
- Modeling and editing
- …



Scene retrieval [SCH∗14]

Object-in-scene retrieval [HZvK∗15]

Functionality-aware applications

- Object and scene retrieval
- **Scene synthesis**
- Modeling and editing
- …

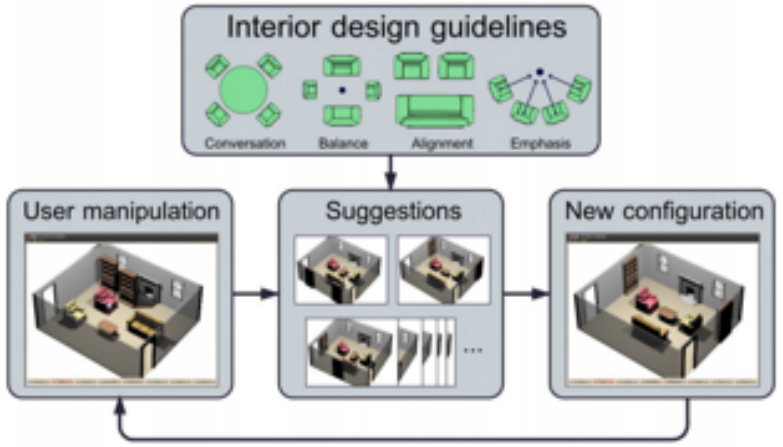
3D scene synthesis
[FSL*15]

Human interaction synthesis
[SCH*16]

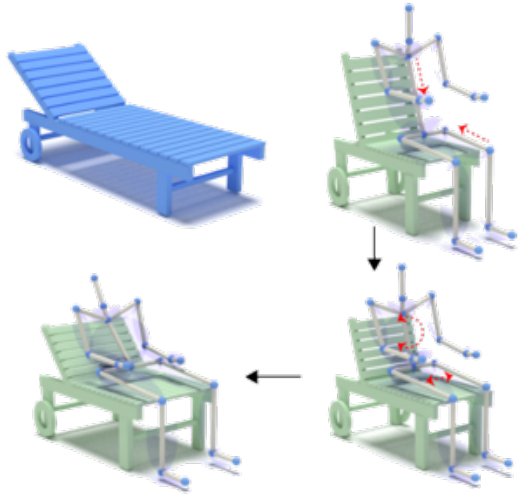
Functionality-aware applications

- Object and scene retrieval
- Scene synthesis
- **Modeling and editing**
- …

Object hybrid
[HvKW∗16]



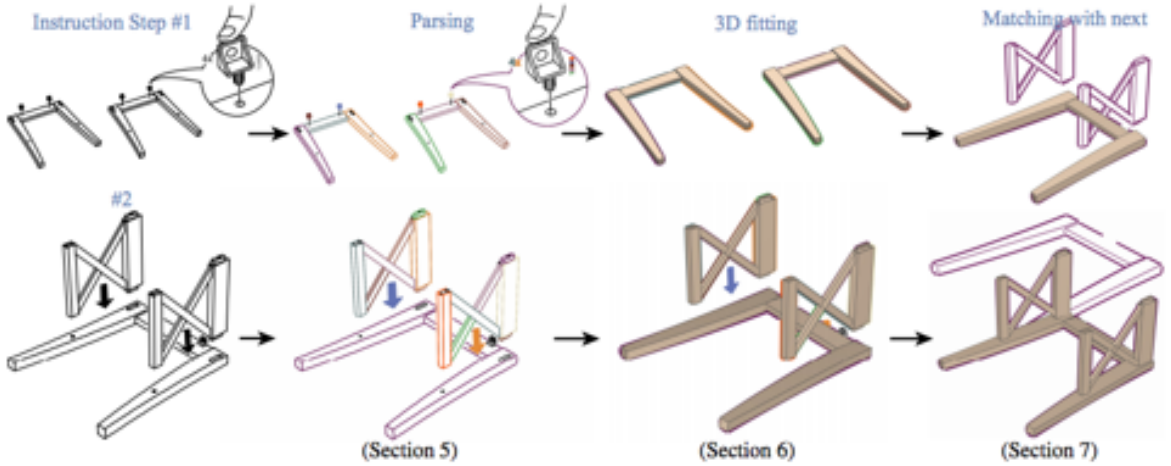
Scene editing
[MSL*11]



Object modeling
[ZLDM16]

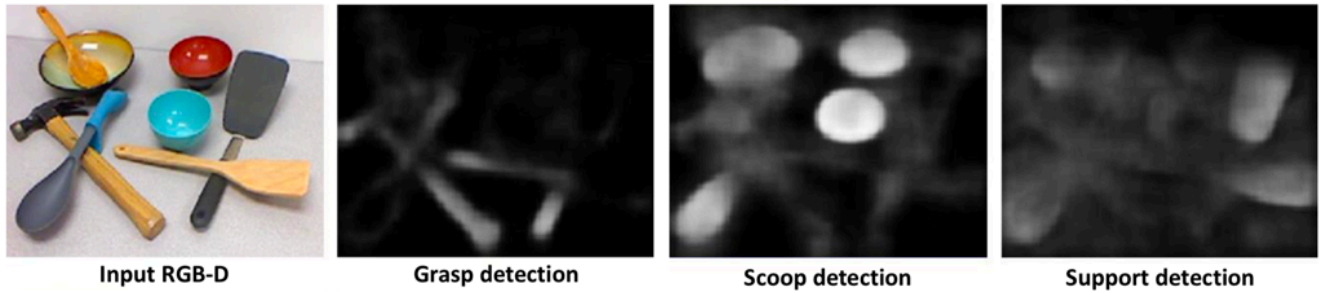
Functionality-aware applications

- Computer graphics is highly related to the virtual **prototyping** and mass **customization** revolution
- In **prototyping** and **customization**, an understanding of functionality is essential!
- A **fundamental problem**
- Still much to be done…

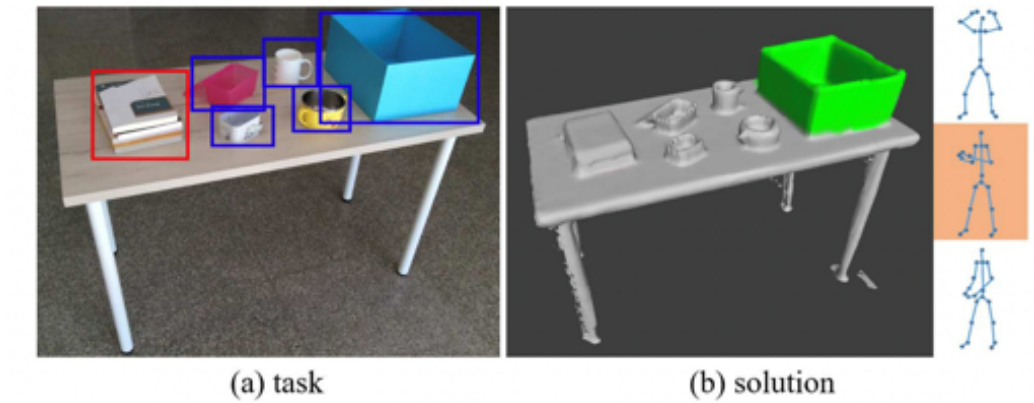


[SLR*16]

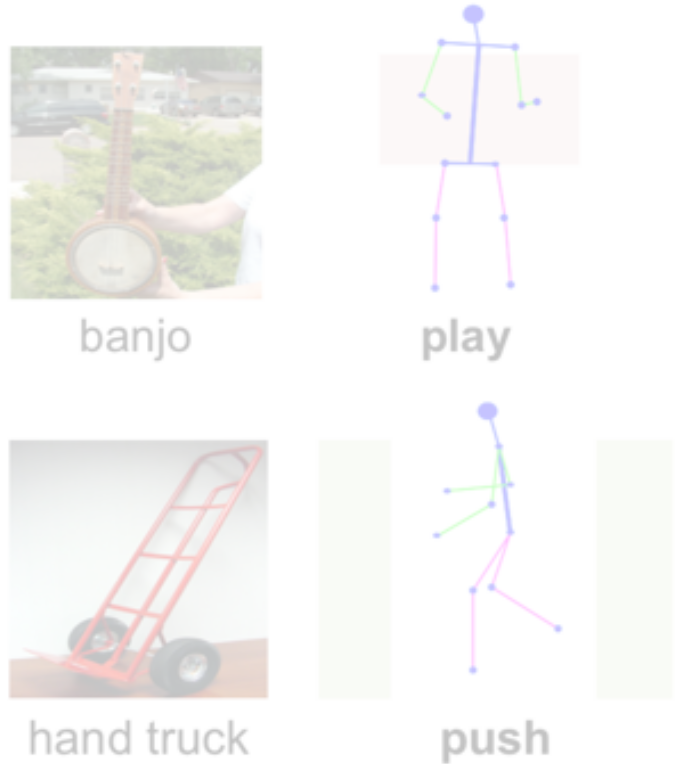
Functionality analysis in computer vision and robotics



Tool Affordance Detection [MTFA15]



Transferring Objects [WLY17]



Knowledge Base [ZFFF14]

What is this course about?

- The goal of this course
  - To provide a comprehensive survey of **functionality analysis** in **computer graphics** and related areas such as **computer vision**
- Audience
  - **Researchers** in graphics/vision
- Criteria
  - General **definition** of functionality

Research questions

- How to **represent** functionality?
- How to derive a functionality **model** from such representations?
- How to incorporate functionality models into **shape analysis** and **modeling**?
- How to **learn** such models?
- How to do all of this **efficiently**?
- …

Research questions

- In this course, we will provide a sampler of different **solutions** to these **questions** as given by existing work

- For various **problem domains** and targeting **diverse applications**

Outline

- Our definition of functionality (Oliver)
- Classification of prior works (Ruizhen + Manolis)
- Functionality-aware applications + future directions (Manolis)

Definition of functionality and classification criteria

Definition of functionality

- **Functionality: use** or **purpose** of an object

- "Function is the action for which a person or thing is specially fitted or used, or for which a thing exists (purpose)" [Merriam-Webster]

- "Functionality is the application of an object in a specific context for the accomplishment of a particular purpose" [BB95]

Our definition of functionality

Goals:

- **Constructive definition** of functionality
- Serve as a **classification guide** for existing work
- Define the functionality of an **entity**

Our definition of functionality

We follow our definition proposed in the following paper:

- Ruizhen Hu, Manolis Savva, and Oliver van Kaick, "**Functionality Representations and Applications for Shape Analysis"**, *Computer Graphics Forum (Eurographics State-of-the-art report)*, vol. 37, n. 4, pp. 603-624, 2018.

Our definition of functionality

Functionality = Geometry + Interaction

Our definition of functionality

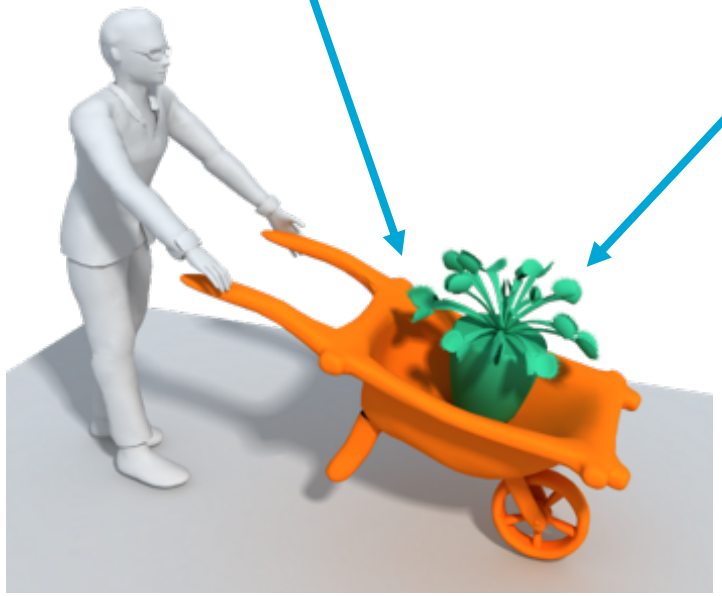
Functionality = Geometry + Interaction

"Form follows function" [Sul96]

Our definition of functionality

Functionality = Geometry + Interaction

Atomic interaction:
<Functional entity, relation, interacting entity>



Our definition of functionality

Functionality = Geometry + Interaction

Atomic interaction:
<Functional entity, relation, interacting entity>

Components of atomic interactions

- Type of **entity**
- Level of **entity**
- Type of **relation**
- Representation of the **relation**

Type of entity

- Static entity
- Dynamic entity
- Human(-oid) agent

Type of entity

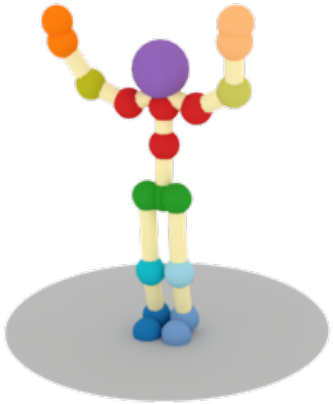
- **Static entity**
- Dynamic entity
- Human(-oid) agent

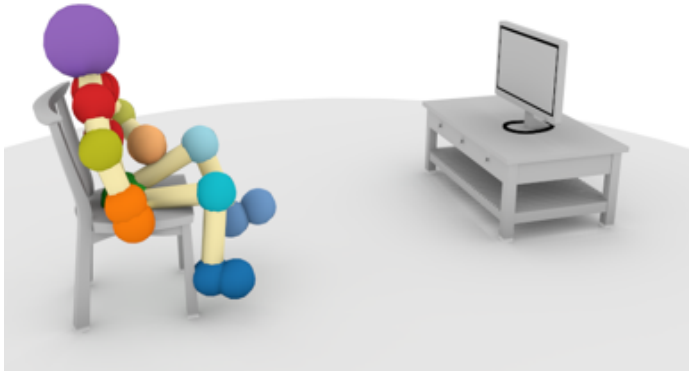
Type of entity

- Static entity
- **Dynamic entity**
- Human(-oid) agent

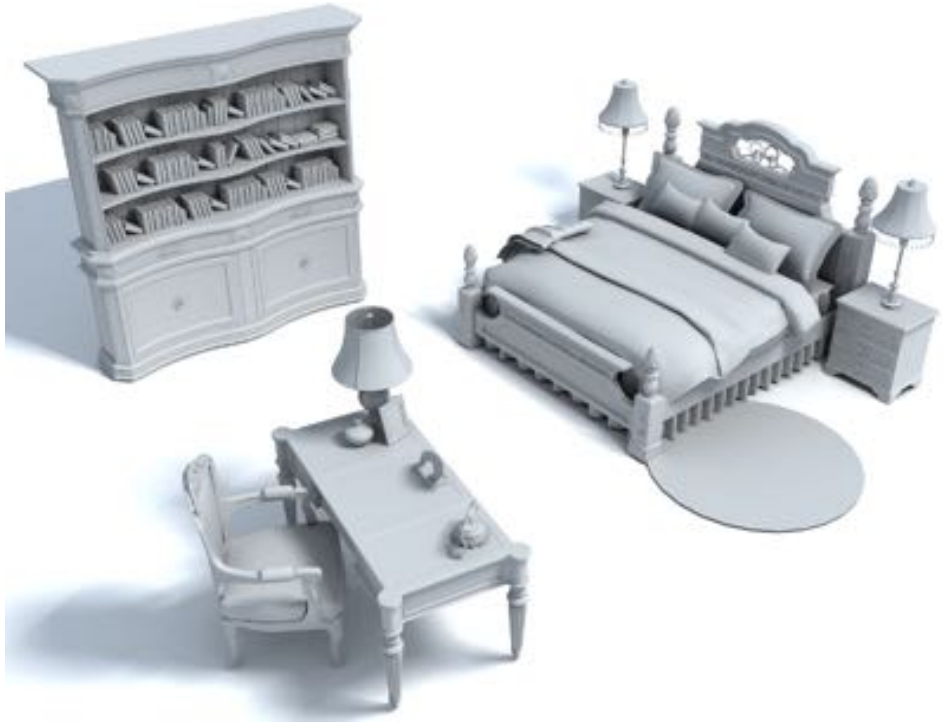
Type of entity

- Static entity
- Dynamic entity
- **Human(-oid) agent**

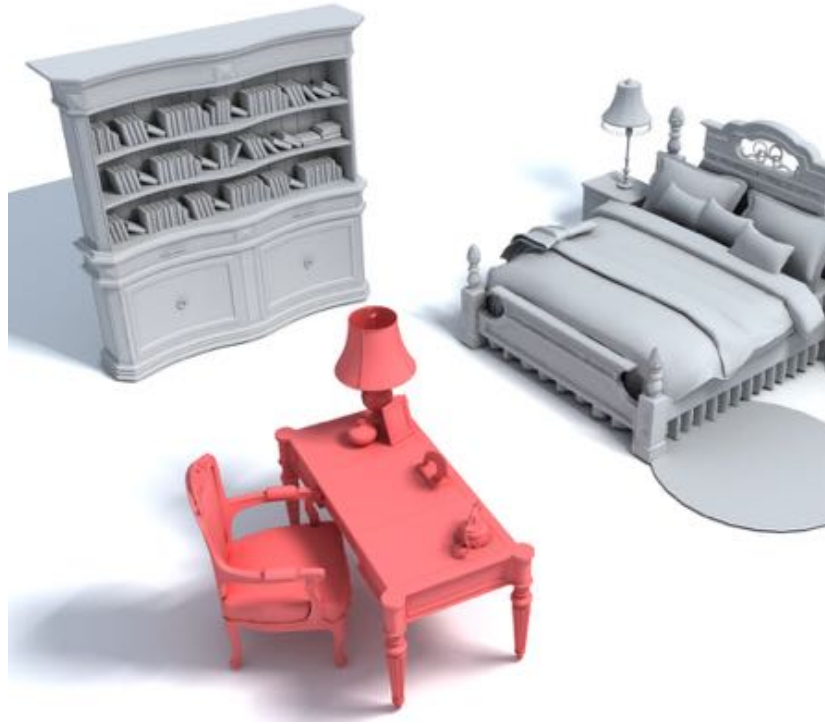




Level of entity



Scene



Multi-object

Type of relation

- Atemporal
- Time-varying

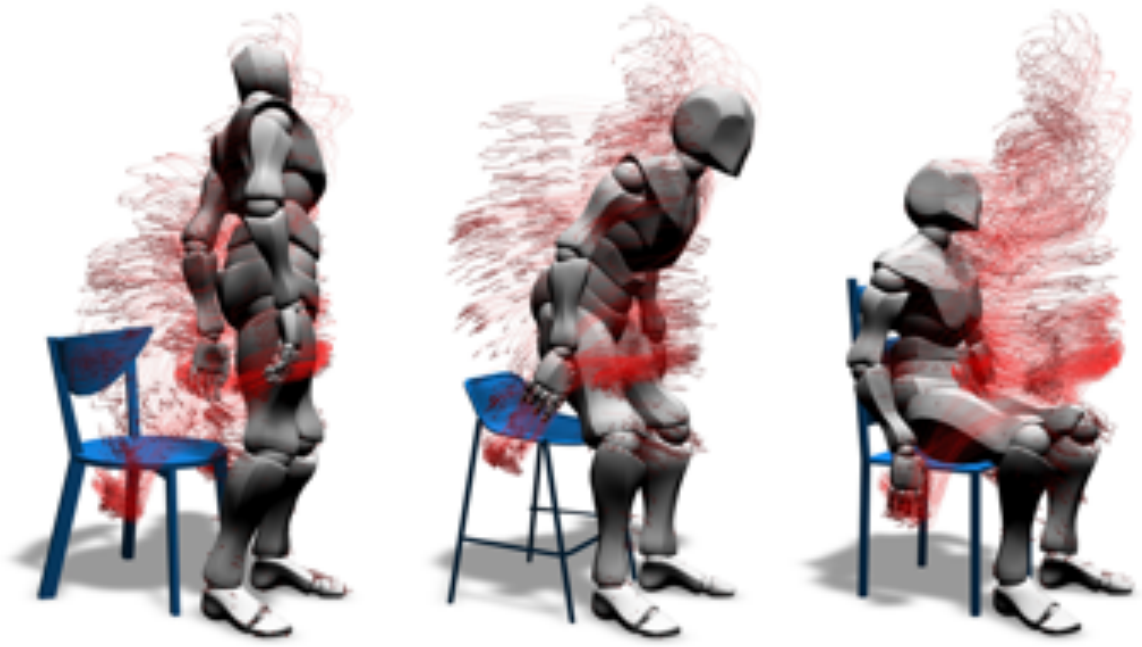
Type of relation

- **Atemporal**
- Time-varying

- ICON descriptor [HZvK*15]

Type of relation

- Atemporal
- **Time-varying**



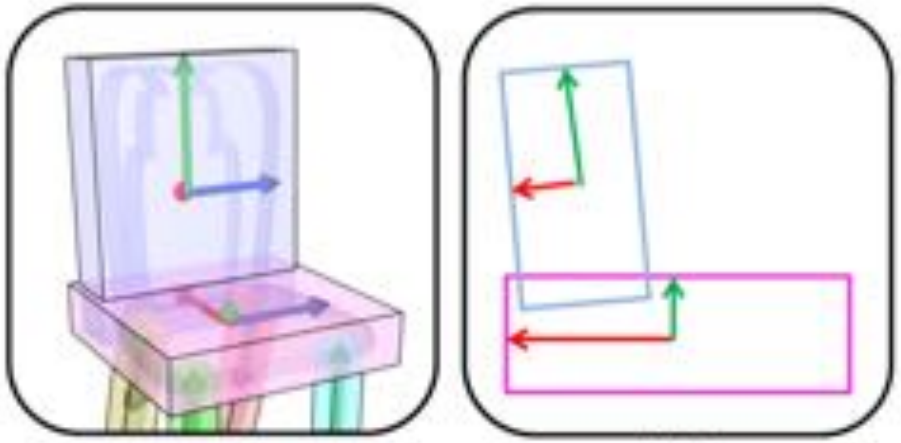
- Interaction landscapes [PKH*17]

Representation of the relation

- Spatial arrangement
- Boundary representation
- Dense volume feature
- Gestalt and symmetry grouping
- Mechanical relations
- Humanoid actions

Representation of the relation

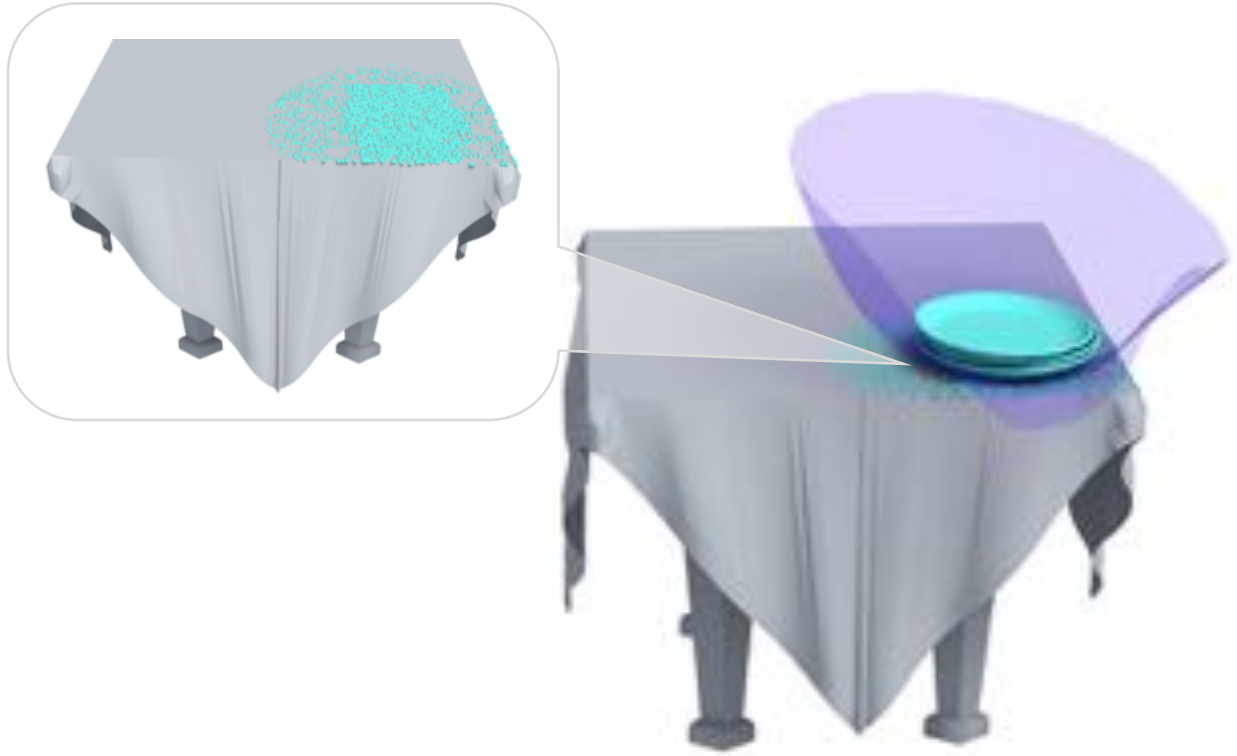
- **Spatial arrangement**
- Boundary representation
- Dense volume feature
- Gestalt and symmetry grouping
- Mechanical relations
- Humanoid actions



- Relative position
- Co-occurrence
- Gravitational support
- Attachment
- Enclosure
- RAID descriptor [GMW16]

Representation of the relation

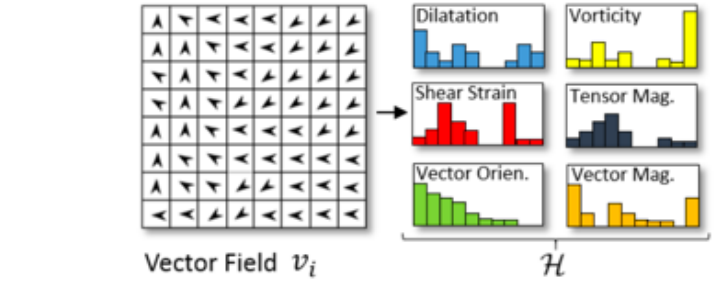
- Spatial arrangement
- **Boundary representation**
- Dense volume feature
- Gestalt and symmetry grouping
- Mechanical relations
- Humanoid actions

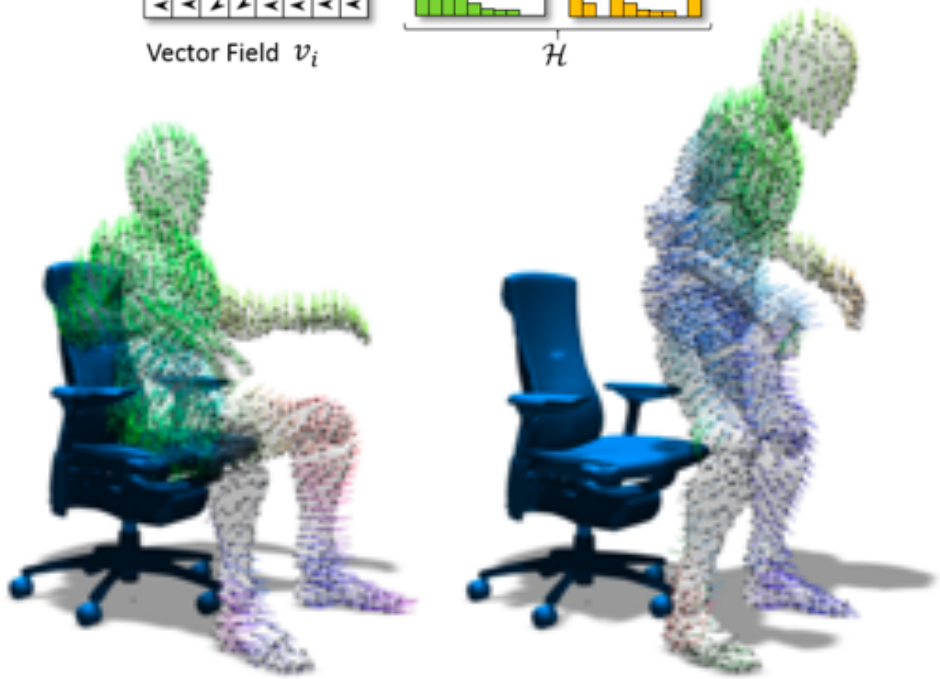


- Intersection bisector surface (IBS) [ZWK14]
- Interaction regions (IR) [HZvK*15]

Representation of the relation

- Spatial arrangement
- Boundary representation
- **Dense volume feature**
- Gestalt and symmetry grouping
- Mechanical relations
- Humanoid actions

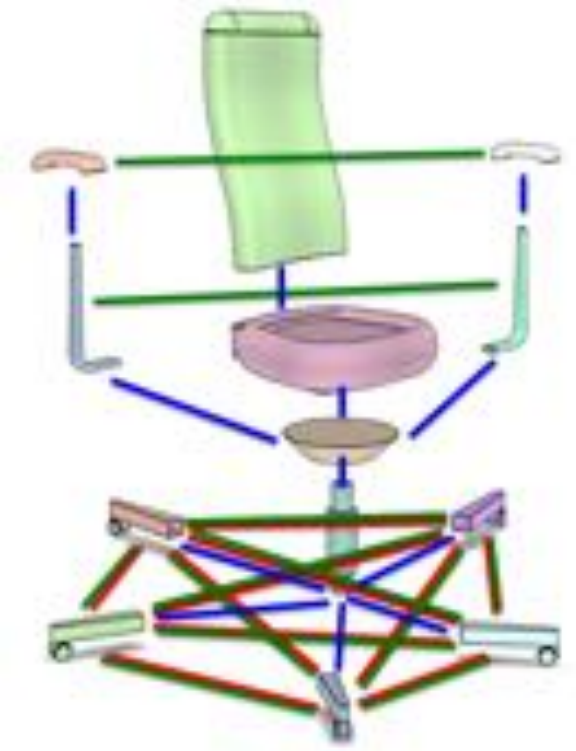




- Interaction landscapes [PKH*17]

Representation of the relation

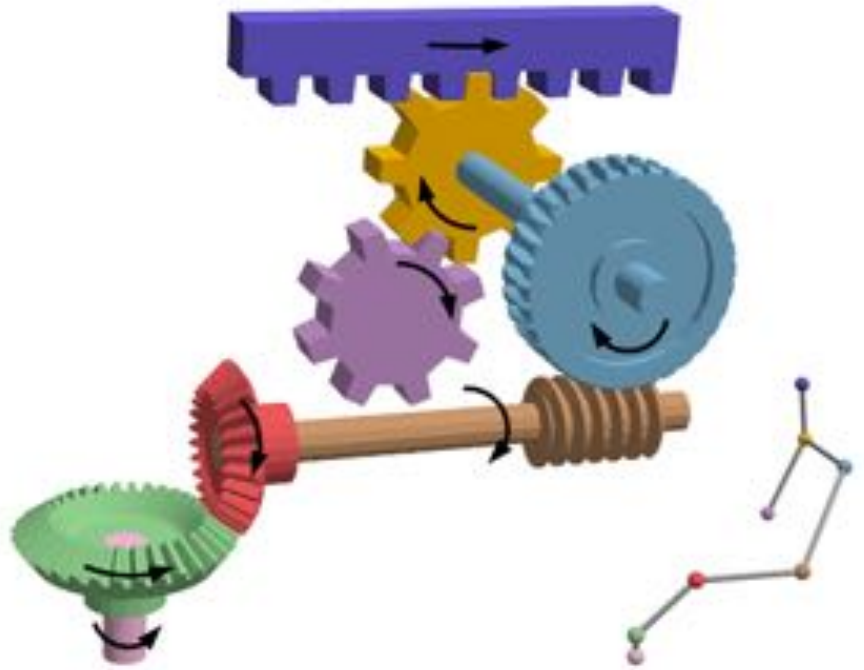
- Spatial arrangement
- Boundary representation
- Dense volume feature
- **Gestalt and symmetry grouping**
- Mechanical relations
- Humanoid actions



- Symmetry hierarchy [WXL*11]

Representation of the relation

- Spatial arrangement
- Boundary representation
- Dense volume feature
- Gestalt and symmetry grouping
- **Mechanical relations**
- Humanoid actions



- Force drivers, joints, and gears [LOMI11, KLY*14, MYY*10, XLX*16]

Representation of the relation

- Spatial arrangement
- Boundary representation
- Dense volume feature
- Gestalt and symmetry grouping
- Mechanical relations
- **Humanoid actions**

- Gazing, grasping, holding, pushing, pulling, and sitting [SCH*14, FSL*15, SCH*16, MLZ*16]

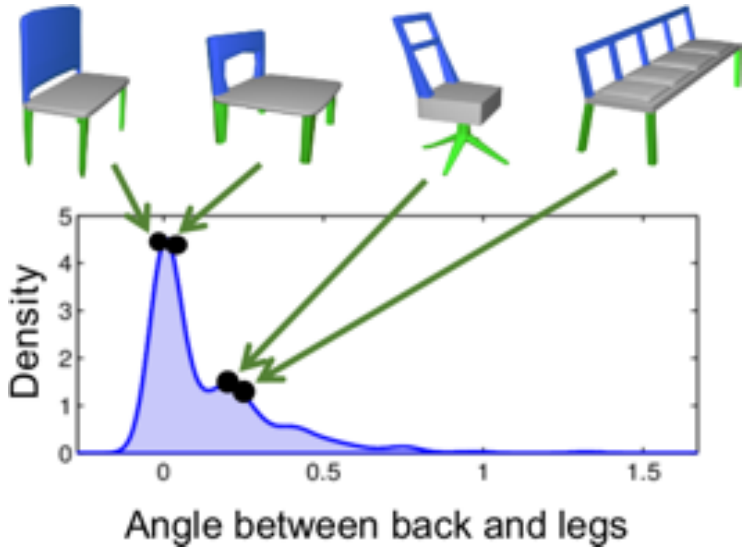
Representations of functionality

Functionality = Geometry + Interaction

Representations of functionality

Functionality = Geometry + Interaction

Geometry-only (G) methods

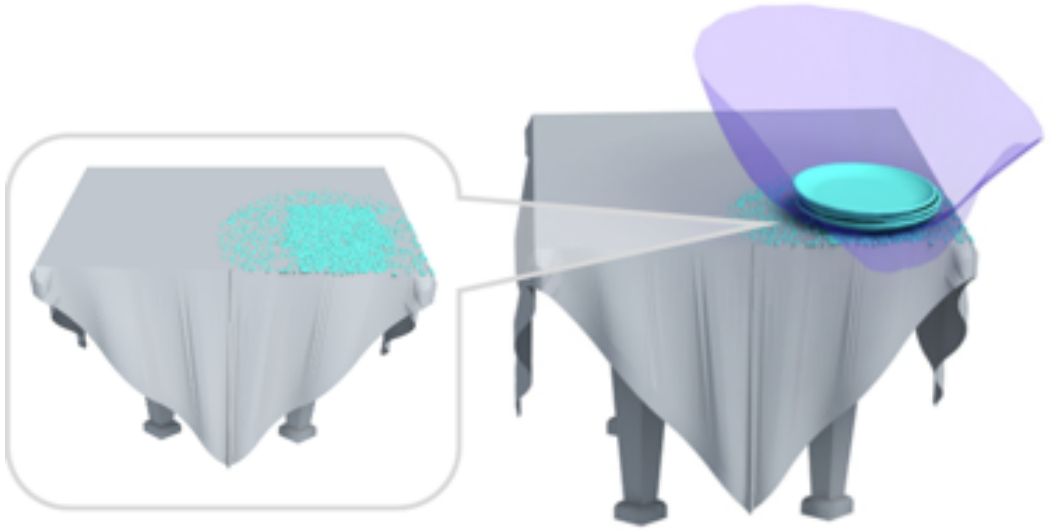


Meta-representation of shape families [FavK*14]

Representations of functionality

Functionality = Geometry + Interaction ✓

Geometry + interaction (GI) methods

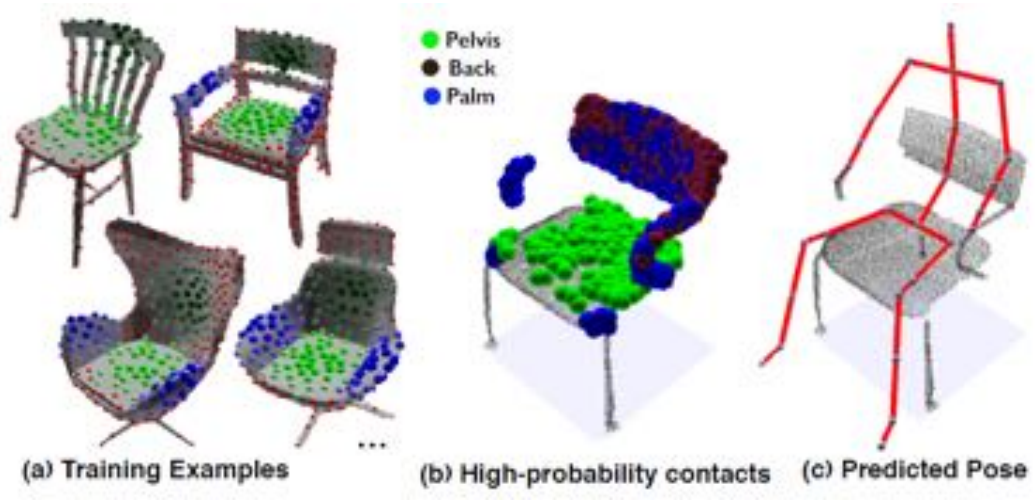


Interaction context (ICON) descriptor [HZvK*15]

Representations of functionality

Functionality = Geometry + Interaction ✓

Geometry + agent (GA) methods



Shape2pose: Human-centric shape analysis [KCGF14]

Additional classification criteria

- **Model type:** discriminative or generative
- **Approach:** supervised, unsupervised, or handcrafted
- **Input data representation:** RGB-D image, point cloud, mesh

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Classification criteria

		Representation of geometry or interactions			Additional classification criteria		
Works	Functional entity	Component / interacting entity	Dynamicity	Relations	Input	Approach	Model type
Geometry-only (G)							
Xu et al. [XSF02]	scene	object-geo	stat	SA	mesh	handcrafted	generative
Merrell et al. [MSL*11]	scene	object-geo	stat	SA	mesh	handcrafted	generative
Yu et al. [YYT*11]	scene	object-geo	stat	SA	mesh	supervised	generative
Fisher et al. [FSH11]	scene	object-geo	stat	SA	mesh	handcrafted	discriminative
Fisher et al. [FRS*12]	multi-object	object-geo	stat	SA	mesh	supervised	generative
Zhao et al. [ZWK14]	multi-object	object-geo	stat	BR	pcl	handcrafted	discriminative
Zhao et al. [ZHG*16]	multi-object	object-geo	stat	BR	mesh	supervised	generative
Zheng et al. [ZCOM13]	object	part-geo	stat	SG	mesh	handcrafted	generative
Mitra et al. [MYY*10]	object	part-geo	stat	SG	mesh	handcrafted	discriminative
Xu et al. [XLX*16]	object	part-geo	stat	SG	rgbd	handcrafted	discriminative
Fish et al. [FAvK*14]	object	part-geo	stat	SA	mesh	supervised	generative
Yumer et al. [YK14]	object	part-geo	stat	SA	mesh	supervised	generative
Pechuk et al. [PSR08]	part	part-geo	stat	SA	rgbd	supervised	discriminative
Gelfand et al. [GG04]	part	–	–	–	mesh	handcrafted	discriminative
Andries et al. [ADSV20]	object	–	stat	–	–	supervised	generative
Krs et al. [KMG*20]	object	part-geo	stat	–	–	unsupervised	generative

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Classification criteria

		Representation of geometry or interactions			Additional classification criteria		
Works	Functional entity	Component / interacting entity	Dynamicity	Relations	Input	Approach	Model type
Geometry+interaction (GI)							
Hu et al. [HZvK*15]	object	stat-inter	stat	BR	pcl	handcrafted	discriminative
Hu et al [HvKW*16]	object	stat-inter	stat	BR	pcl	supervised	discriminative
Pirk et al. [PKH*17]	object	dyn-inter	dyn	VF	mesh	handcrafted	discriminative
Myers et al. [MTFA15]	part	stat-inter	stat	SA	rgbd	supervised	discriminative
Kim et al. [KS14]	part	stat-inter	stat	SA	rgbd	supervised	discriminative
Laga et al. [LMS13]	part	stat-inter	stat	SA+SG	mesh	supervised	discriminative
Hu et al. [HLK*17]	part	stat-inter	dyn	SA+BR	pcl	supervised	discriminative
Xiang et al. [XQM*20]	part	stat-inter	dyn	SA	mesh	supervised	discriminative
Hu et al. [HYZ*18]	object	stat-inter	stat	SA+BR	vol	supervised	generative
Yi et al. [YHL*18]	part	stat-inter	dyn	SA	pcl	supervised	discriminative
Wang et al. [WZS*19]	part	stat-inter	dyn	SA	pcl	supervised	discriminative
Yan et al. [YHY*19]	part	stat-inter	dyn	SA	pcl	supervised	discriminative
Li et al. [LWY*20]	part	stat-inter	dyn	SA	pcl	supervised	discriminative
Kokic et al. [KSHK17]	part	stat-inter	dyn	SA	pcl	supervised	generative
Li et al. [LSK20]	part	stat-inter	dyn	SA	pcl	supervised	generative

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Classification criteria

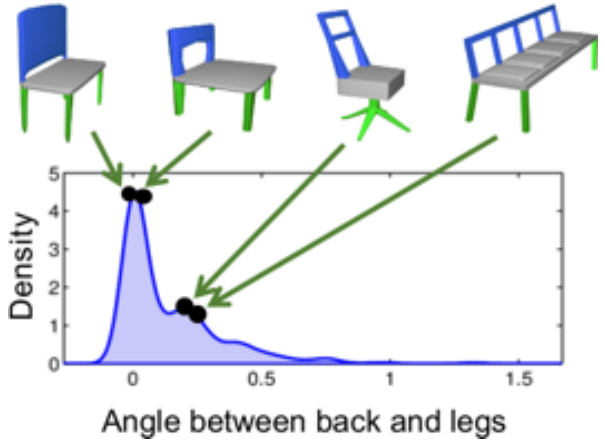
		Representation of geometry or interactions			Additional classification criteria		
Works	Functional entity	Component / interacting entity	Dynamicity	Relations	Input	Approach	Model type
Geometry+agent (GA)							
Grabner et al. [GGVG11]	scene	agent-inter	stat	HA	mesh	supervised	generative
Savva et al. [SCH*14]	scene	agent-inter	stat	SA+HA	mesh	supervised	discriminative
Zhu et al. [ZJZ*16]	scene	agent-inter	stat	SA	mesh	supervised	generative
Jiang et al. [JKS13]	multi-object	agent-inter	stat	SA	rgbd	supervised	discriminative
Wang et al. [WLY17]	multi-object	agent-inter	stat	SA+HA	mesh	supervised	discriminative
Fisher et al. [FSL*15]	multi-object	agent-inter	stat	SA+HA	mesh	supervised	generative
Savva et al. [SCH*16]	multi-object	agent-inter	stat	SA+HA	mesh	supervised	generative
Ma et al. [MLZ*16]	multi-object	agent-inter	dyn	SA+HA	mesh	unsupervised	generative
Zheng et al. [ZLDM16]	object	agent-inter	stat	SA	mesh	handcrafted	generative
Kim et al. [KCGF14]	object	agent-inter	stat	SA	mesh	supervised	generative
Bar-Aviv & Rivlin [BAR06]	object	agent-inter	stat	SA+HA	mesh	handcrafted	discriminative
Zhu et al. [ZZCZ15]	object	agent-inter	dyn	SA+HA	rgbd	supervised	discriminative
Zhao et al. [ZCK17]	object	agent-inter	dyn	SA+HA	mesh	handcrafted	discriminative
Lee et al. [LCL06]	object	agent-inter	dyn	SA	mesh	supervised	generative
Li et al. [LLK*19]	scene	agent-inter	stat	SA+HA	rgbd	supervised	generative
Zhang et al. [ZHN*20]	scene	agent-inter	stat	SA+HA	rgbd	supervised	generative
Mao et al. [MZX*19]	object	agent-inter	stat	SA	mesh	supervised	generative
Fu et al. [FFY*20]	scene	agent-inter	stat	SA+HA	mesh	supervised	discriminative
Monszpart et al. [MGC*19]	scene	agent-inter	stat	SA	rgbd	supervised	generative
Ruiz et al. [RMC19]	scene	agent-inter	stat	SA+BR	mesh	supervised	generative
Starke et al. [SZKS19]	object	agent-inter	dyn	SA	vol	supervised	generative

Summary for definition

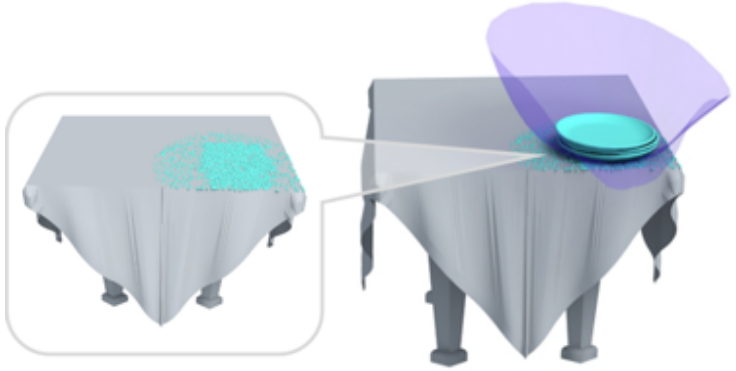
- Use **definition of functionality** and **additional criteria** to classify and discuss **previous work**
- Definition provides **three groups of functionality methods**
- **Classification** also useful when discussing **unexplored areas of research and future work**

Next: discussion of methods

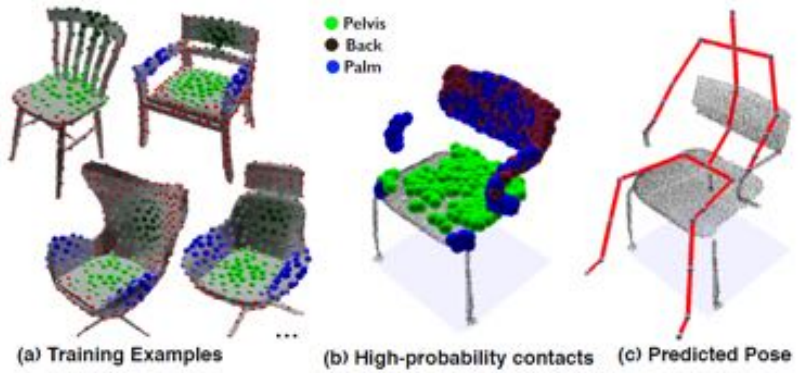
Functionality = Geometry + Interaction



G methods



GI methods



GA methods

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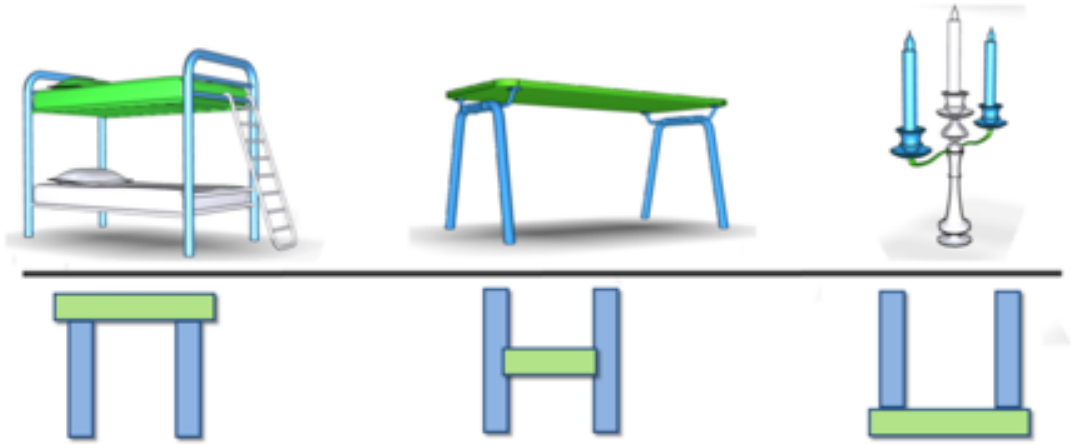
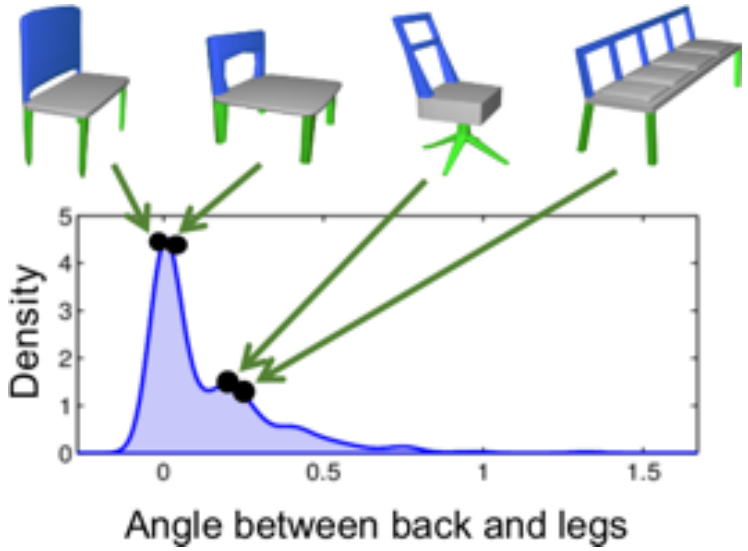
Geometry-only (G) methods



Geometry-only methods

Functionality = Geometry + Interaction

Geometry-only (G) methods



Meta-representation of shape families [FavK*14]

Geometry-only methods

- Derive **functionality** only from **geometry** and **structure**
- Geometry and structure of **parts, objects, or scenes**
- **Interactions** with other entities are **not considered**
- Relations considered in the analysis are **static**

Geometry-only methods

Discussion follows **level of the entity**:

- Scene-level functionality
- Object-level functionality
- Part-level functionality

Geometry-only methods

Discussion follows **level of the entity**:

- **Scene-level functionality**
- Object-level functionality
- Part-level functionality

Scene-level functionality

- Describe the **functionality of a scene**
- Specific **object arrangements** enable certain functionalities
- Consider **relations between objects** in the scene
- **Spatial arrangements** or **boundary representations**

Scene-level functionality

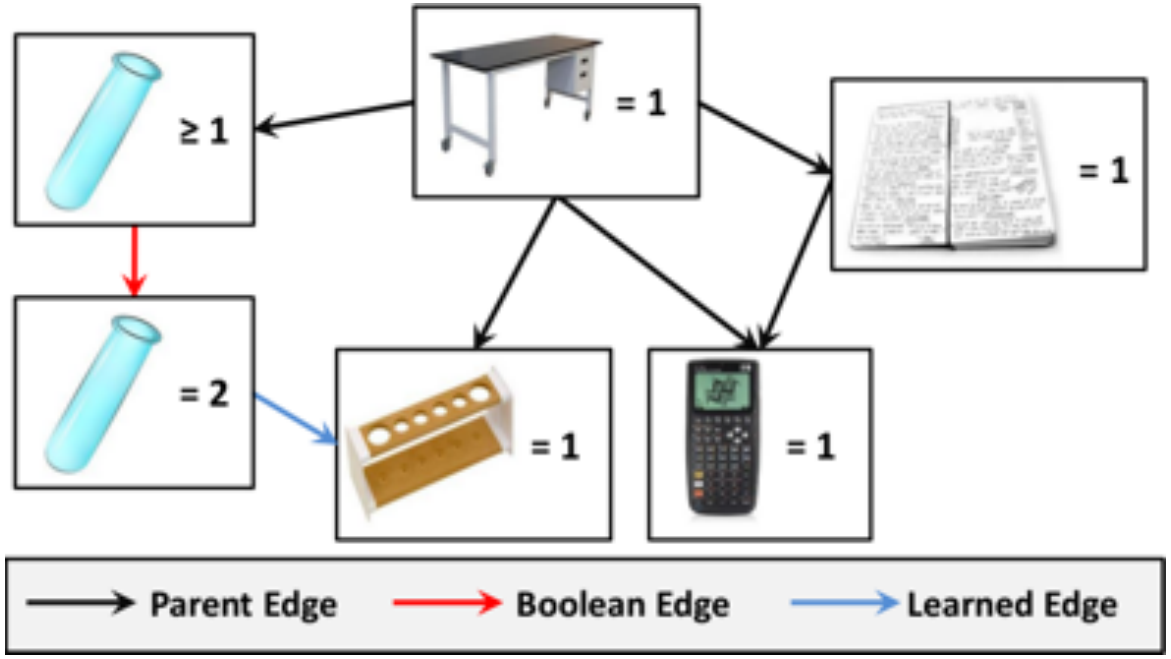
Constrained placement
[XSF02]

Interior design guidelines
[MSL*11]

"Make it home"
[YYT*11]

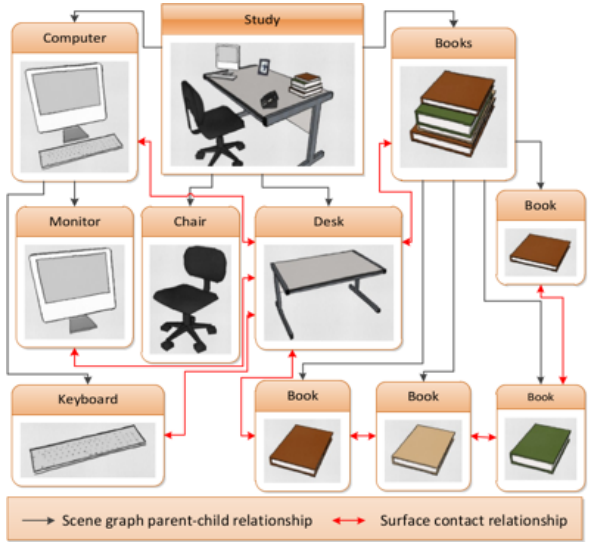
- Automatically **place objects** to **generate a scene**
- Using **placement constraints and rules**, **pseudo-physics**, **interior design guidelines**, and **ergonomic factors**

Scene-level functionality

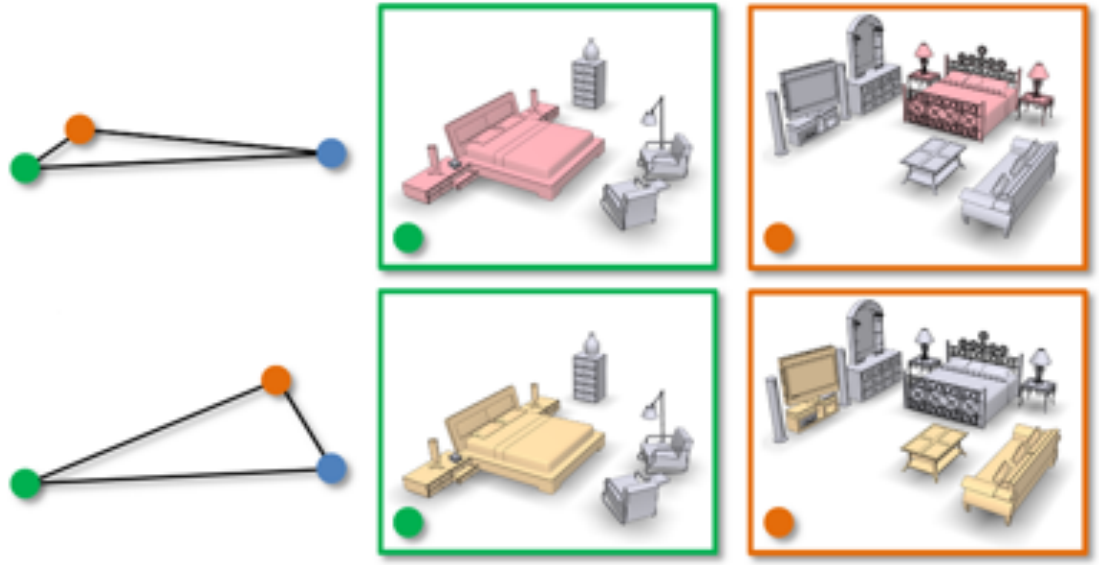


- "Example-based synthesis of 3D object arrangements" [FRS*12]
- **Synthesize scenes** with a **learned object co-occurrence model**

Scene-level functionality



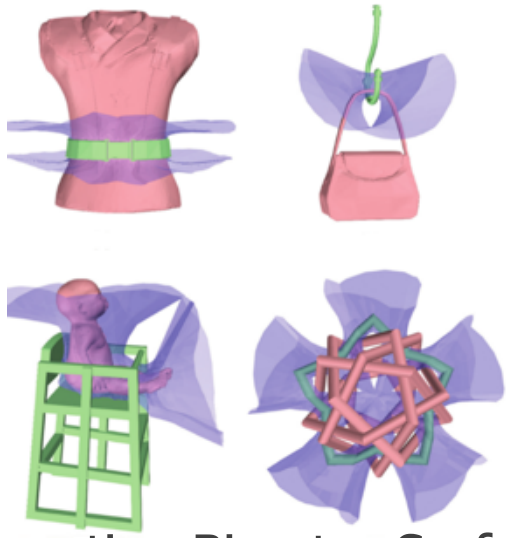
Graph kernels
[FSH11]



Focal points
[XMZ*14]

- Content-based **comparison** for **scene retrieval**
- Considering **co-occurrence of objects**

Scene-level functionality

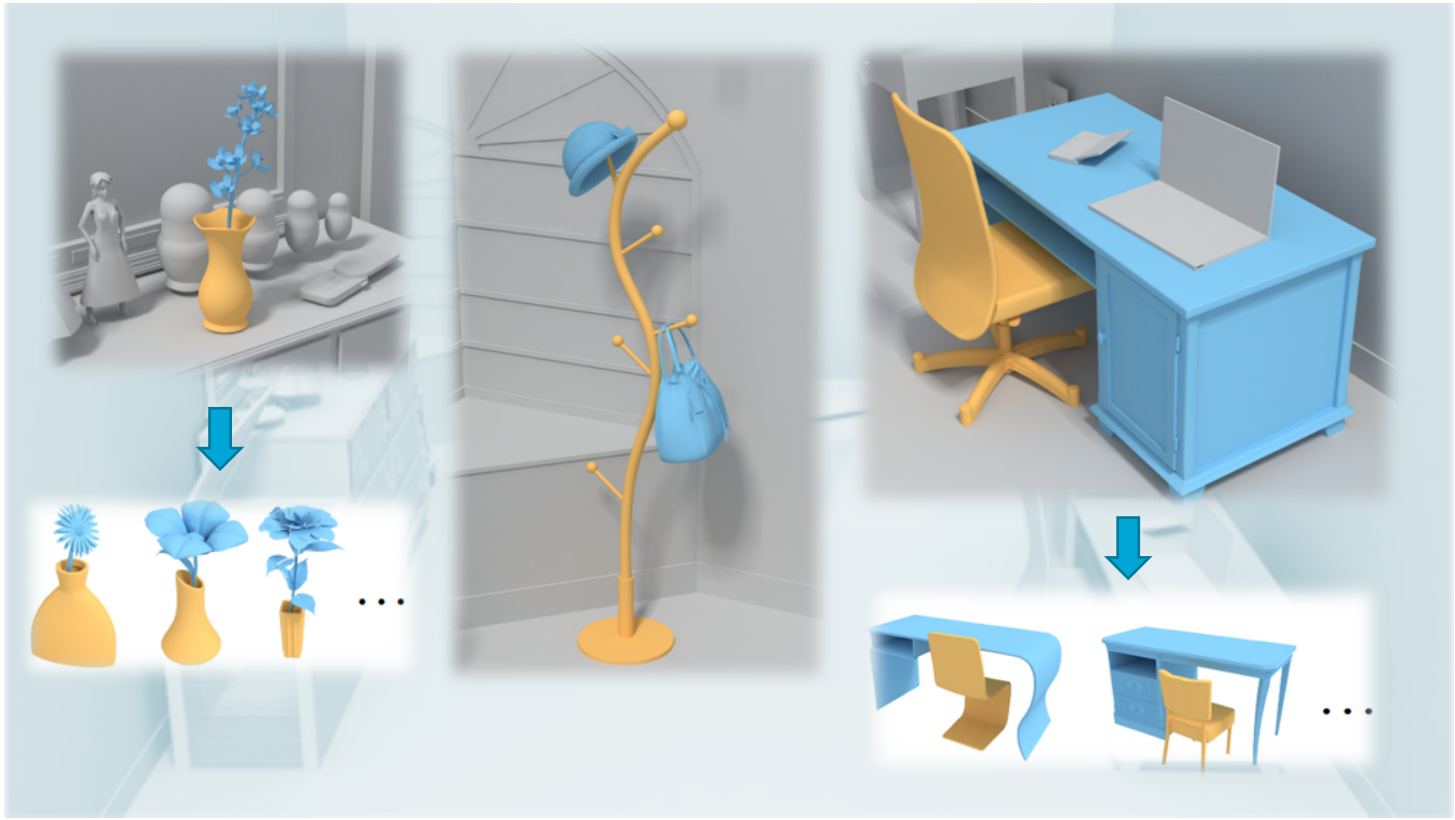


Interaction Bisector Surface
[ZWK14]

Relationship template
[ZHG*16]

- Represent the **spatial boundary** between objects
- Applicable to **scene comparison** and **template-based synthesis**

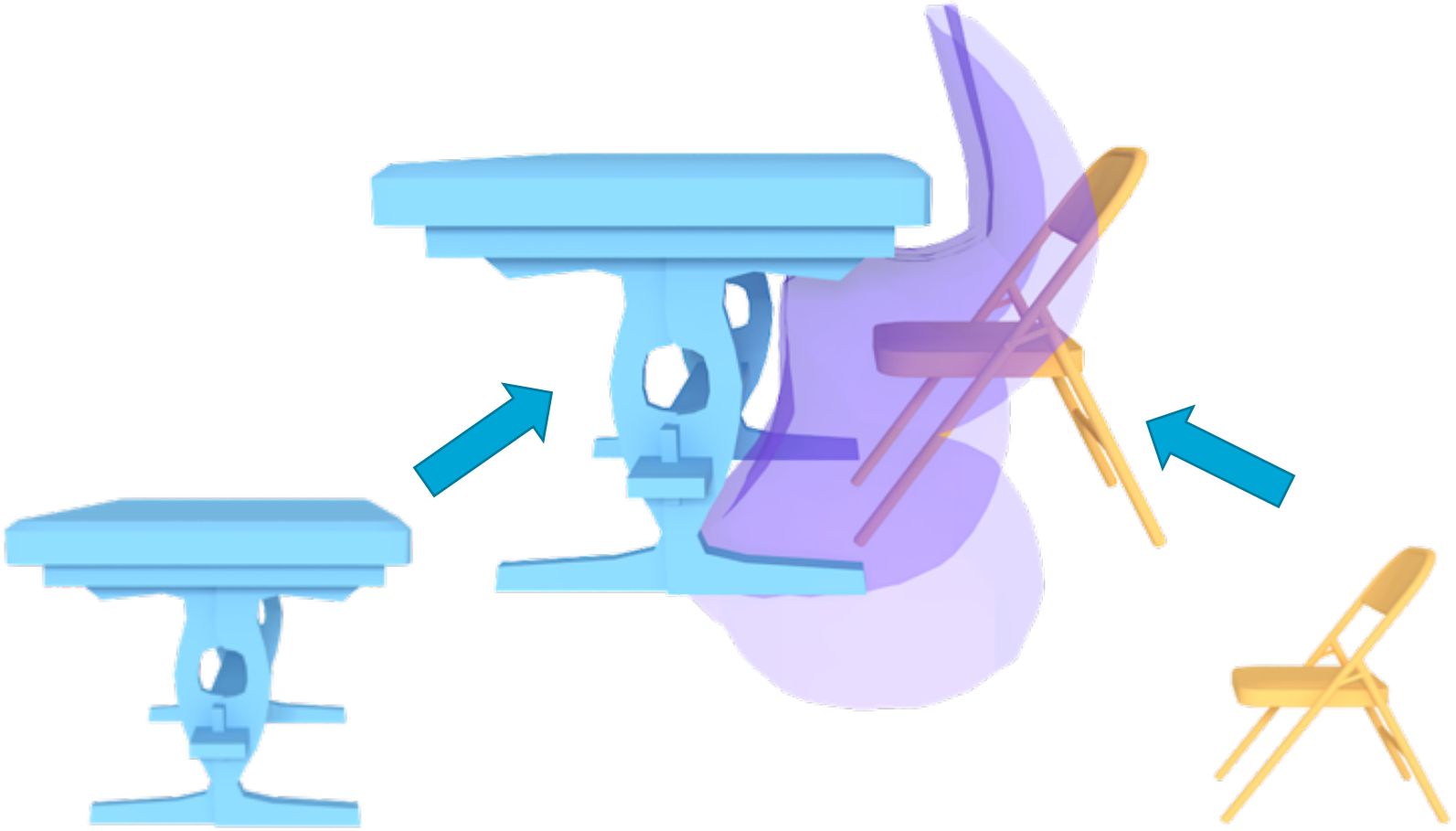
Relationship templates [ZHG*16]



How to make variations of complex relationship?

Relationship templates
[ZHG*16]

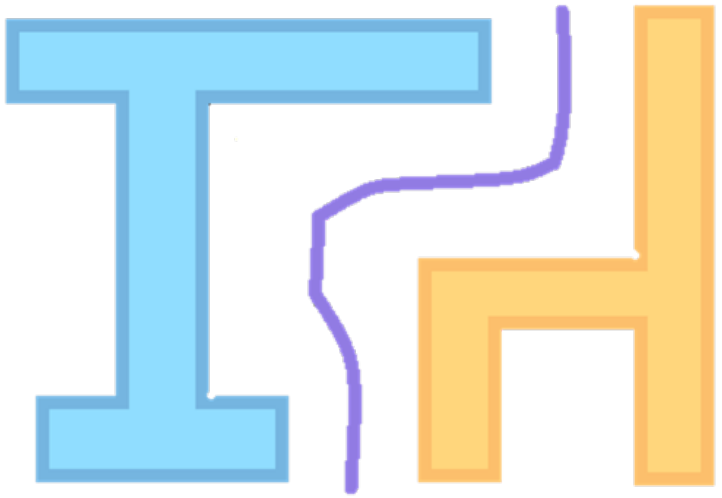
Example scene :



Novel object 1

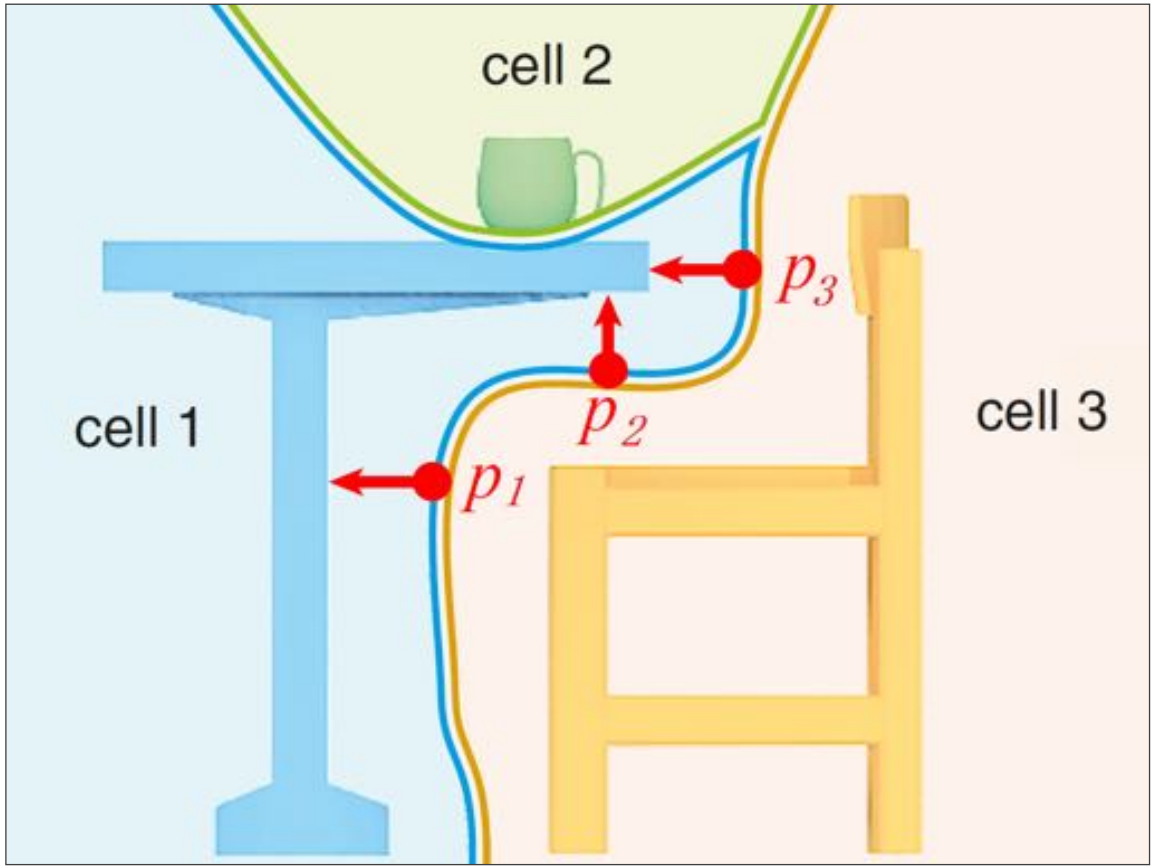
Novel object 2

Relationship templates
[ZHG*16]



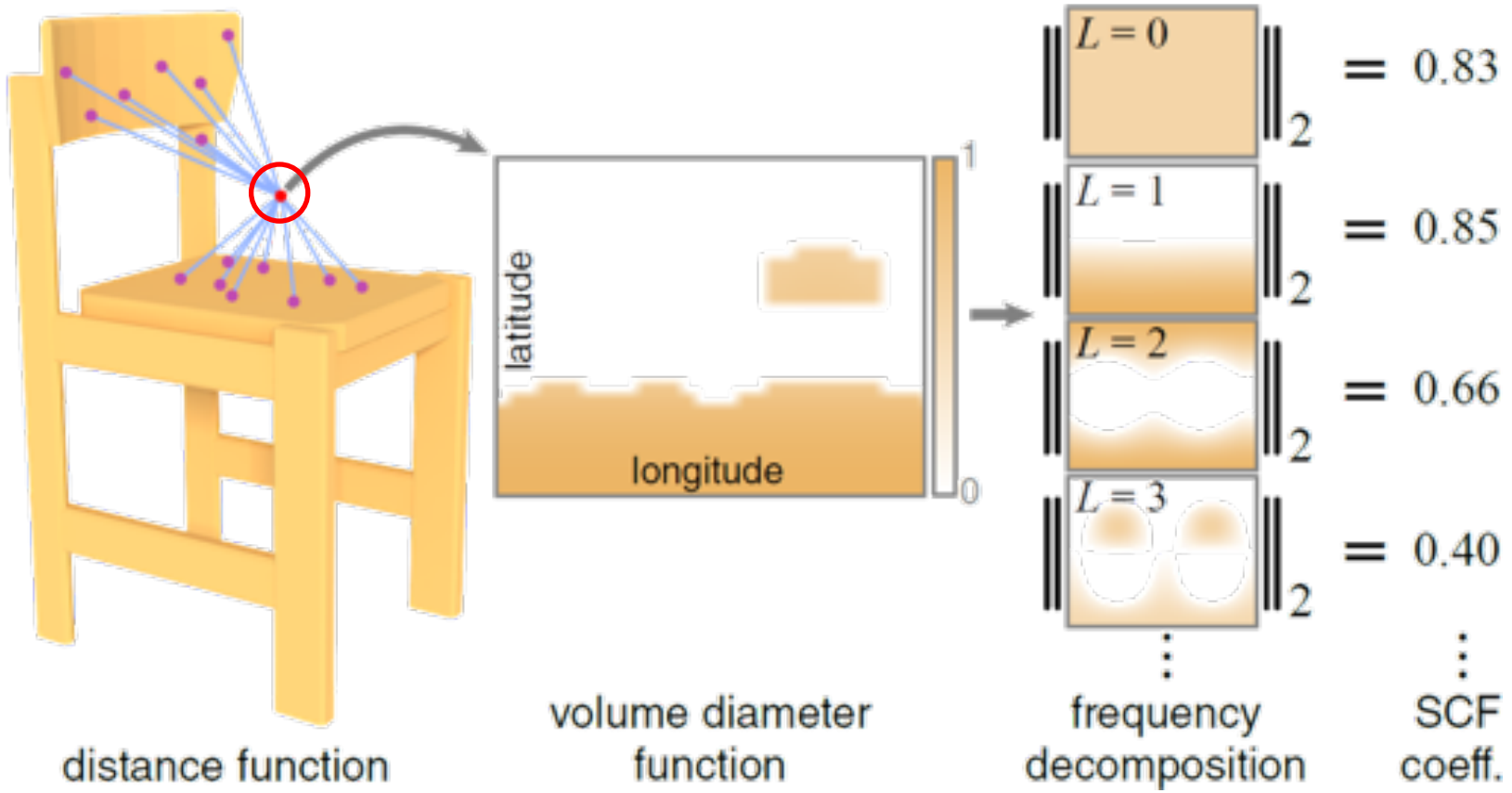
Template construction: IBS

Relationship templates
[ZHG*16]



Template construction: cells and features

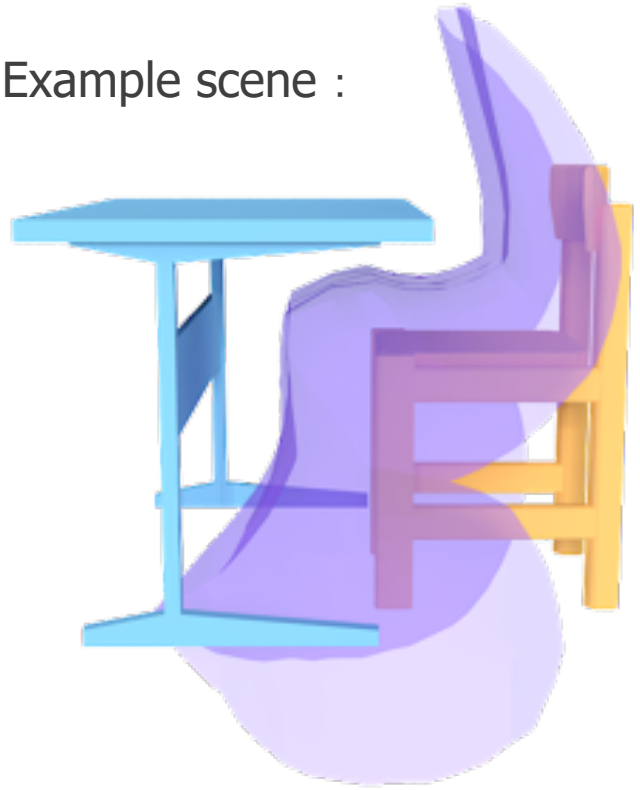
Relationship templates
[ZHG*16]

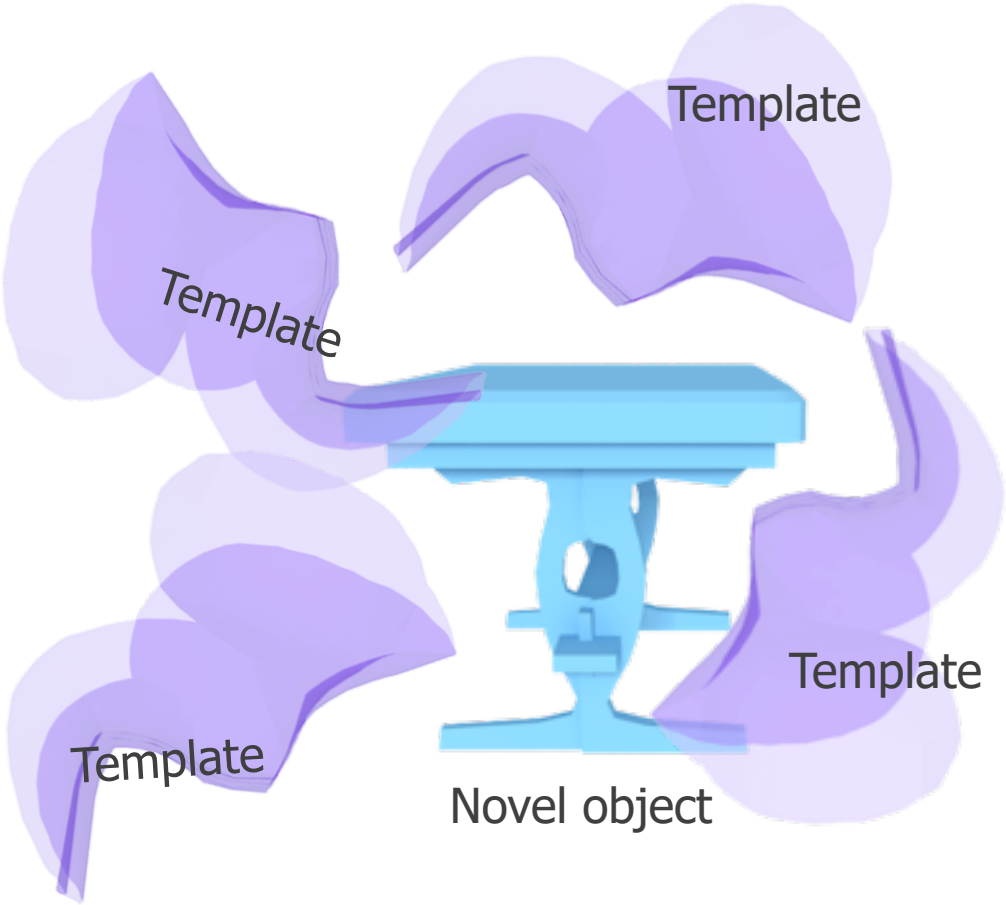


Shape Coverage Feature (SCF)

Relationship templates
[ZHG*16]

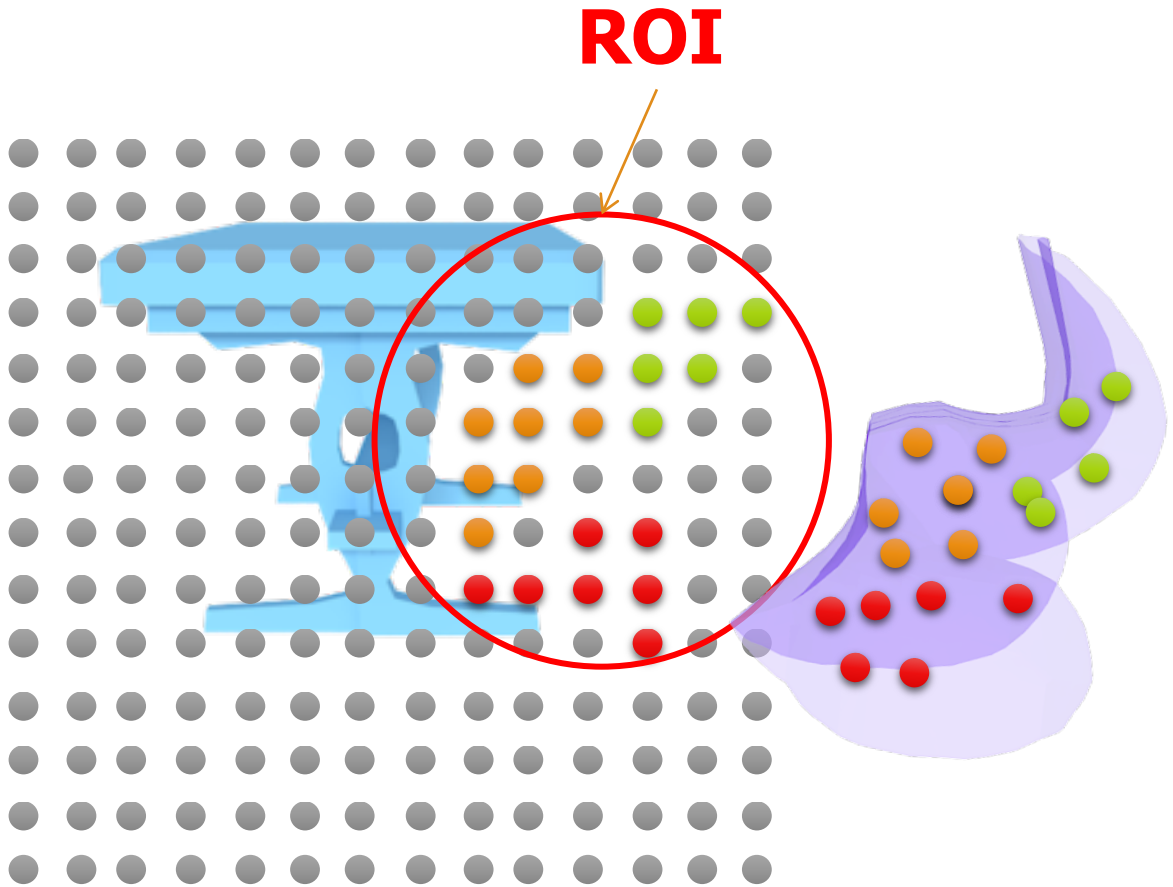
Example scene :





Novel Object Fitting

Relationship templates
[ZHG*16]



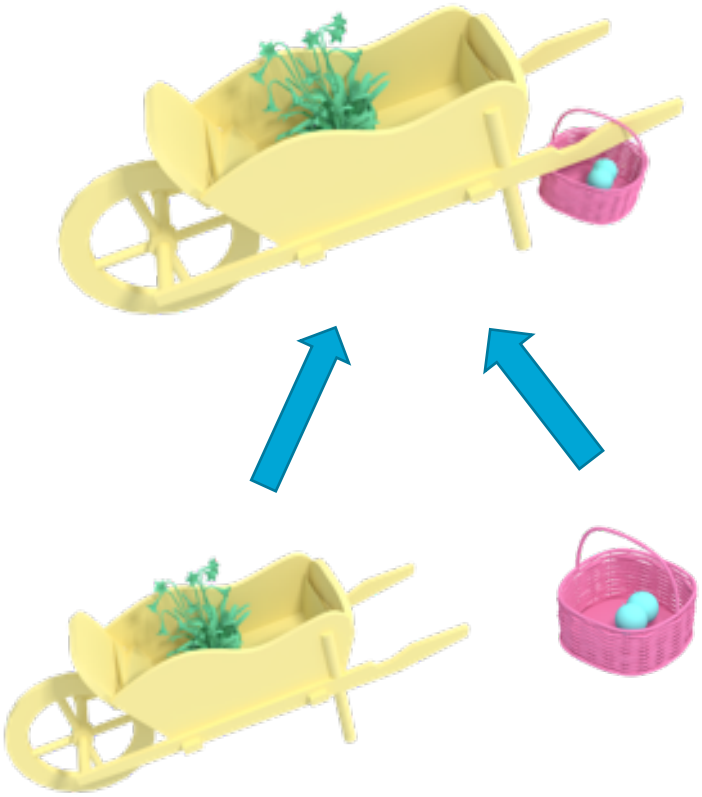
Novel Object Fitting: initial matching

Relationship templates
[ZHG*16]

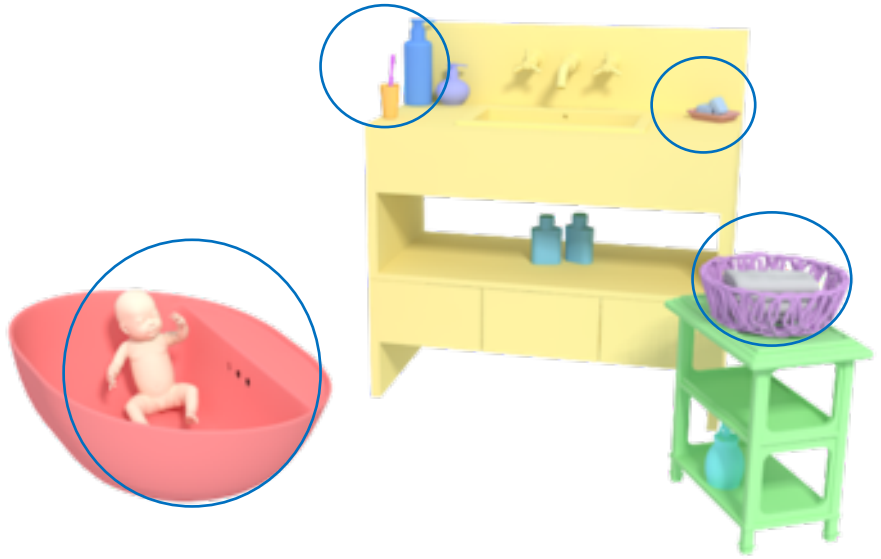
Novel Object Fitting: refinement

Relationship templates [ZHG*16]

Scene hierarchy



Combine with other scene synthesis system



M. Fisher, D. Ritchie, M. Savva, T. Funkhouser, and P. Hanrahan, "**Example-based Synthesis of 3D Object Arrangements**" *SIGGRAPH ASIA2012*

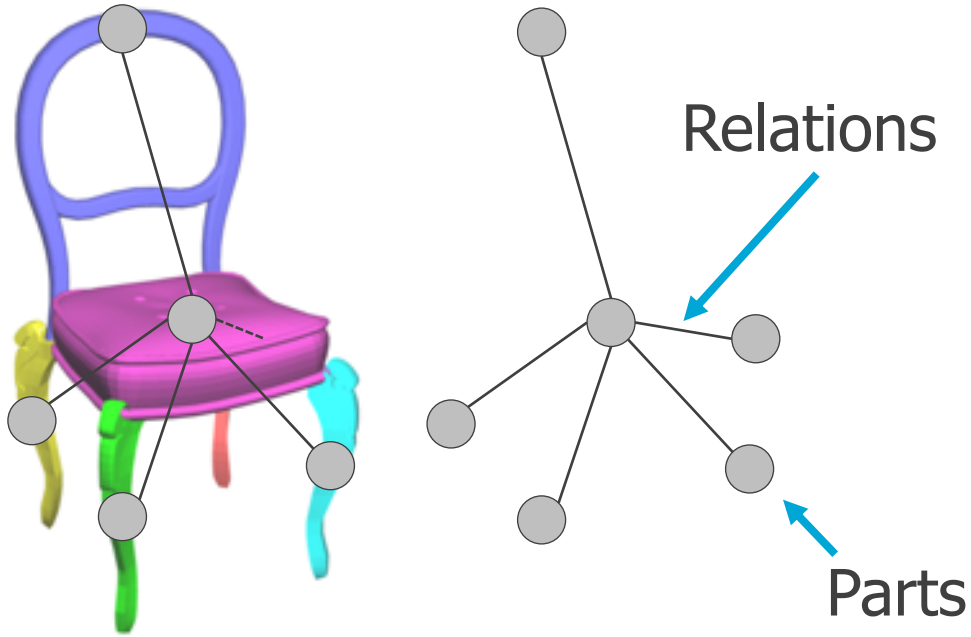
Geometry-only methods

Discussion follows **level of the entity**:

- Scene-level functionality
- **Object-level functionality**
- Part-level functionality

Object-level functionality

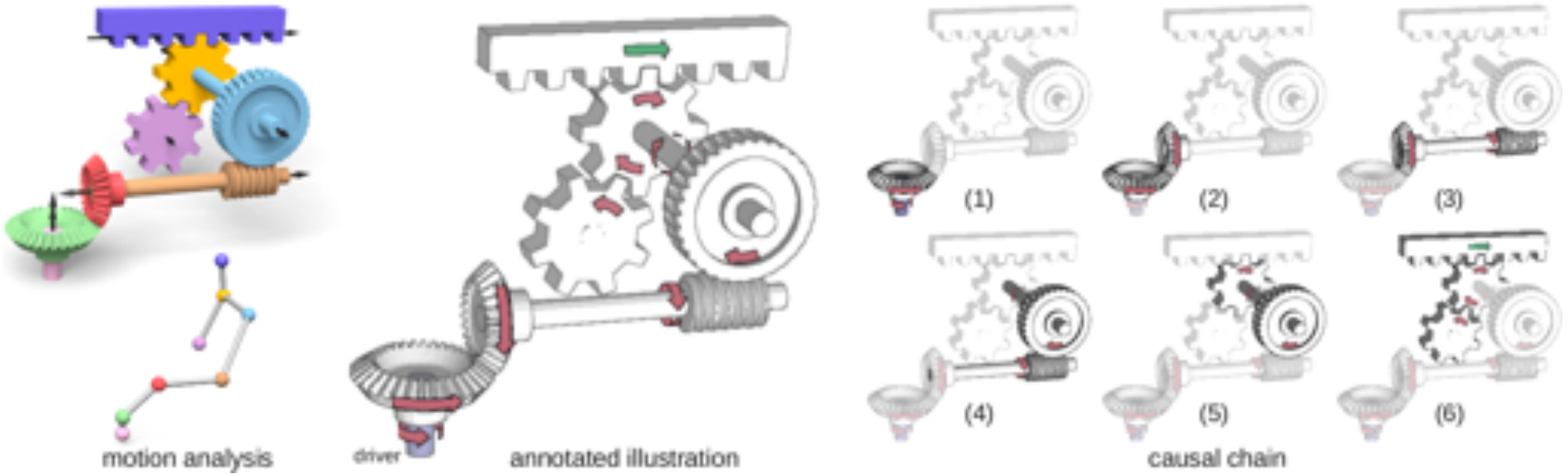
- Examine the **geometry** and **structure** of the object
- Structure: represent a shape as a **graph of parts**
- Edges represent **relations** between connected parts



Object-level functionality

- Symmetric functional arrangements (**sFARRs**) [ZCOM13]
- **Handcrafted rules** to detect **special groupings of parts**
- **Exchange sFARRs** between shapes to **generate plausible shapes**

Object-level functionality

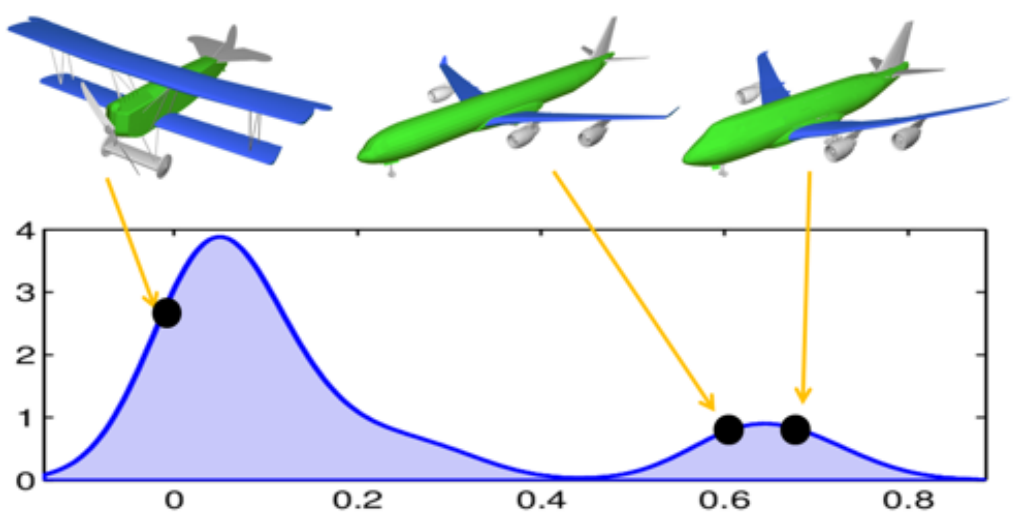


- Illustrate the **functioning** of **mechanical assemblies** [MYY*10]
- Assemblies composed of mechanical components such as **gears**
- Infer **motion** with **handcrafted rules** based on **symmetry relations**

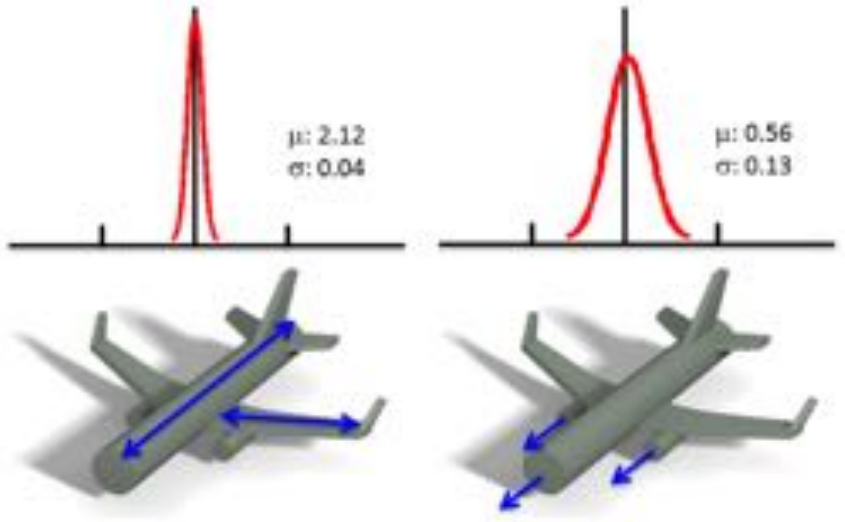
Object-level functionality

- Recover **functioning of mechanical assemblies** from **images** [XLX*16]
- Analysis of the **geometry of linked parts** in **multiple views**

Object-level functionality



Meta-representation
[FAvK*14]



Co-constrained handles
[YK14]

- **Learn** a **part configuration model** from a set of shapes of same family
- Evaluate **validity** of a shape based on how well it **fits the model**

Meta-representation of shapes [FAvK*14]

Are these shapes “valid”?

Meta-representation of shapes [FAvK*14]

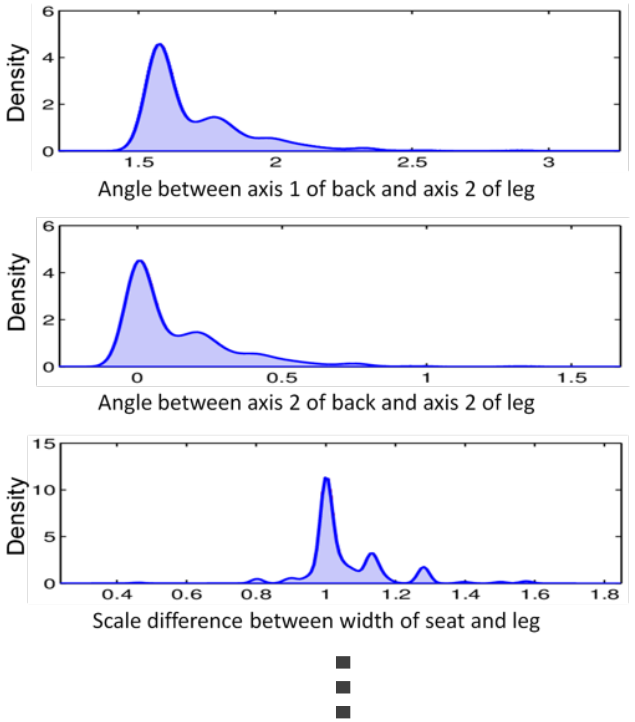
Learn validity from a collection

Meta-representation of shapes [FAvK*14]

Input

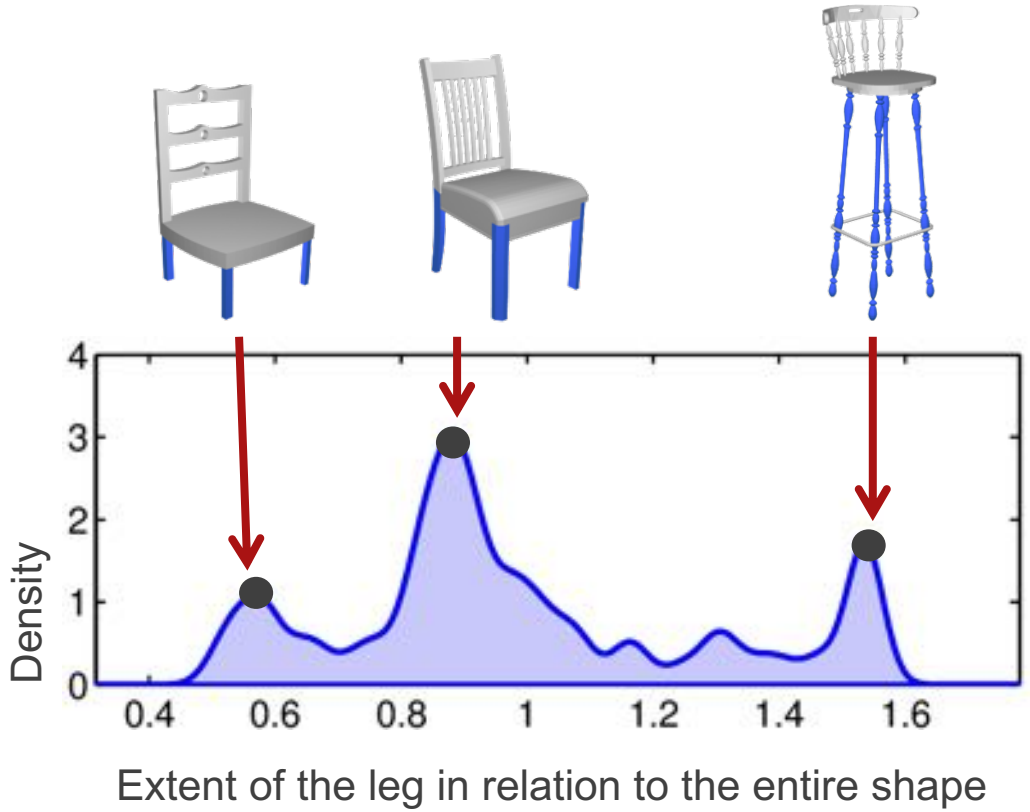
Analysis

Meta-representation



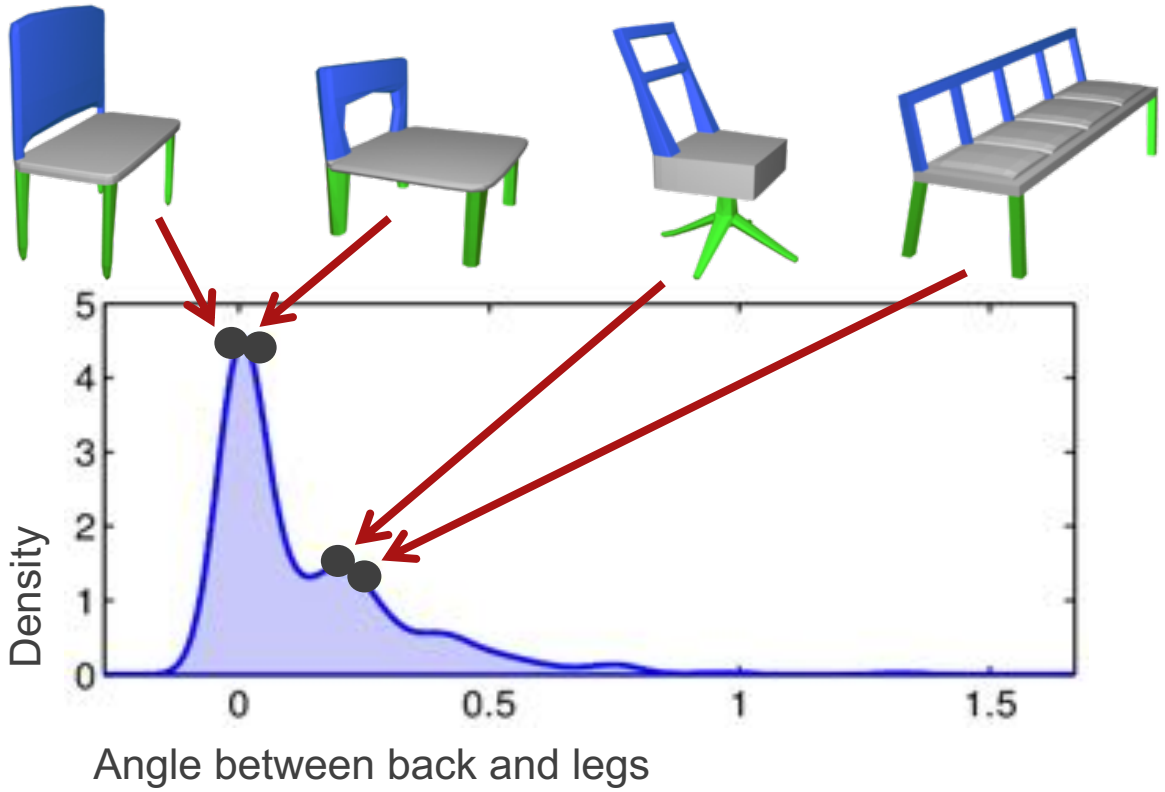
How to characterize "validity"?

Meta-representation of shapes [FAvK*14]



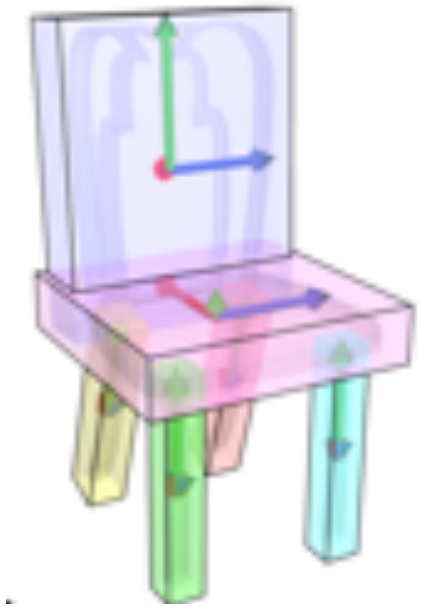
Relations for single parts

Meta-representation of shapes [FAvK*14]

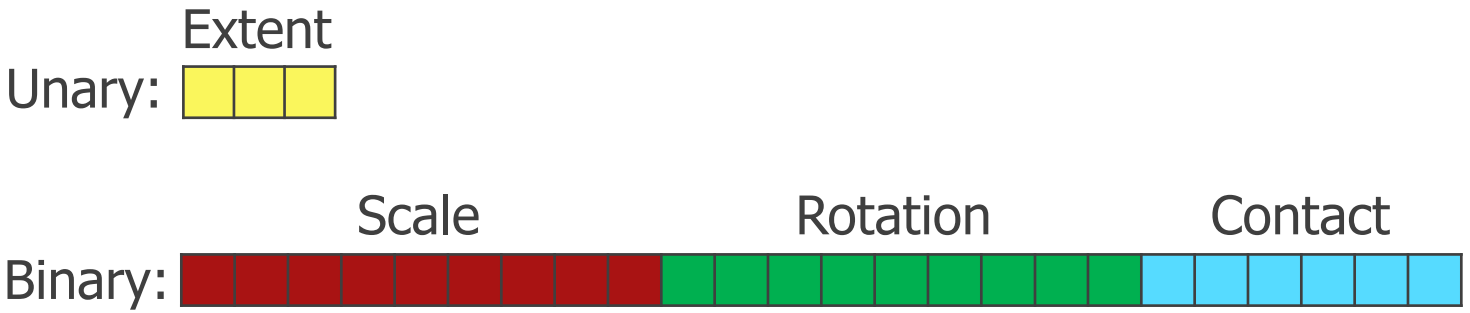


Relations for pairs of parts

Meta-representation of shapes [FAvK*14]

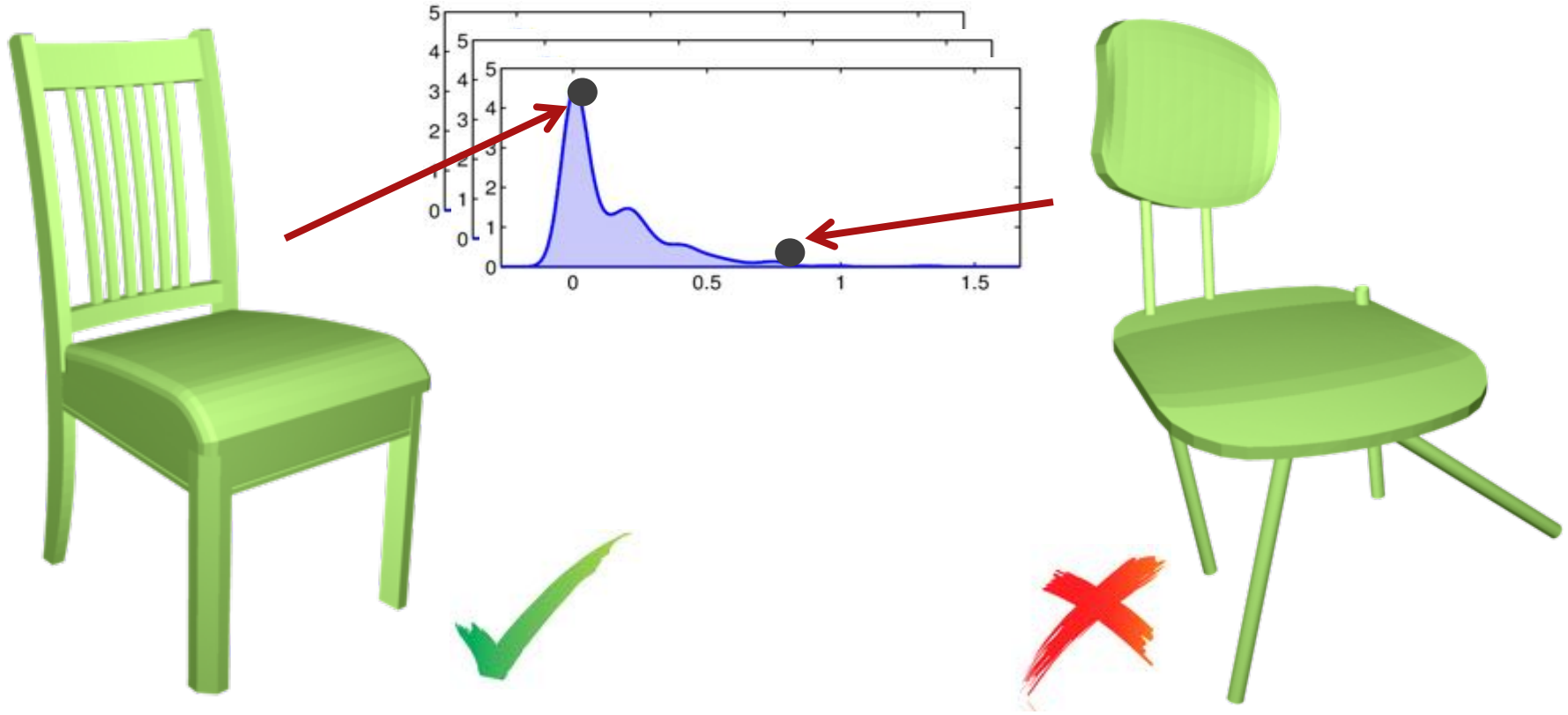


	Back	Seat	Leg
Back	unary	binary	binary
Seat		unary	binary
Leg			unary



Relations per shape

Meta-representation of shapes [FAvK*14]

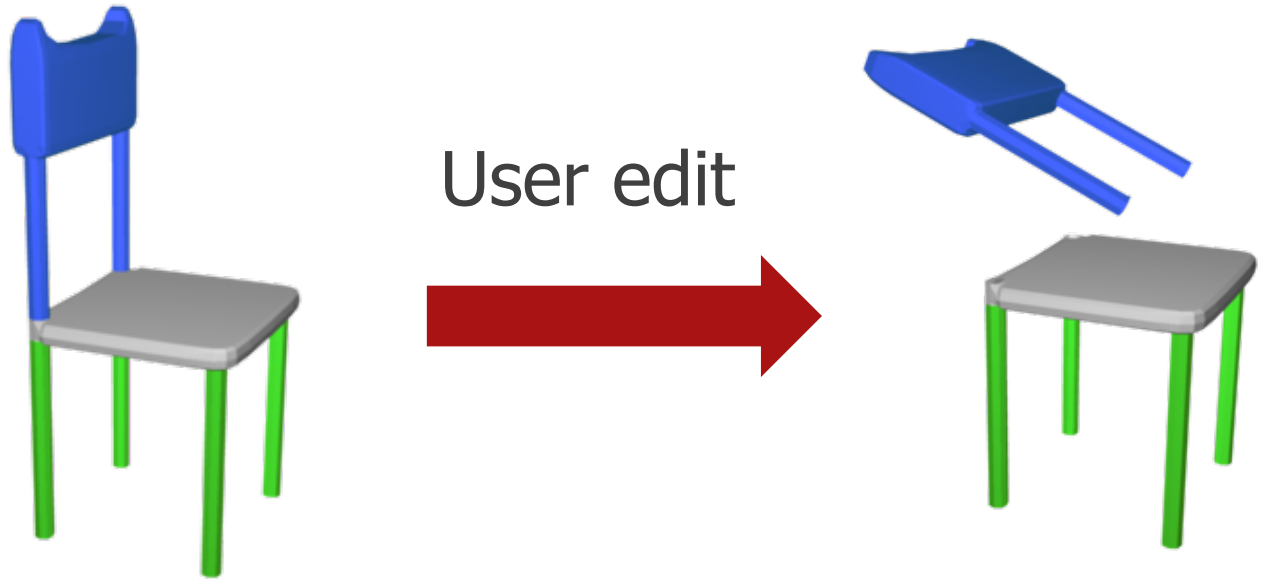


Characterize validity with the relations

Meta-representation of shapes [FAvK*14]

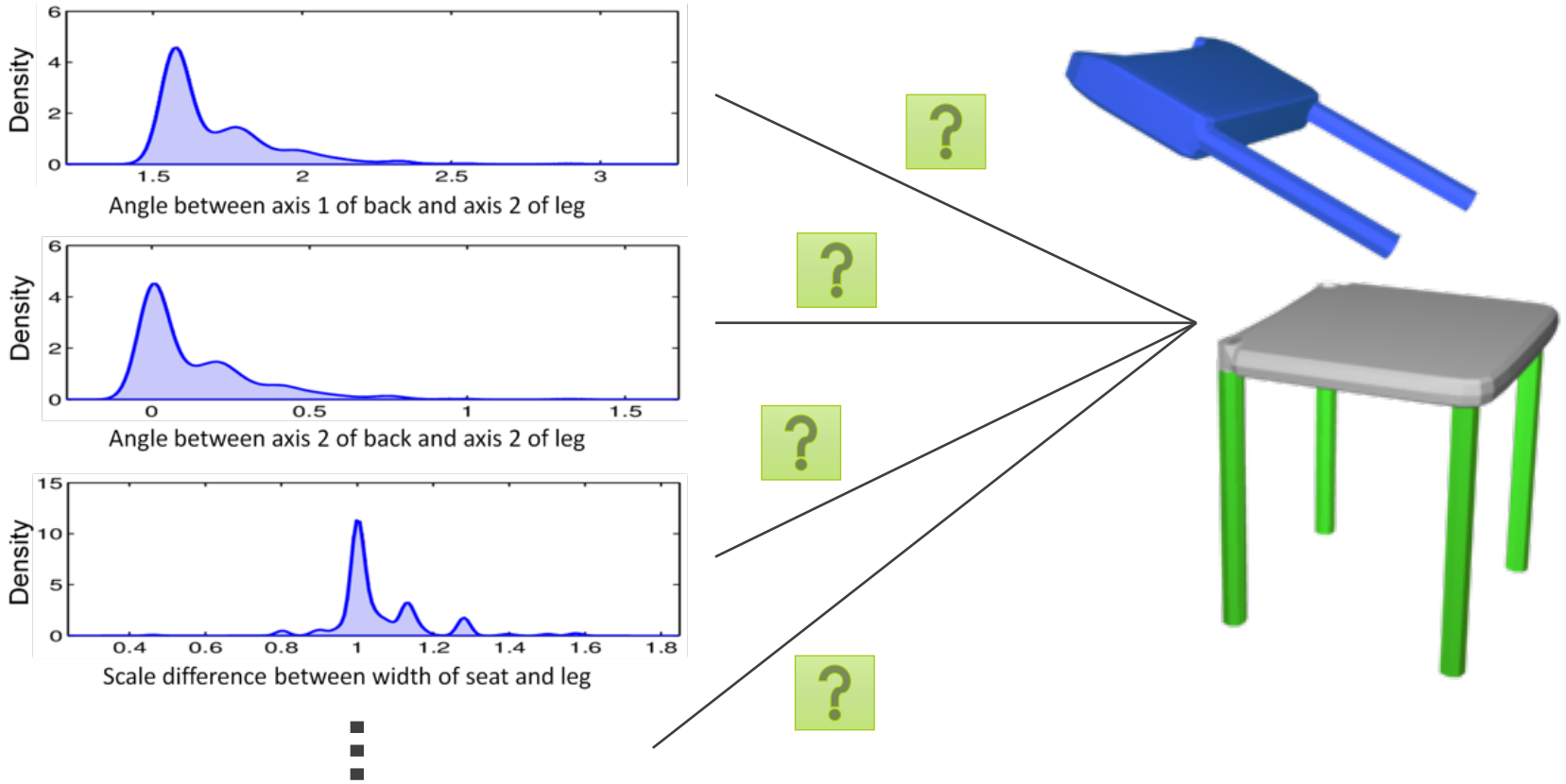
- Validity is useful in several applications:
  - Exploration
  - Guided modeling
  - Coupled editing

Meta-representation of shapes [FAvK*14]



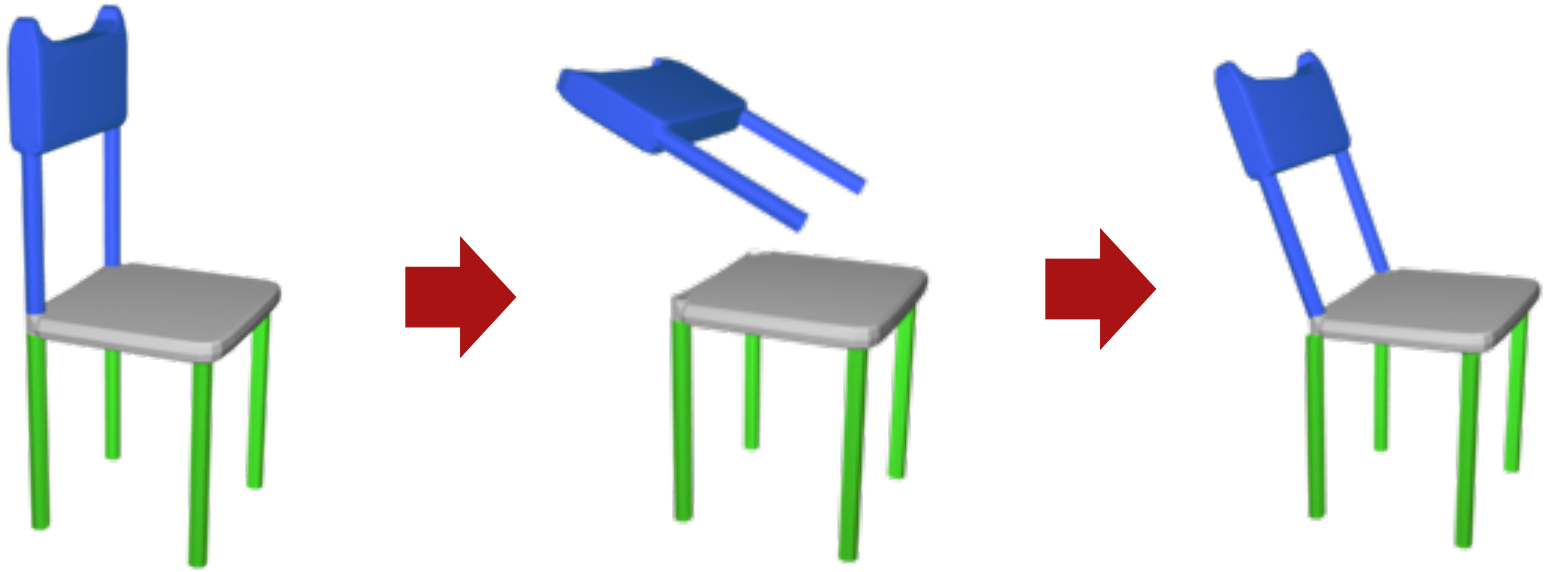
General editing approach

Meta-representation of shapes [FAvK*14]



General editing approach

Meta-representation of shapes [FAvK*14]



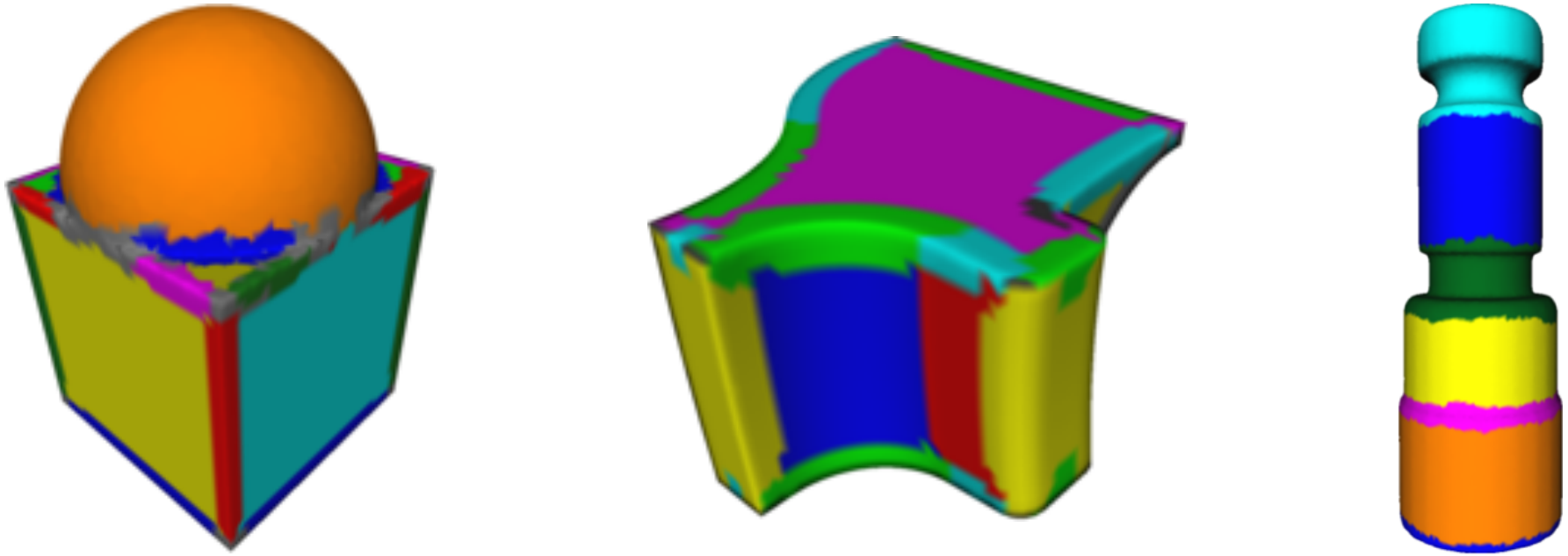
General editing approach

Geometry-only methods

Discussion follows **level of the entity**:

- Scene-level functionality
- Object-level functionality
- **Part-level functionality**

Part-level functionality



- "Shape segmentation using local slippage analysis" [GG04]
- Discover **slippable motions** of a shape
- Reveal **regions of shapes** that are **kinematic surfaces** with same motion

Discussion

- Functionality models derived from **geometry** and **structure**
- Models **often** capture **functional properties** of a shape
- **But not all** discovered **properties** relate to **functionality**
- **Handcrafted models** often include only few **manually-defined functionality types**

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Geometry + Interaction

Our definition of functionality

Functionality = Geometry + Interaction

Atomic interaction:
<Functional entity, relation, interacting entity>

Key observation

- The functionality of an entity is well reflected by the way how the entity is used when performing its functionality



Challenges

- Capture multiple, different interactions

Challenges

- Insensitivity to object geometry and count

Challenges

- Group interactions in a meaningful manner

Structural organization

Geometry + interaction methods

Works	Representation of geometry or interactions: Functional entity	Component / interacting entity	Dynamicity	Relations	Additional classification criteria: Input	Approach	Model type
Geometry+interaction (GI)							
Hu et al. [HZvK*15]	object	stat-inter	stat	BR	pcl	handcrafted	discriminative
Hu et al [HvKW*16]	object	stat-inter	stat	BR	pcl	supervised	discriminative
Pirk et al. [PKH*17]	object	dyn-inter	dyn	VF	mesh	handcrafted	discriminative
Myers et al. [MTFA15]	part	stat-inter	stat	SA	rgbd	supervised	discriminative
Kim et al. [KS14]	part	stat-inter	stat	SA	rgbd	supervised	discriminative
Laga et al. [LMS13]	part	stat-inter	stat	SA+SG	mesh	supervised	discriminative
Hu et al. [HLK*17]	part	stat-inter	dyn	SA+BR	pcl	supervised	discriminative
Xiang et al. [XQM*20]	part	stat-inter	dyn	SA	mesh	supervised	discriminative
Hu et al. [HYZ*18]	object	stat-inter	stat	SA+BR	vol	supervised	generative
Yi et al. [YHL*18]	part	stat-inter	dyn	SA	pcl	supervised	discriminative
Wang et al. [WZS*19]	part	stat-inter	dyn	SA	pcl	supervised	discriminative
Yan et al. [YHY*19]	part	stat-inter	dyn	SA	pcl	supervised	discriminative
Li et al. [LWY*20]	part	stat-inter	dyn	SA	pcl	supervised	discriminative
Kokic et al. [KSHK17]	part	stat-inter	dyn	SA	pcl	supervised	generative
Li et al. [LSK20]	part	stat-inter	dyn	SA	pcl	supervised	generative

Geometry + interaction methods

- Handcrafted descriptors
  - Atemporal interaction
  - Time-varying interaction
- Supervised learning
  - Object-level functionality
    - Discriminative recognition
    - Generative modeling
  - Part-level functionality
    - Atemporal interaction
    - Time-varying interaction

Geometry + interaction methods

- **Handcrafted descriptors**
  - Atemporal interaction
  - Time-varying interaction

- Supervised learning
  - Object-level functionality
    - Discriminative recognition
    - Generative modeling
  - Part-level functionality
    - Atemporal interaction
    - Time-varying interaction

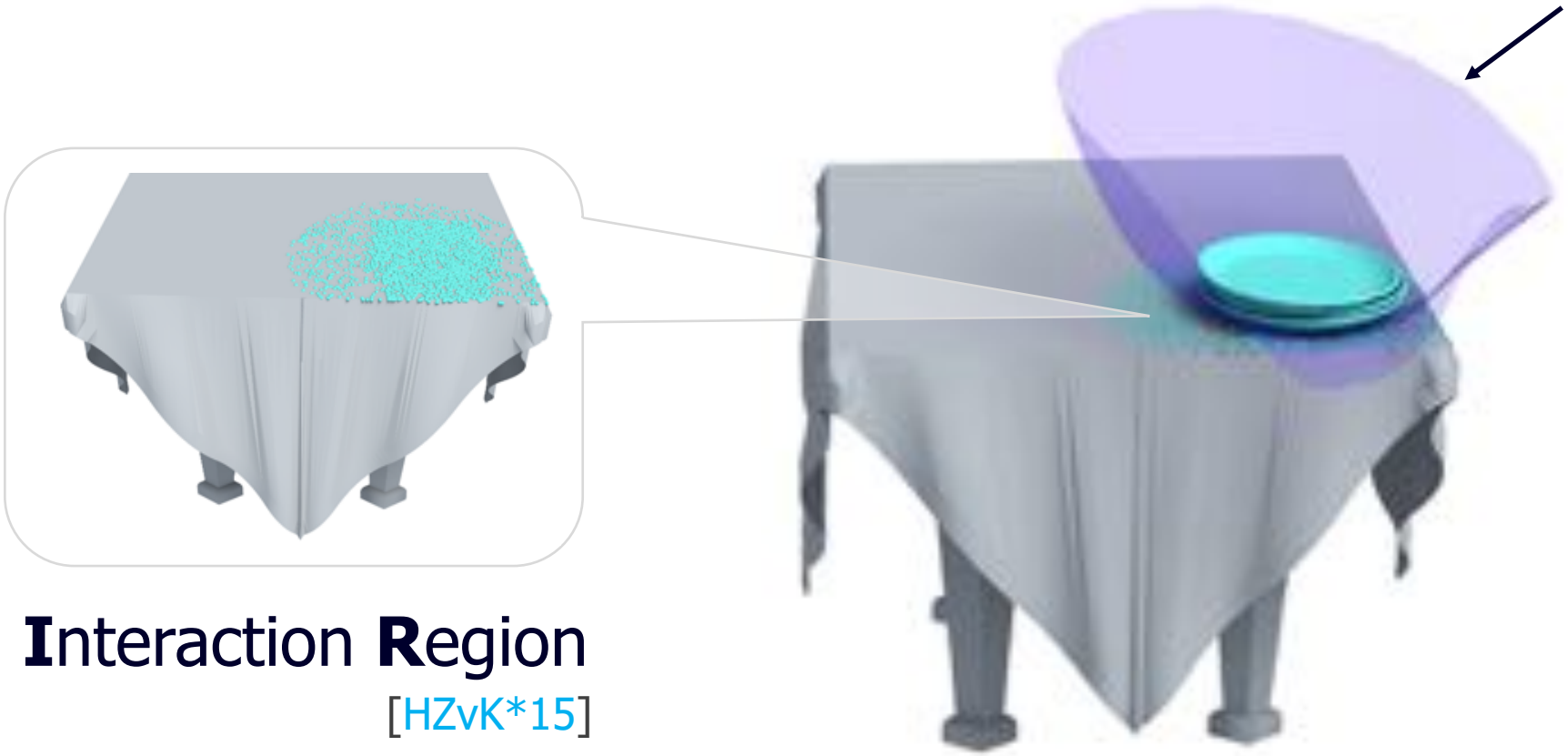
Geometry + interaction methods

- **Handcrafted descriptors**
  - **Atemporal interaction**
  - Time-varying interaction
- Supervised learning
  - Object-level functionality
    - Discriminative recognition
    - Generative modeling
  - Part-level functionality
    - Atemporal interaction
    - Time-varying interaction

Atemporal interaction representation

Interaction **B**isector **S**urface

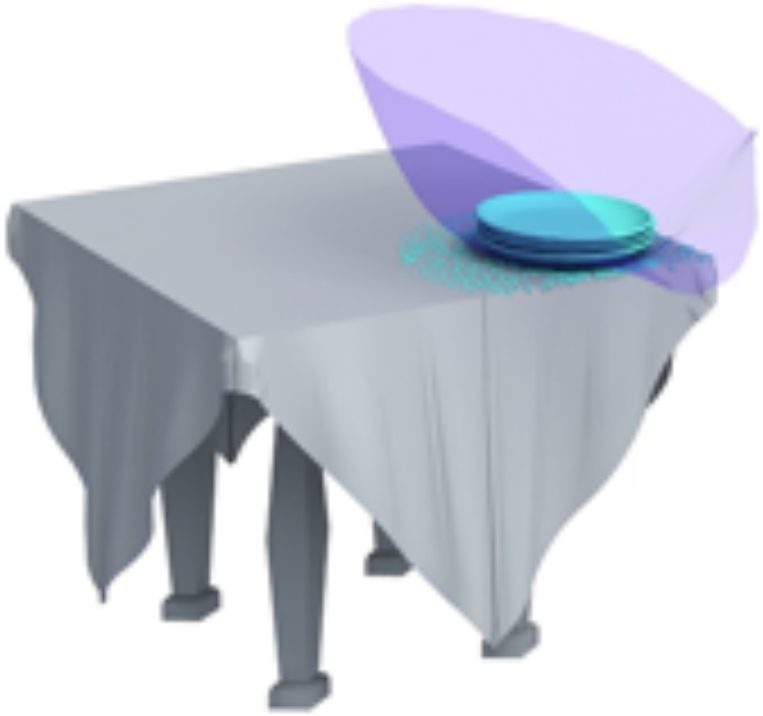
[ZWK14]

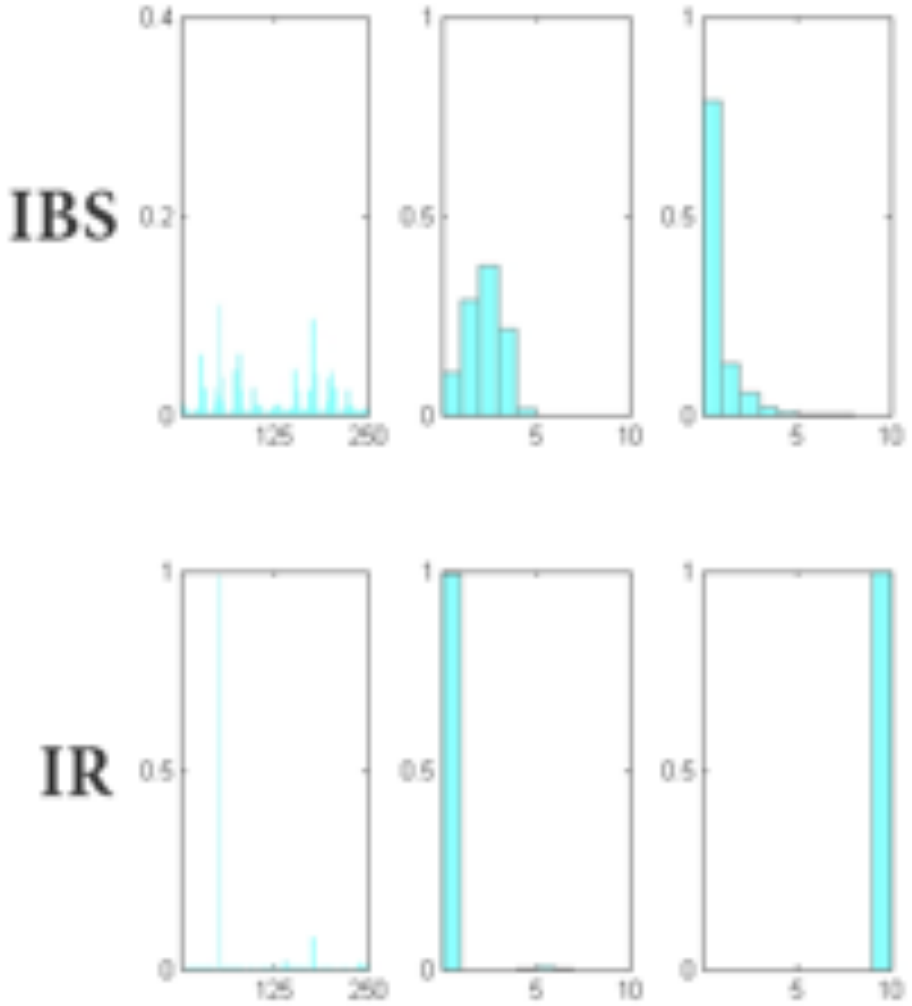


Interaction **R**egion

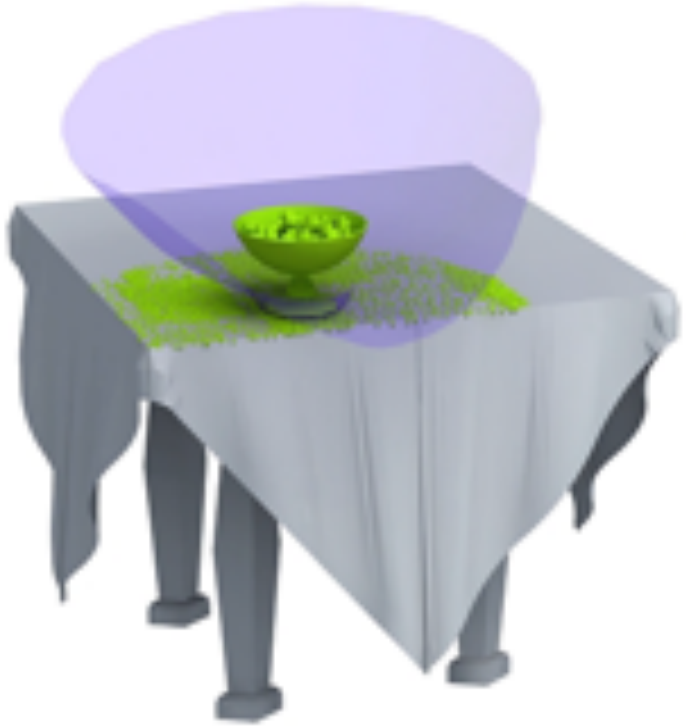
[HZvK*15]

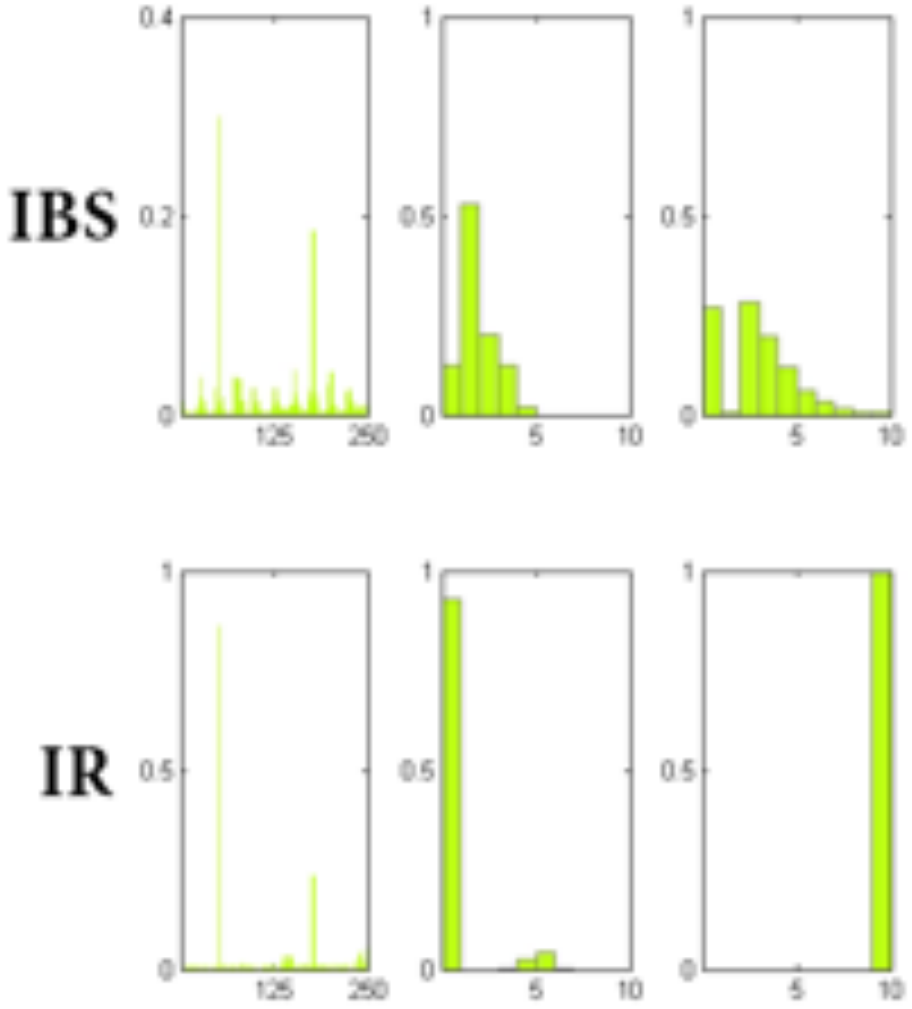
Atemporal interaction representation



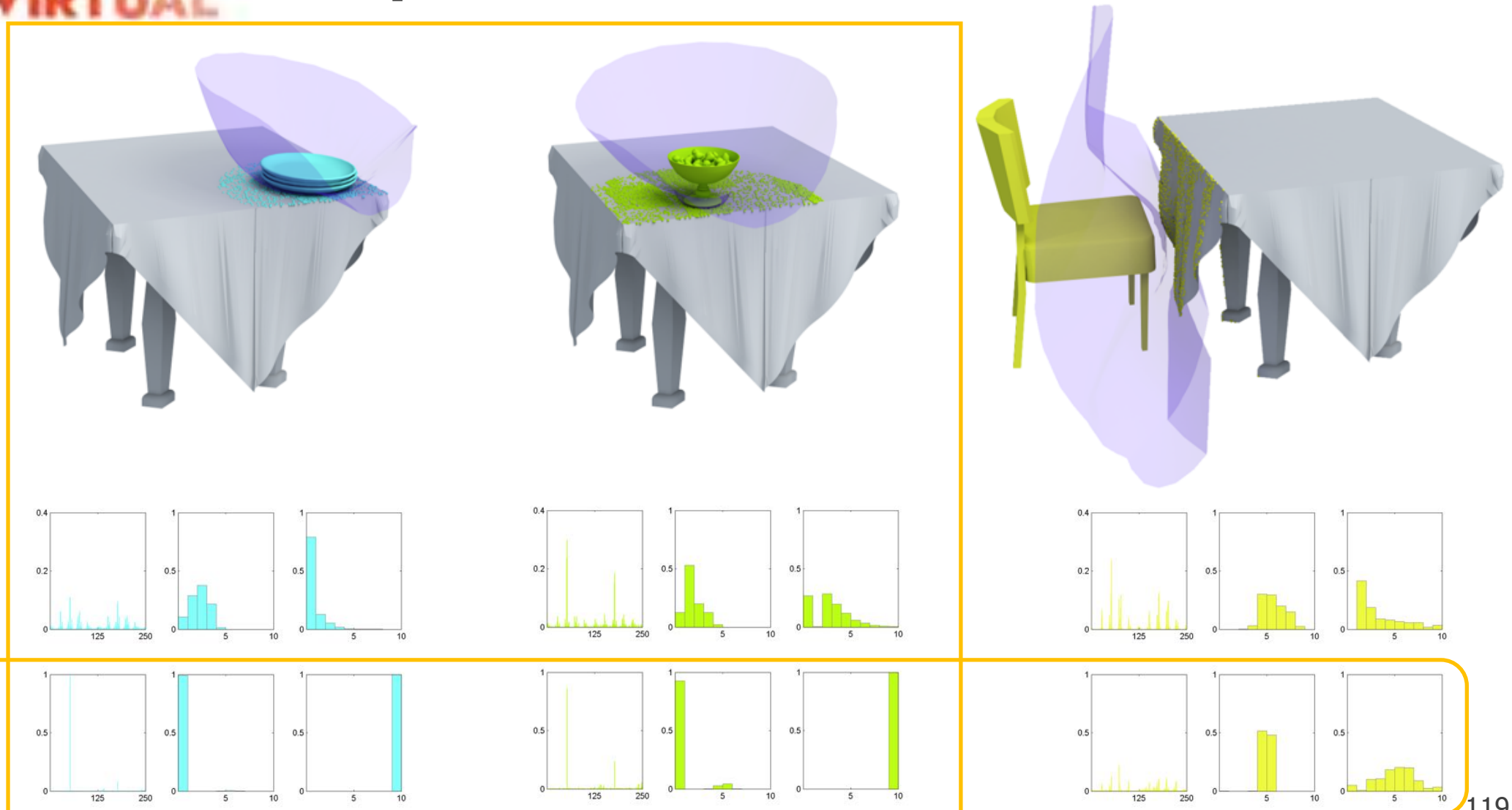


Atemporal interaction representation

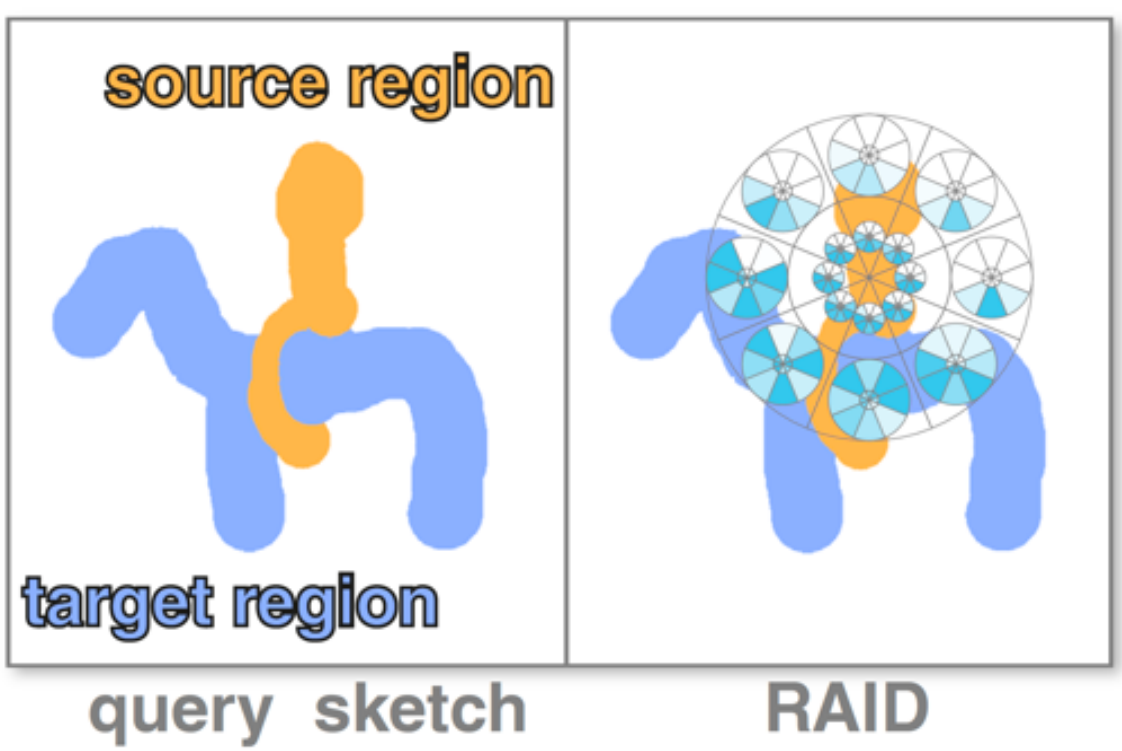




Atemporal interaction representation



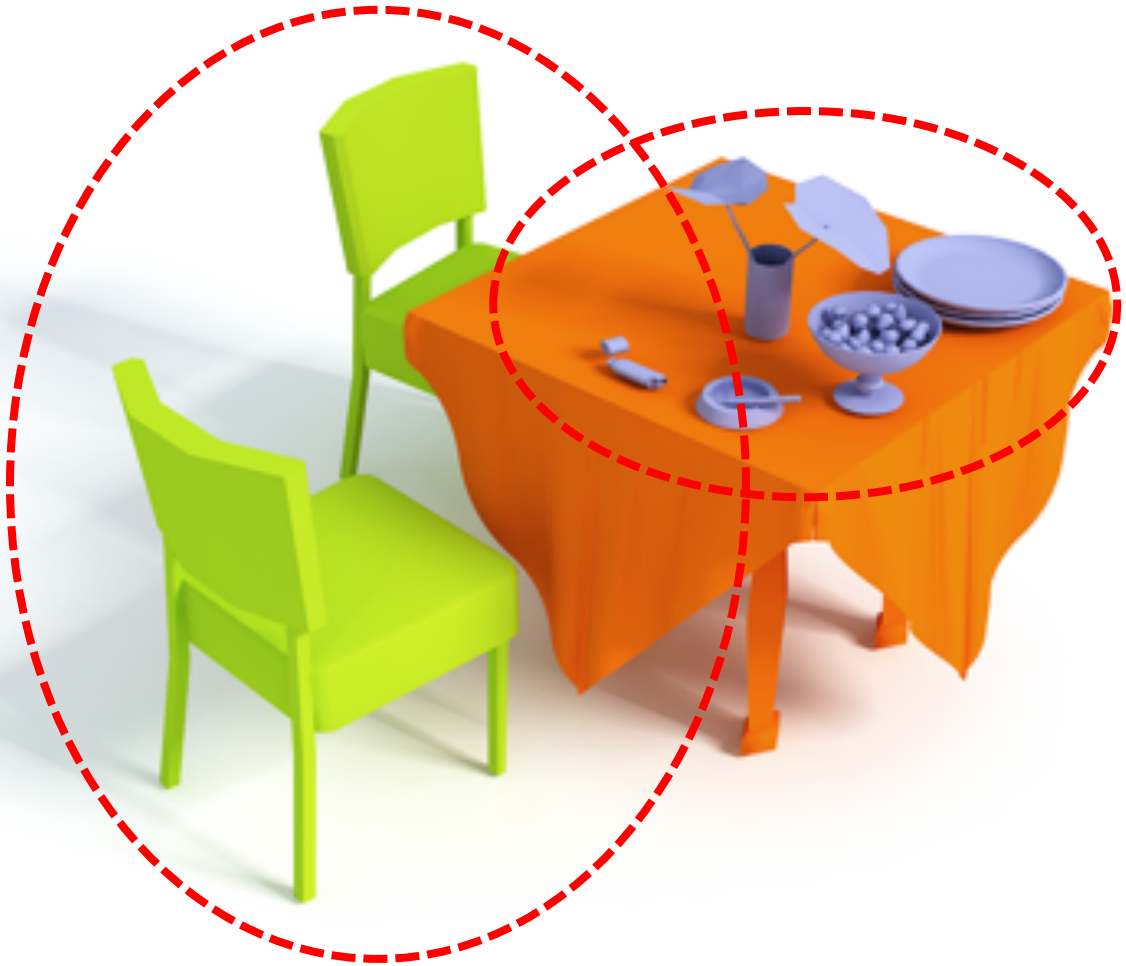
Atemporal interaction representation

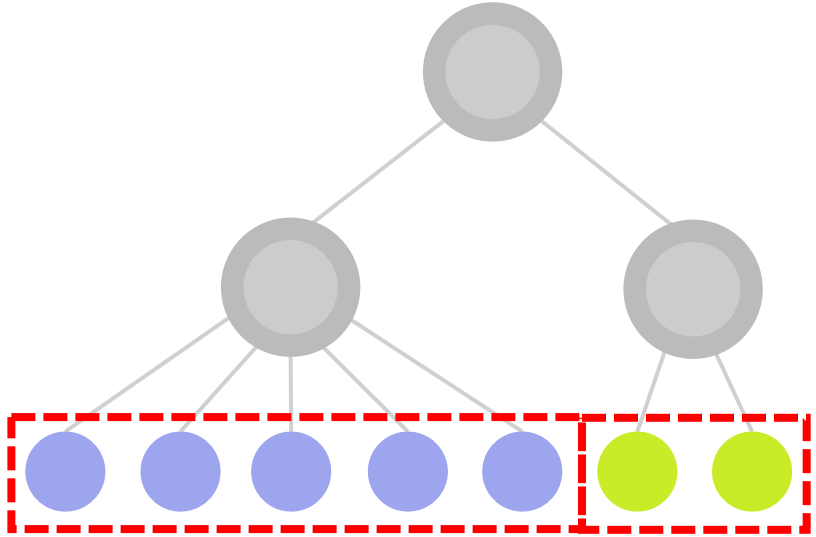


RAID: A Relation-Augmented Image Descriptor
[GMW16]

3D RAID
[HLK*17]

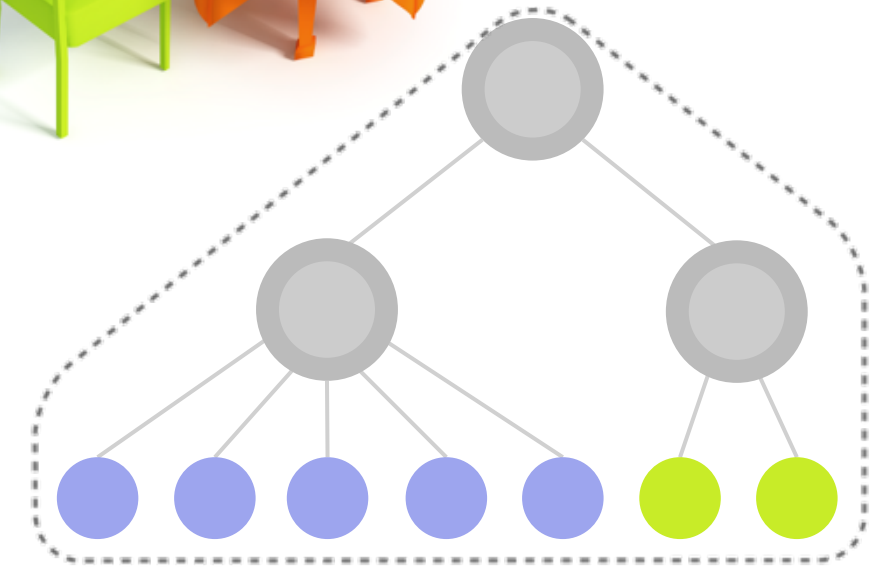
Atemporal multi-interaction organization

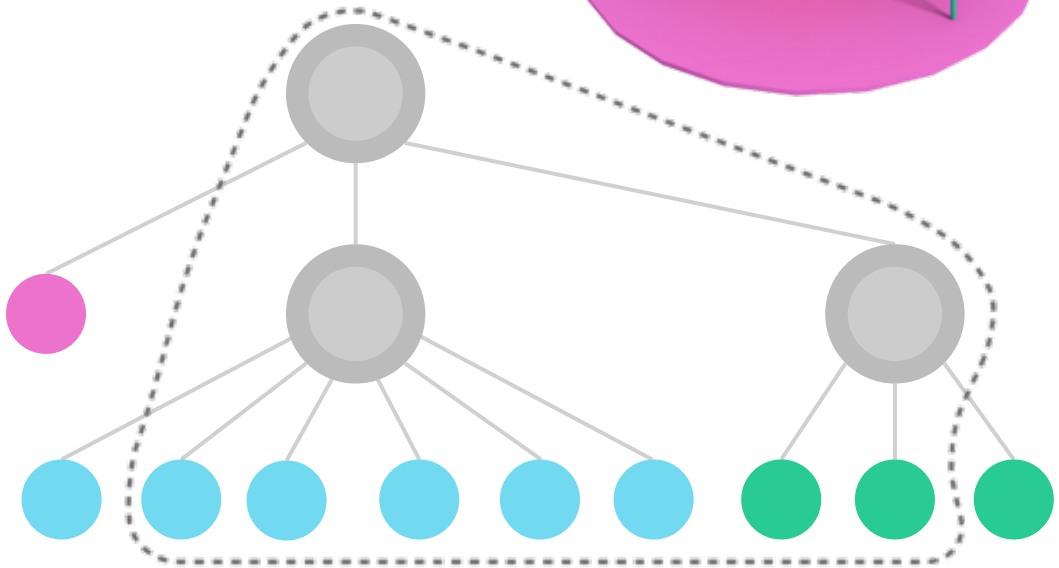




Interaction context (ICON)
[HZvK*15]

Atemporal multi-interaction organization

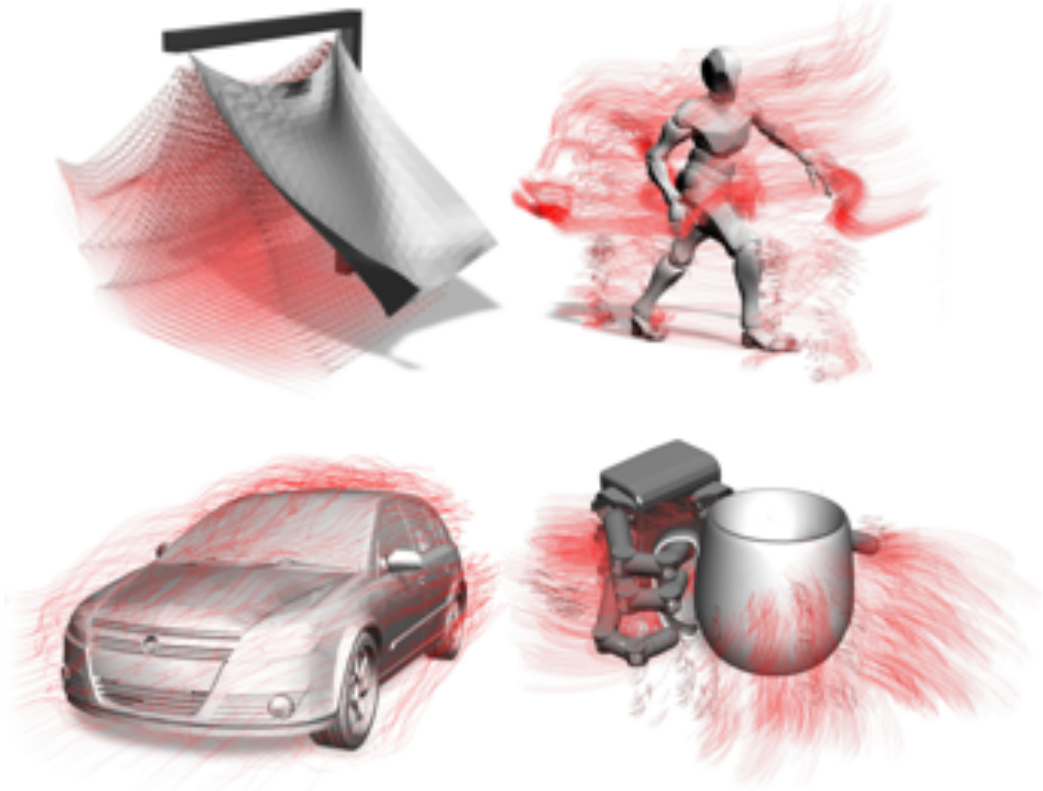




Geometry + interaction methods

- **Handcrafted descriptors**
  - Atemporal interaction
  - **Time-varying interaction**

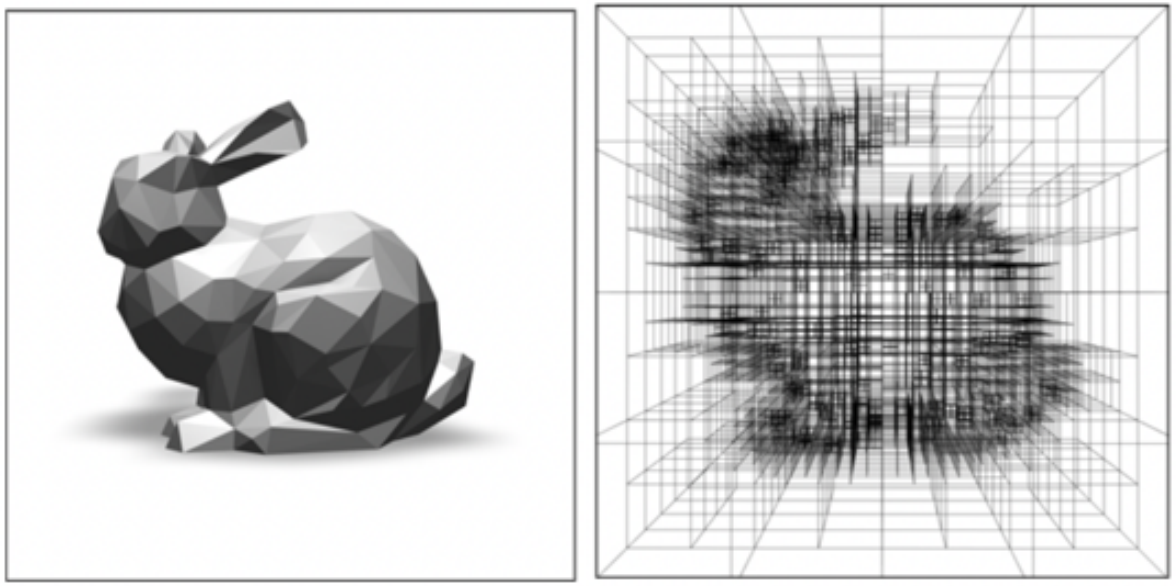
- Supervised learning
  - Object-level functionality
    - Discriminative recognition
    - Generative modeling
  - Part-level functionality
    - Atemporal interaction
    - Time-varying interaction



[PKH*17]

Time-varying interaction representation

Motion particles



Sensor regions

Interaction Landscapes descriptor

[PKH*17]

Application: interaction-based retrieval

RAID [GMW16]

ICON [HZvK*15]

Interaction Landscapes descriptor [PKH*17]

Functionality recognition

?

- Backpack
- Chair
- Drying Rack
- Handcart
- Hook
- ...

?

Geometry + interaction methods

- Handcrafted descriptors
  - Atemporal interaction
  - Time-varying interaction

- **Supervised learning**
  - Object-level functionality
    - Discriminative recognition
    - Generative modeling
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Geometry + interaction methods

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    - Discriminative recognition
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  - Part-level functionality
    - Atemporal interaction
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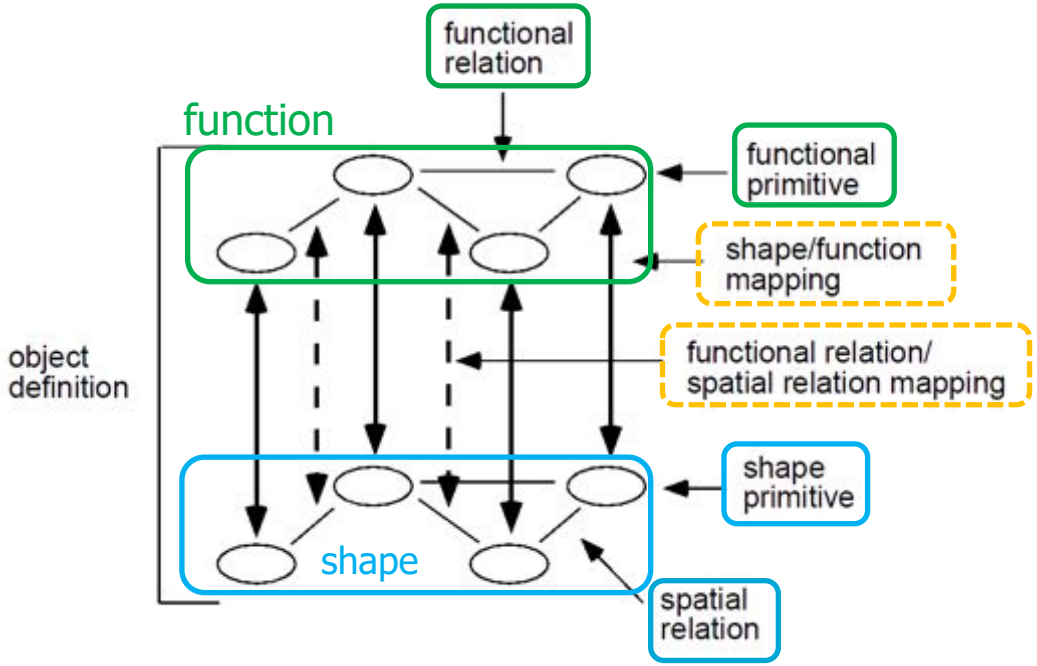


Functional parts [RDR95]

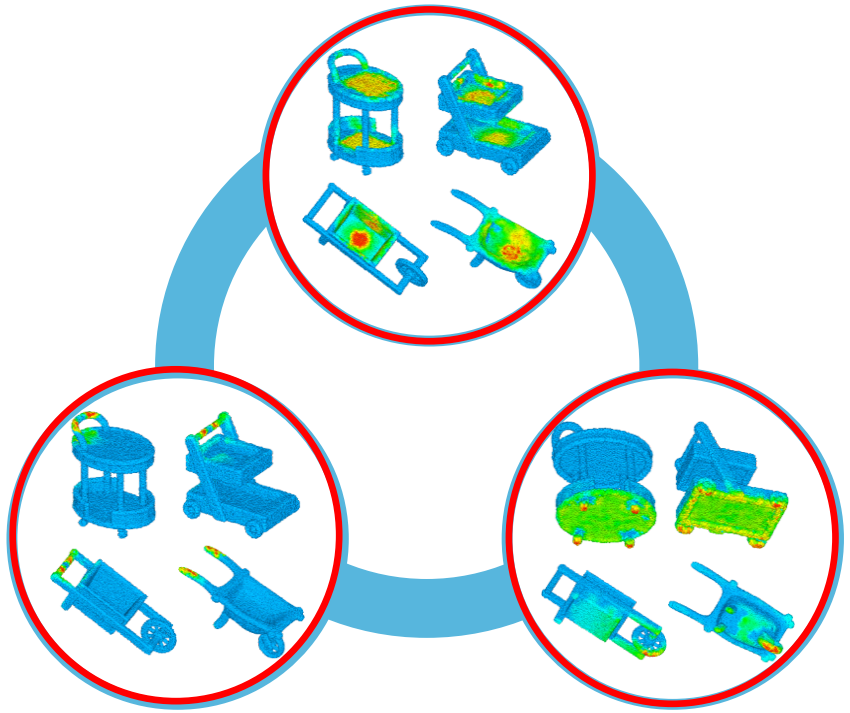
Object-level functionality recognition

Learning how objects function via co-analysis of interactions
[HvKW∗16]

Object-level functionality recognition

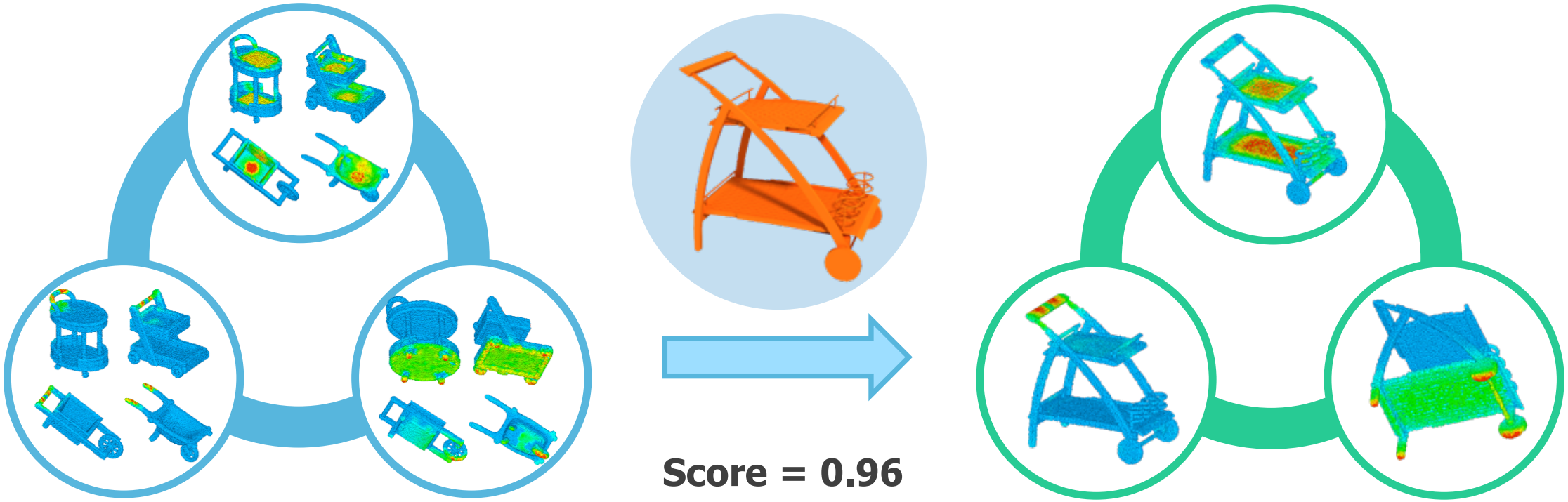
Learning how objects function via co-analysis of interactions
[HvKW∗16]

Object-level functionality recognition



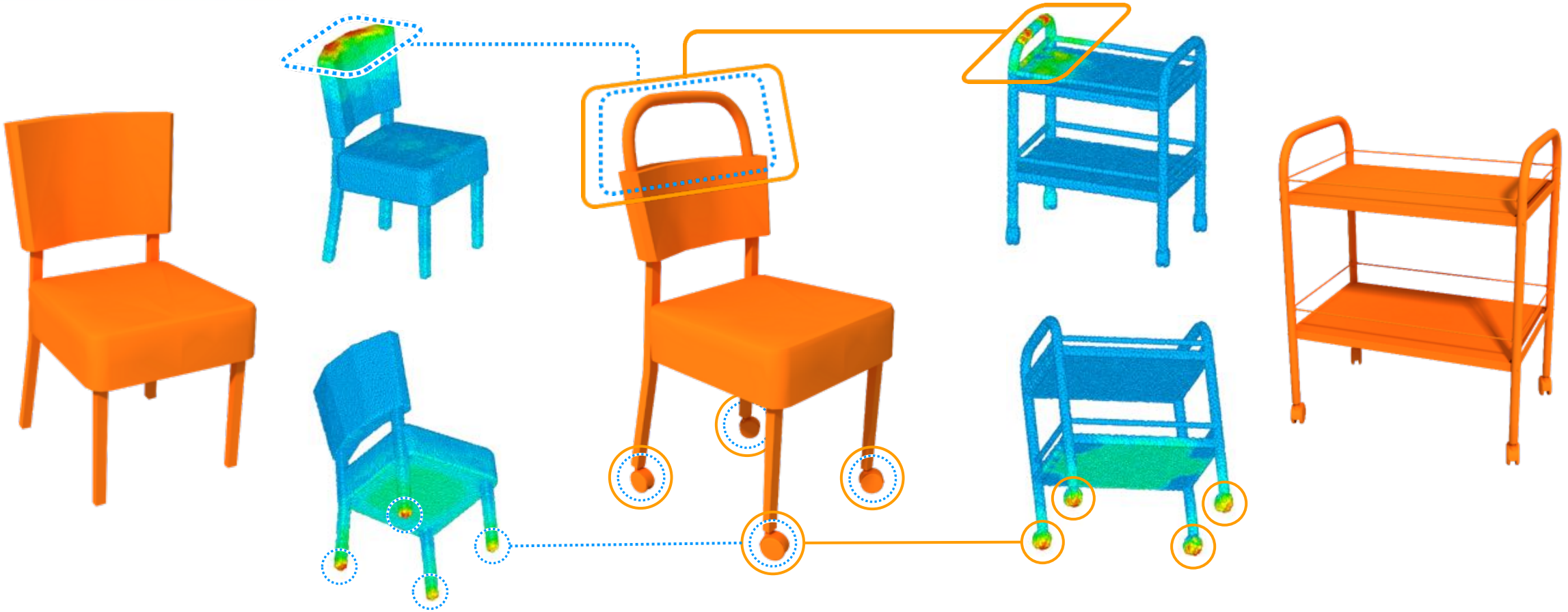
Learning how objects function via co-analysis of interactions
[HvKW∗16]

Object-level functionality recognition



Learning how objects function via co-analysis of interactions
[HvKW∗16]

Application: function enhancement



Learning how objects function via co-analysis of interactions
[HvKW∗16]

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Generative model

Object usage hallucination

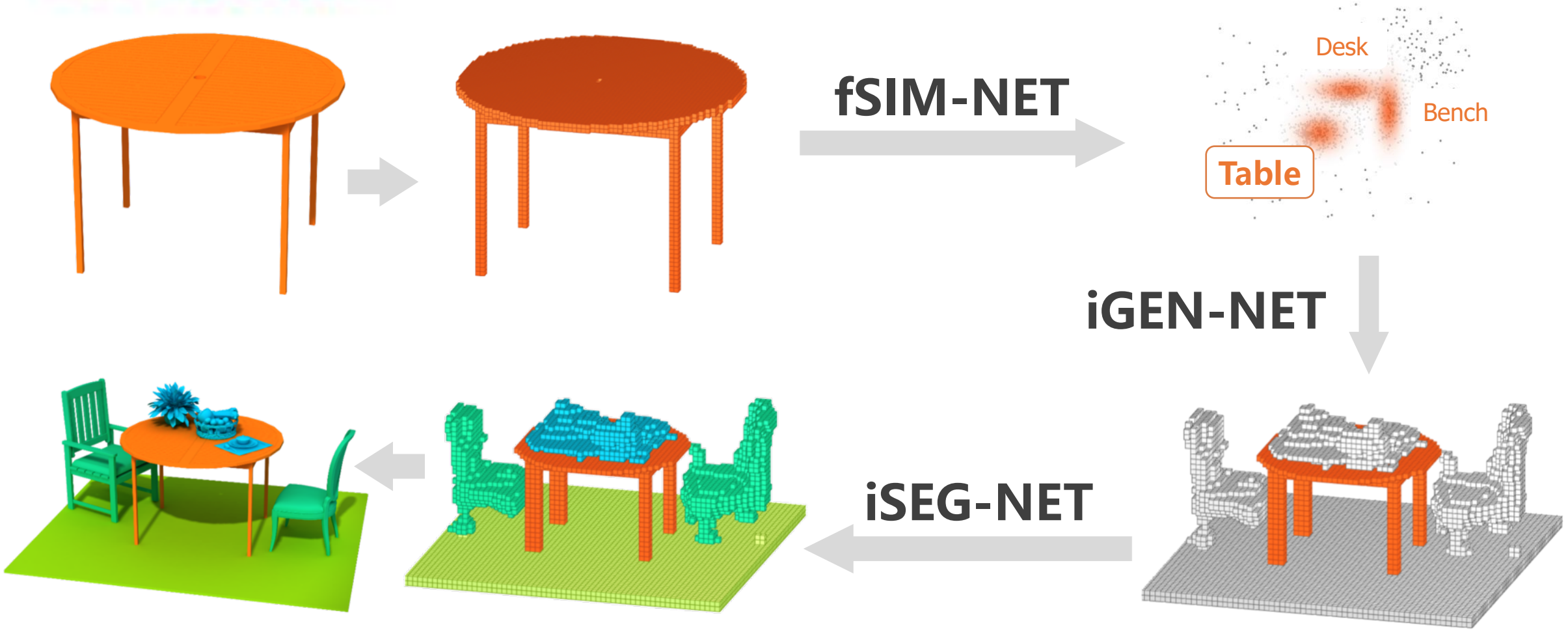
Functionality recognition and context generation

Table

Desk

Predictive and Generative Neural Networks for Object Functionality [HYZ∗18]

PG-DNN



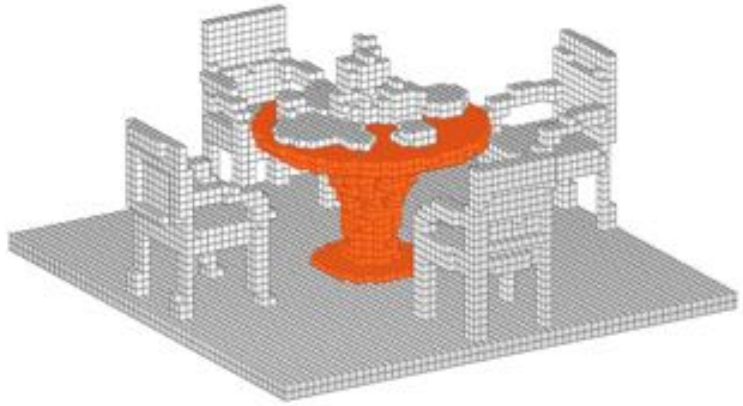
Predictive and Generative Neural Networks for Object Functionality
[HYZ∗18]

Goal 1: Functionality prediction

- Map given object to scenes showing suitable functionalities
  - Learn a functional similarity measure between **objects** and **scenes**

Object

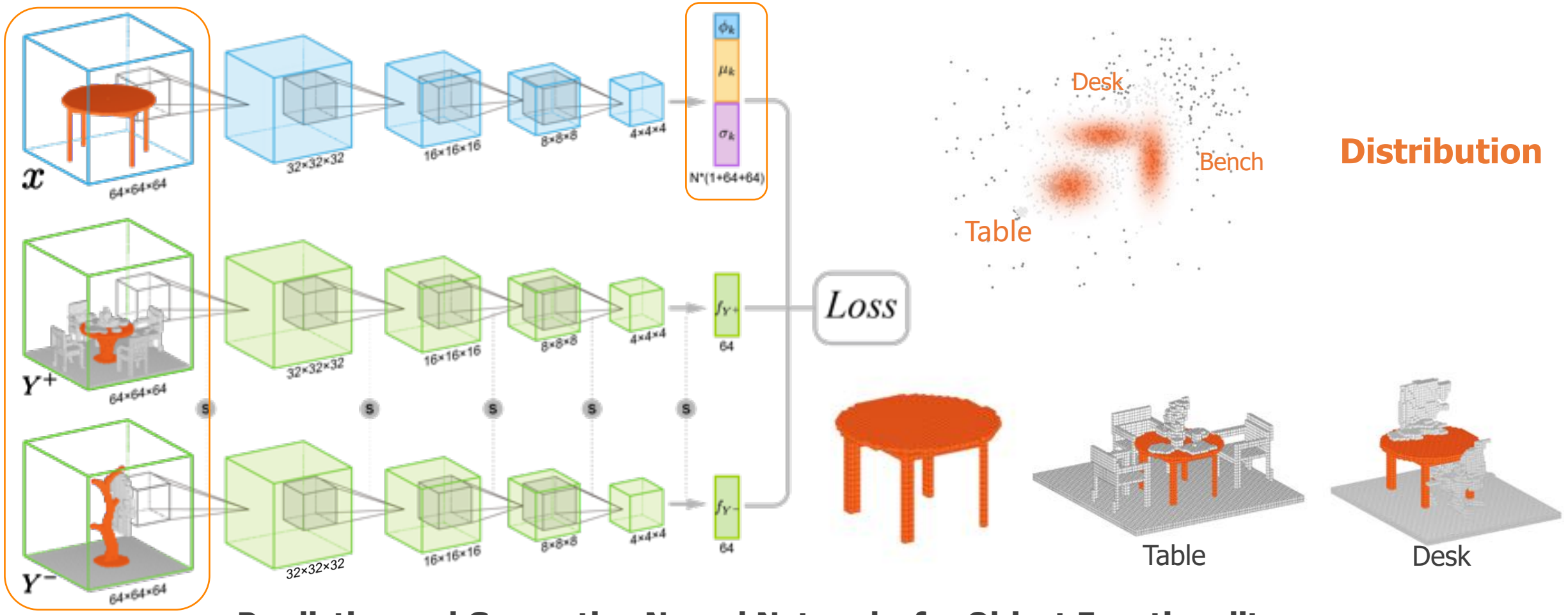
Scene



Predictive and Generative Neural Networks for Object Functionality
[HYZ∗18]

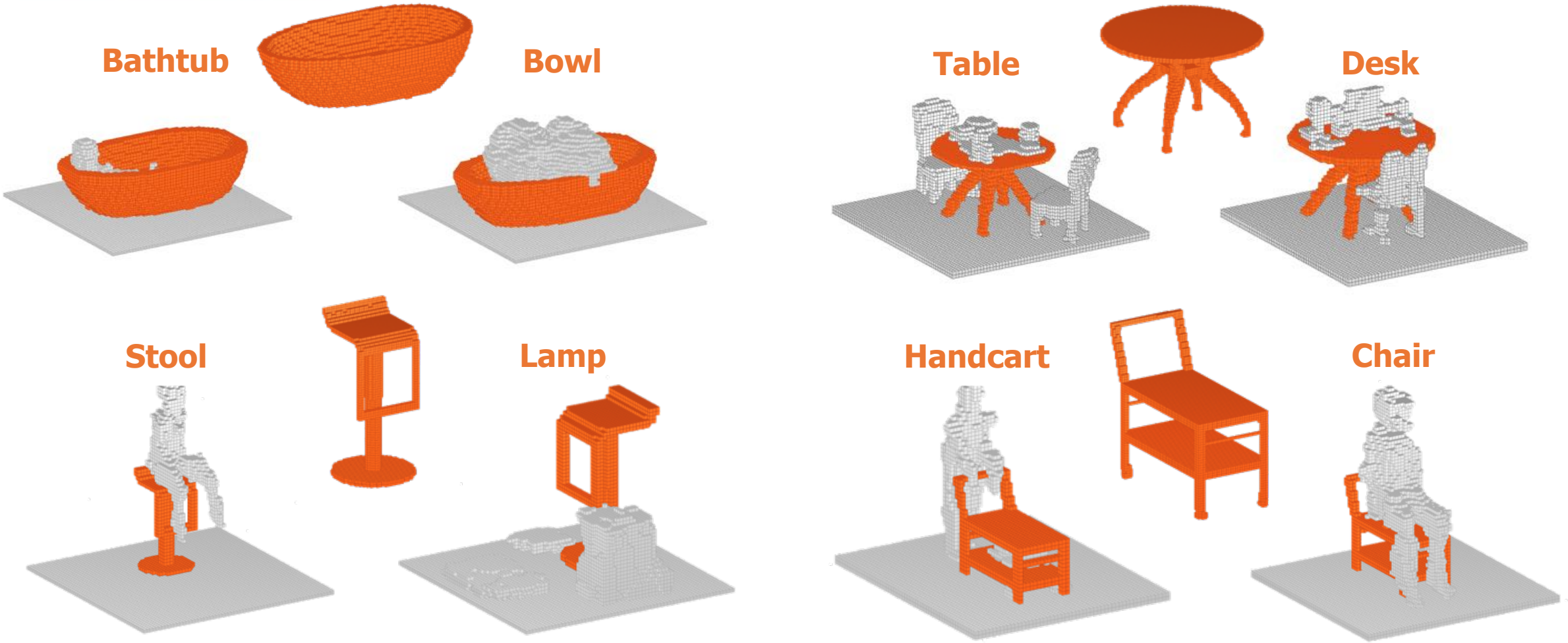
fSIM-NET

Multiple functionalities



Predictive and Generative Neural Networks for Object Functionality
[HYZ∗18]

Multi-functionality



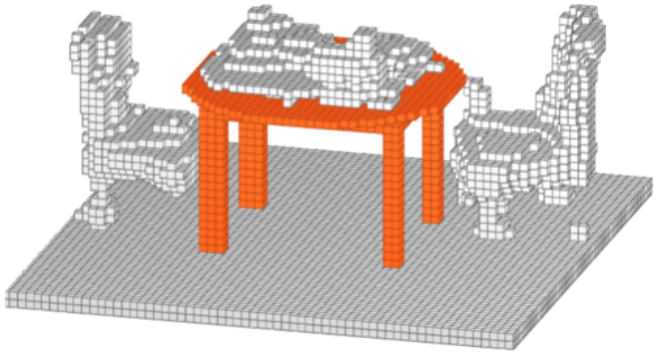
Predictive and Generative Neural Networks for Object Functionality
[HYZ∗18]

Goal 2: Object usage hallucination

- Achieve into two steps: context generation and segmentation

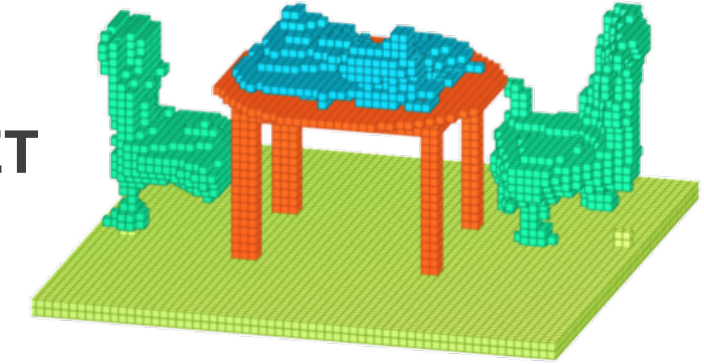
Table

iGEN-NET



64^3 voxels × 3 indicators

iSEG-NET



64^3 voxels × (2+m) indicators

Predictive and Generative Neural Networks for Object Functionality
[HYZ∗18]

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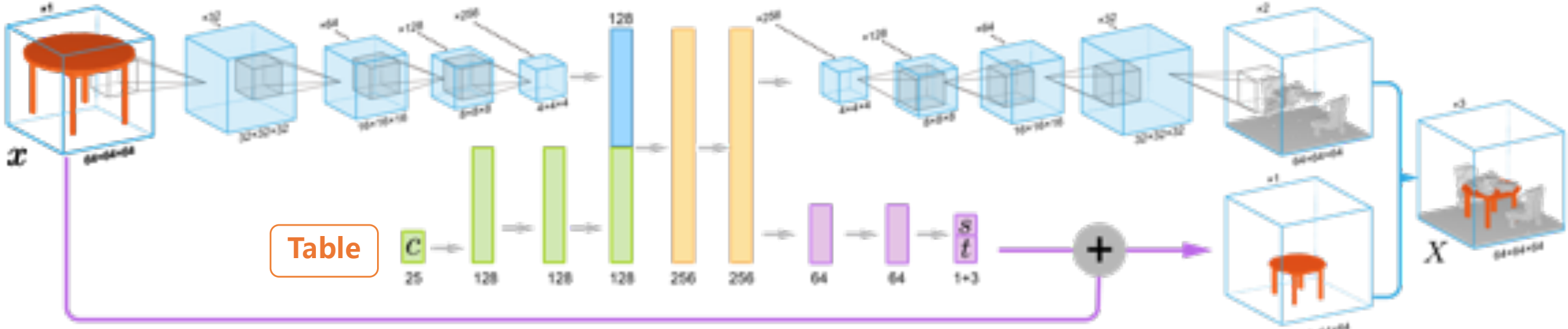
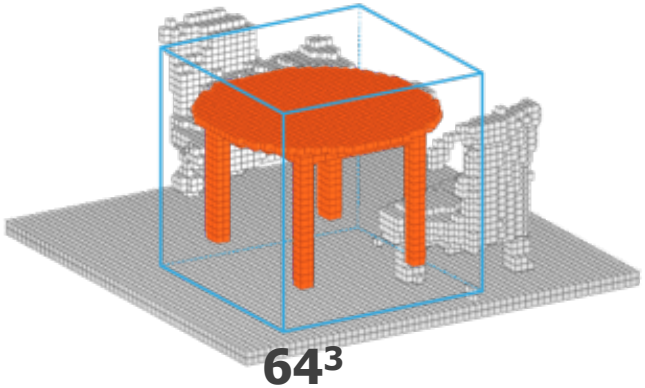
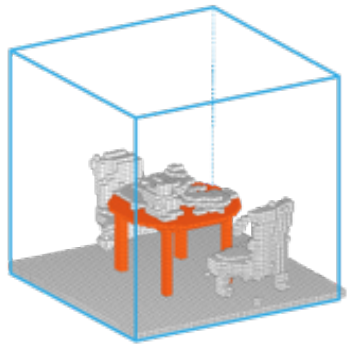
iGEN-NET





64^3



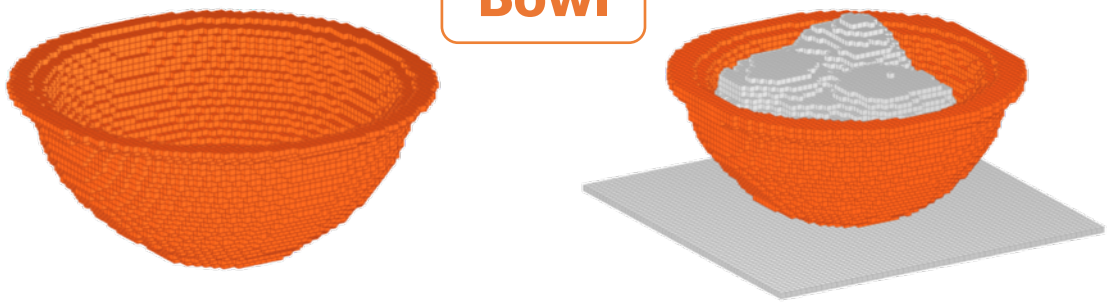
64^3

Central Object
Scaled and Translated

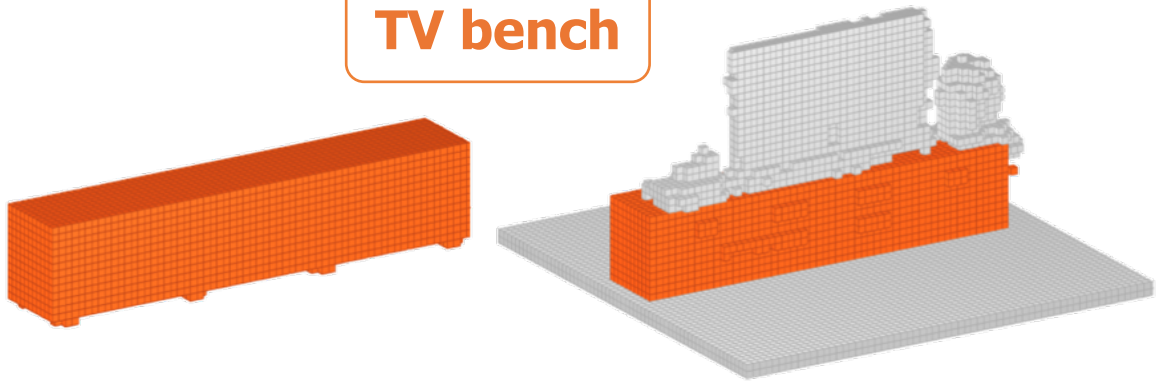
Predictive and Generative Neural Networks for Object Functionality
[HYZ∗18]

Generation results

Bowl

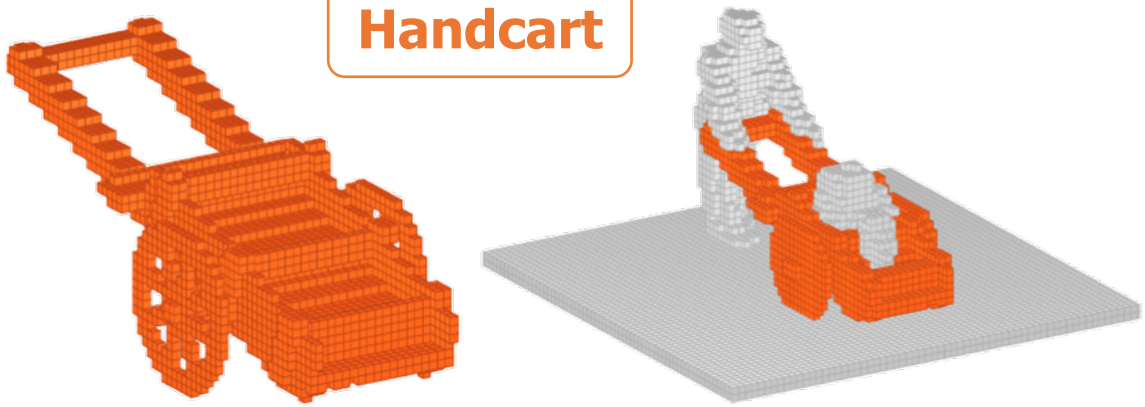


TV bench



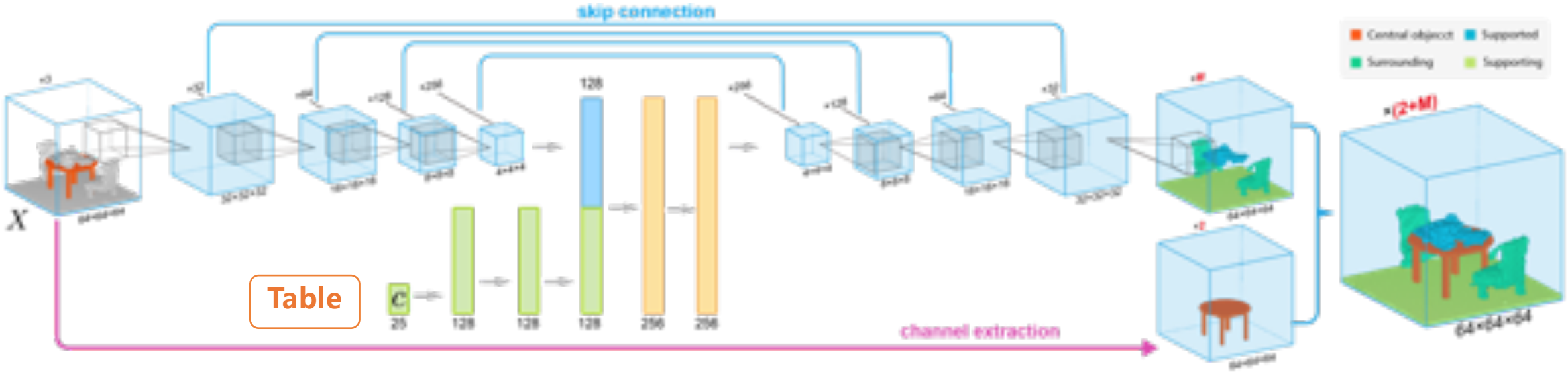
Drying rack

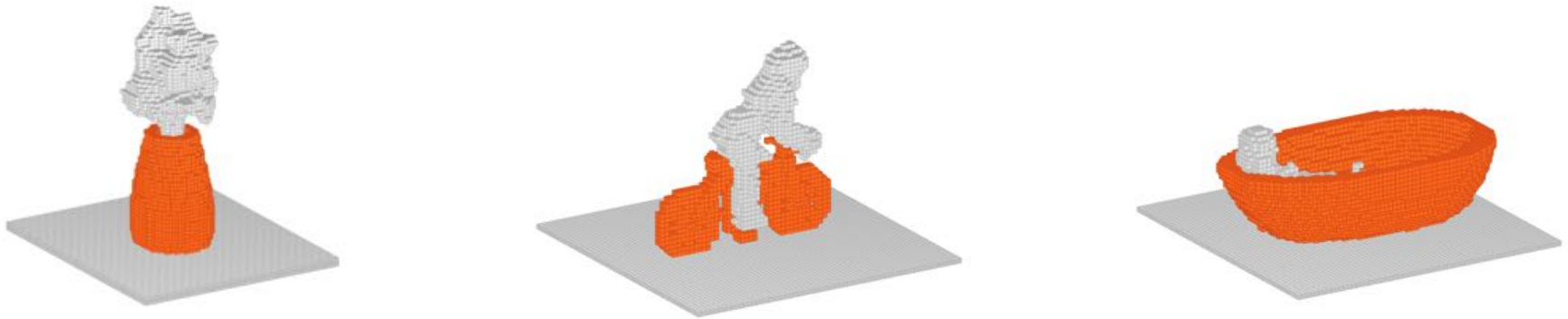
Handcart



Predictive and Generative Neural Networks for Object Functionality
[HYZ∗18]

iSEG-NET



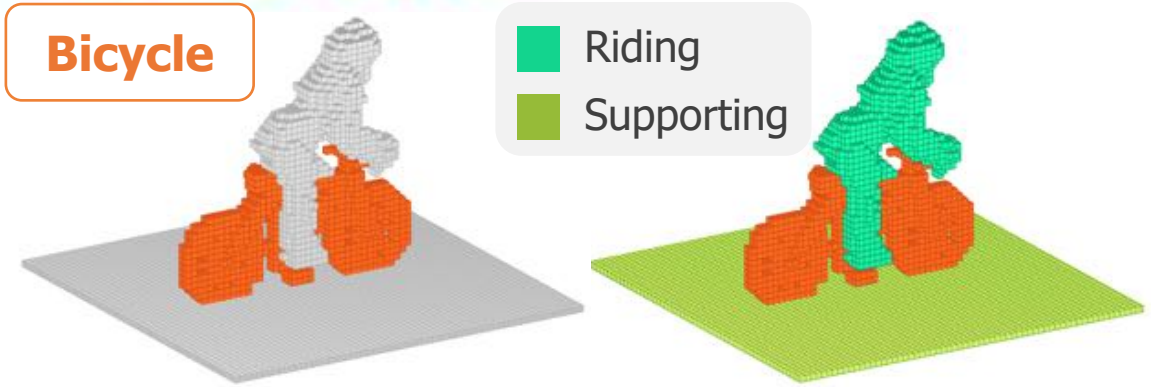


Central Object Fixed

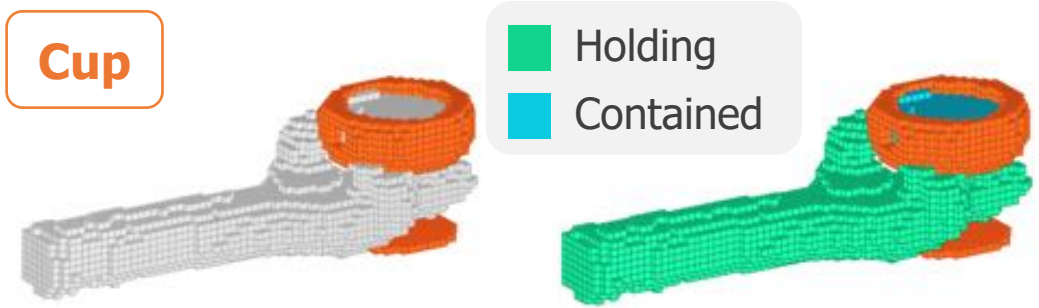
Predictive and Generative Neural Networks for Object Functionality
[HYZ∗18]

Segmentation results

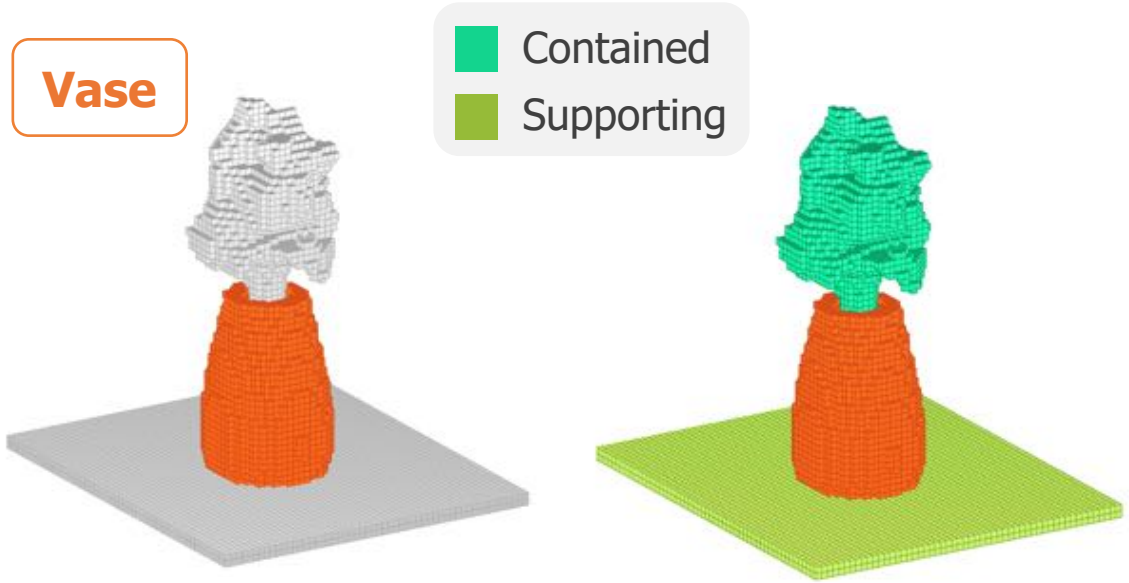
Bicycle



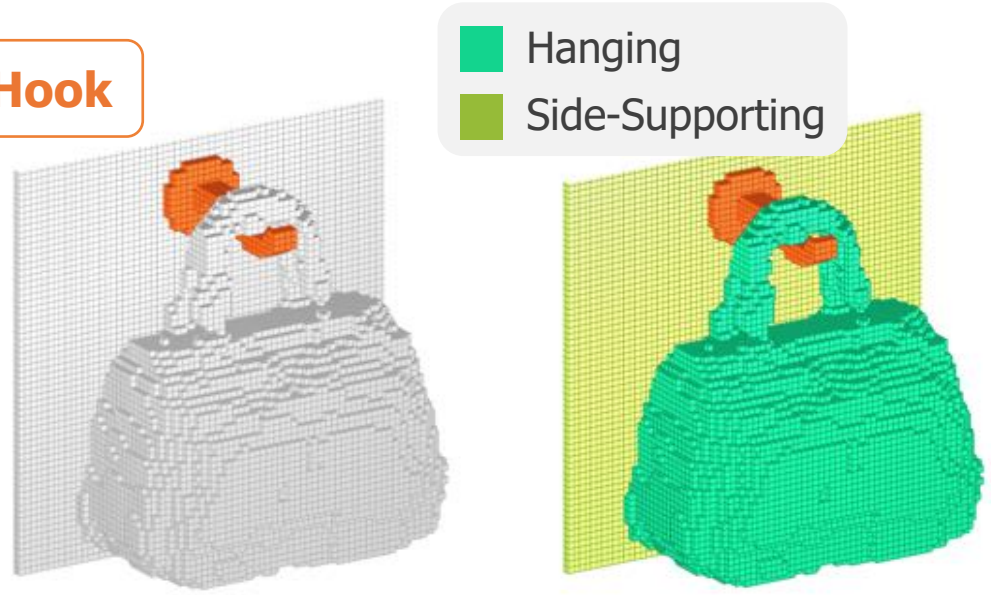
Cup



Vase



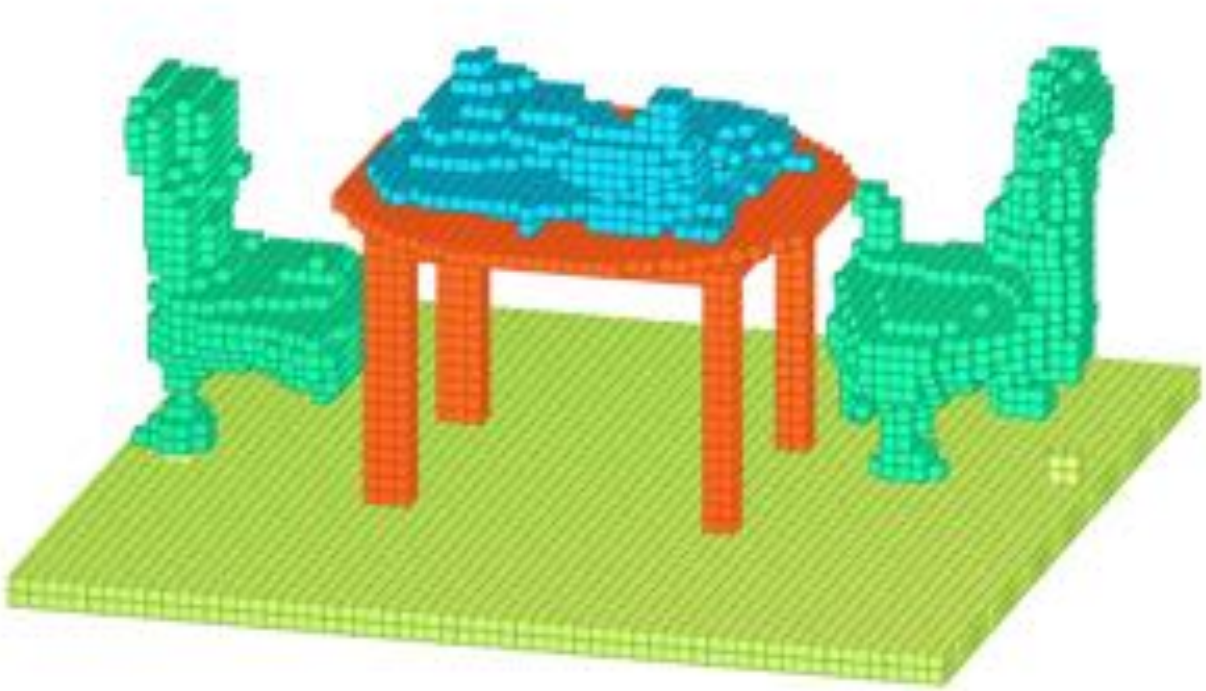
Hook

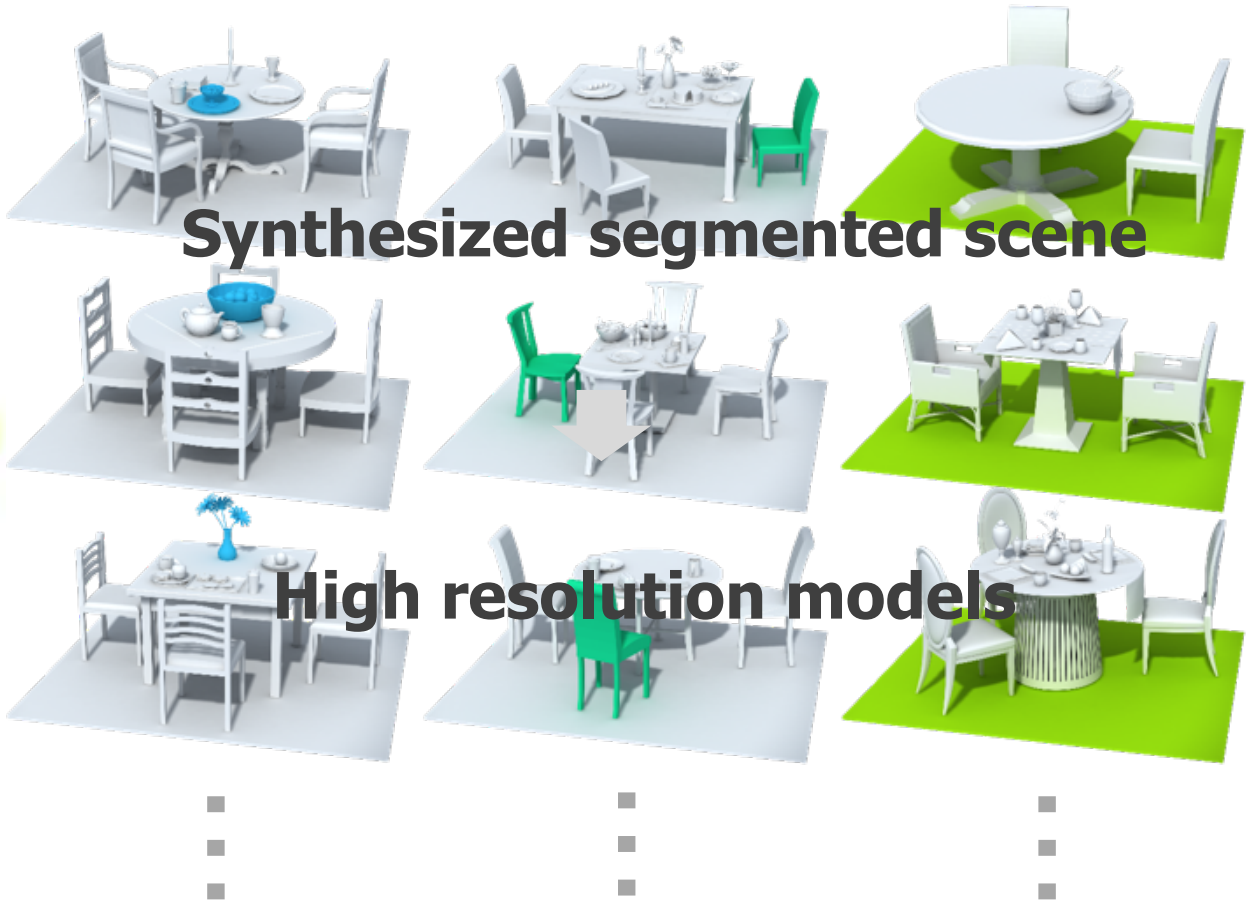


Predictive and Generative Neural Networks for Object Functionality

[HYZ*18]

Scene refinement





Predictive and Generative Neural Networks for Object Functionality
[HYZ∗18]

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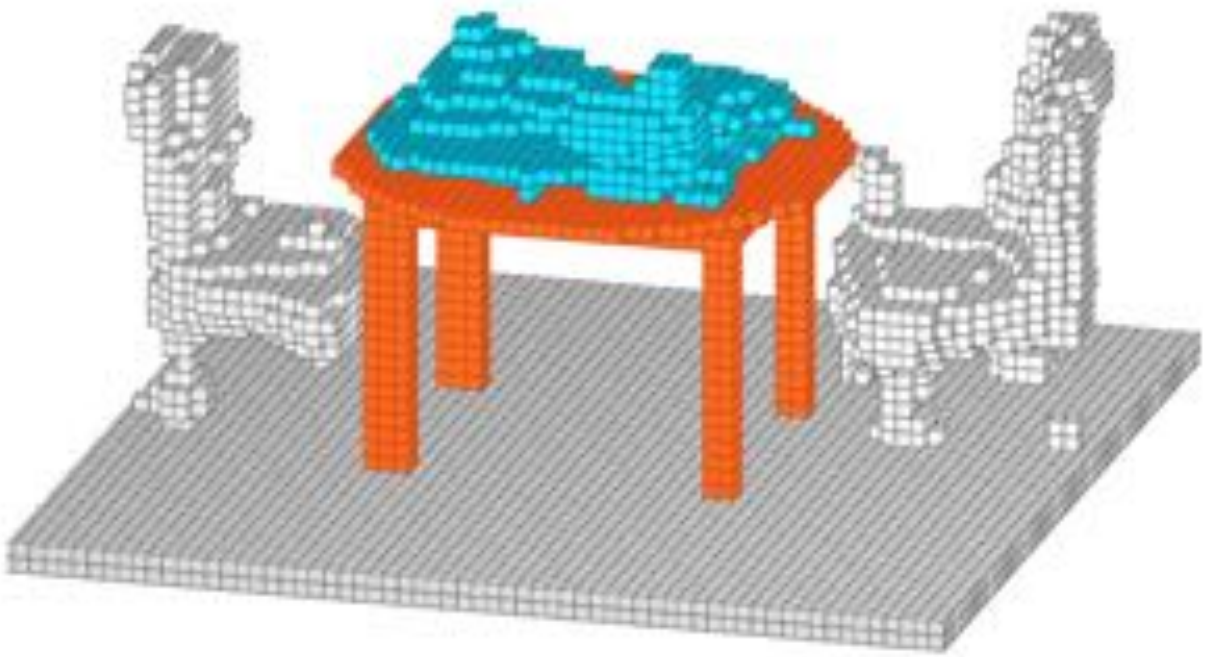
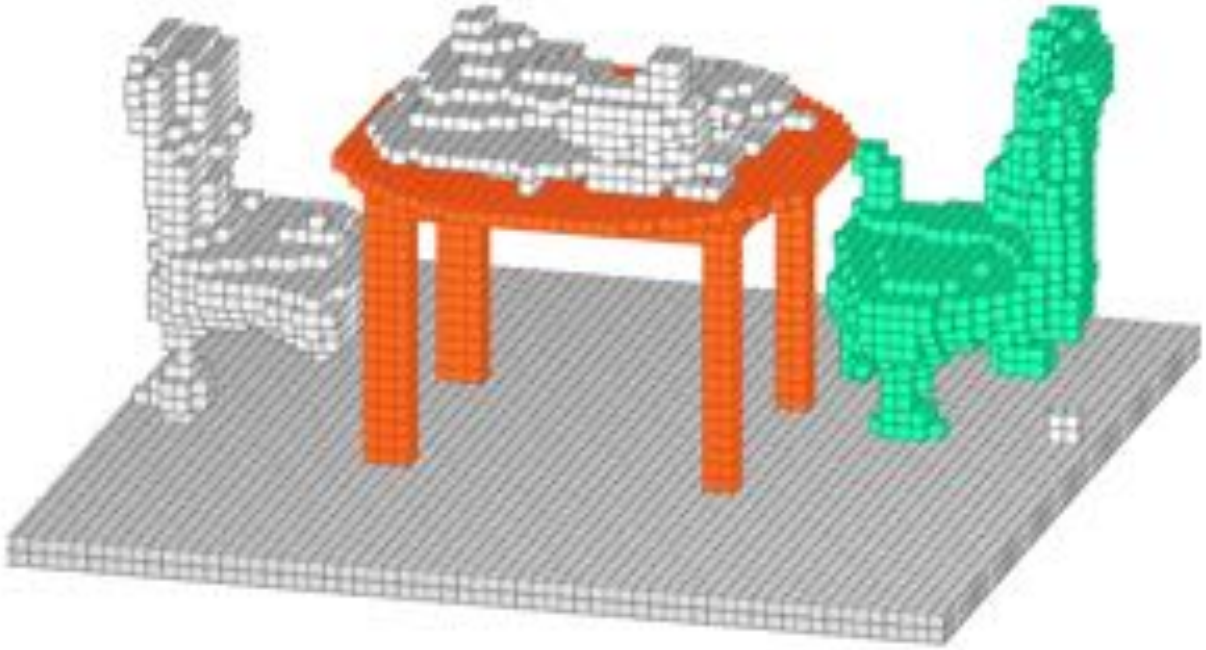
Scene refinement



Predictive and Generative Neural Networks for Object Functionality

[HYZ∗18]

Scene refinement



Predictive and Generative Neural Networks for Object Functionality
[HYZ∗18]

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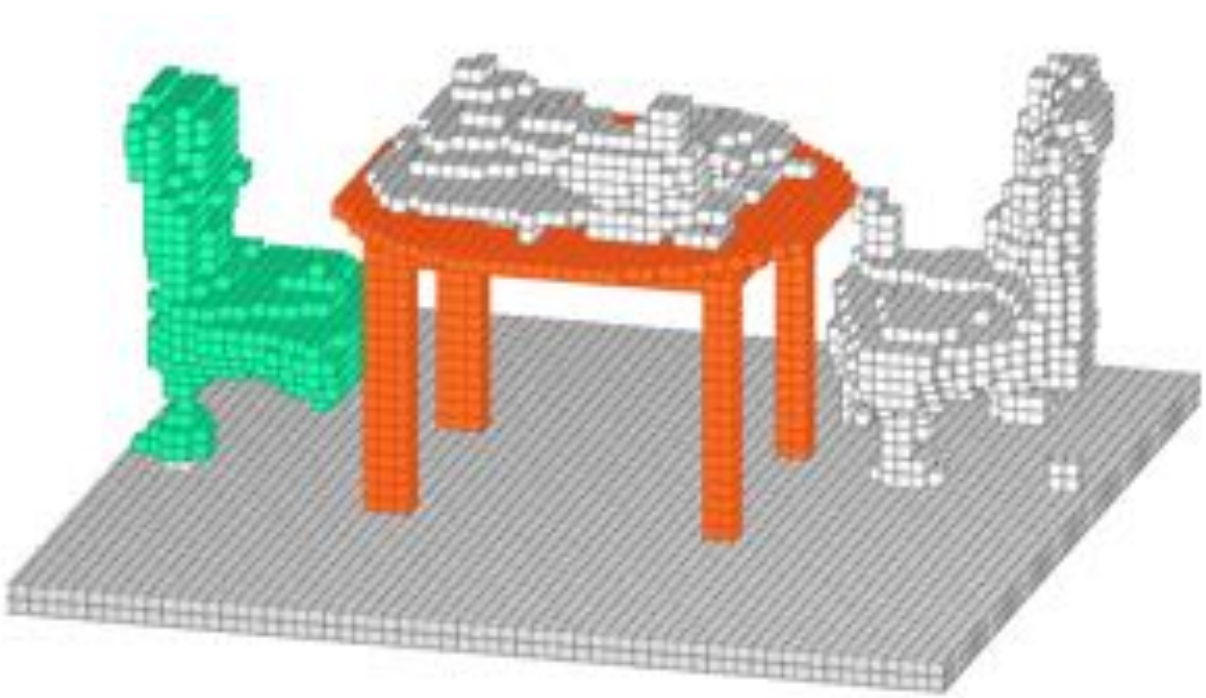
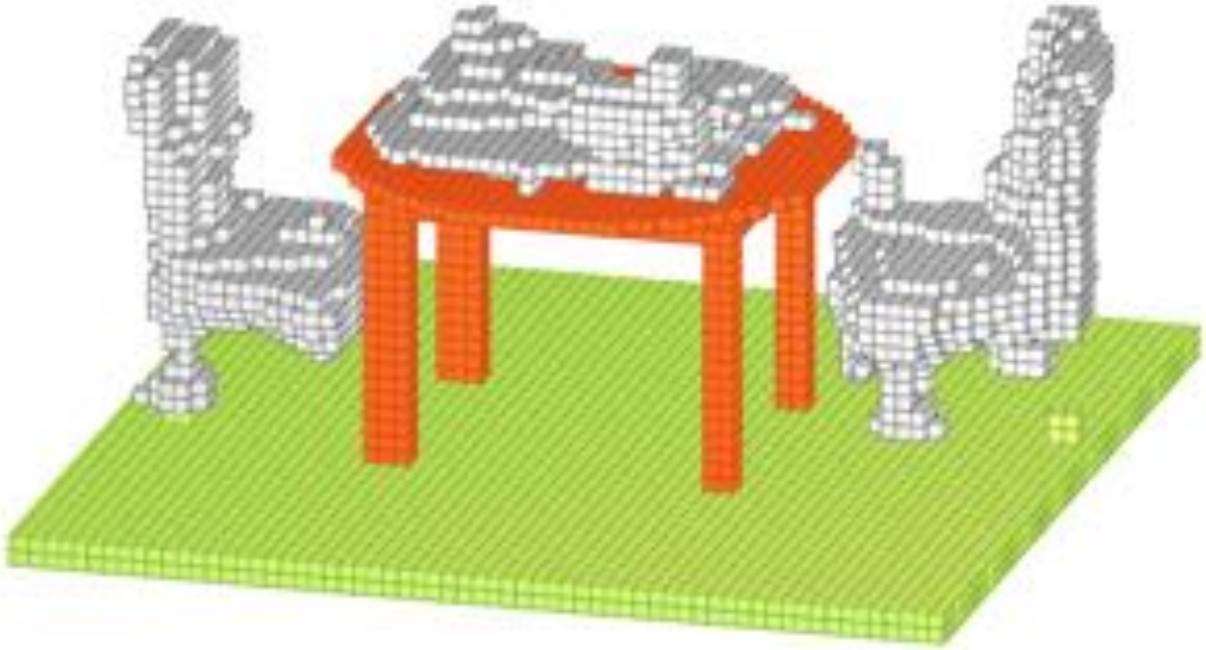
Scene refinement



Predictive and Generative Neural Networks for Object Functionality
[HYZ∗18]

SIGGRAPH ASIA 2020 VIRTUAL

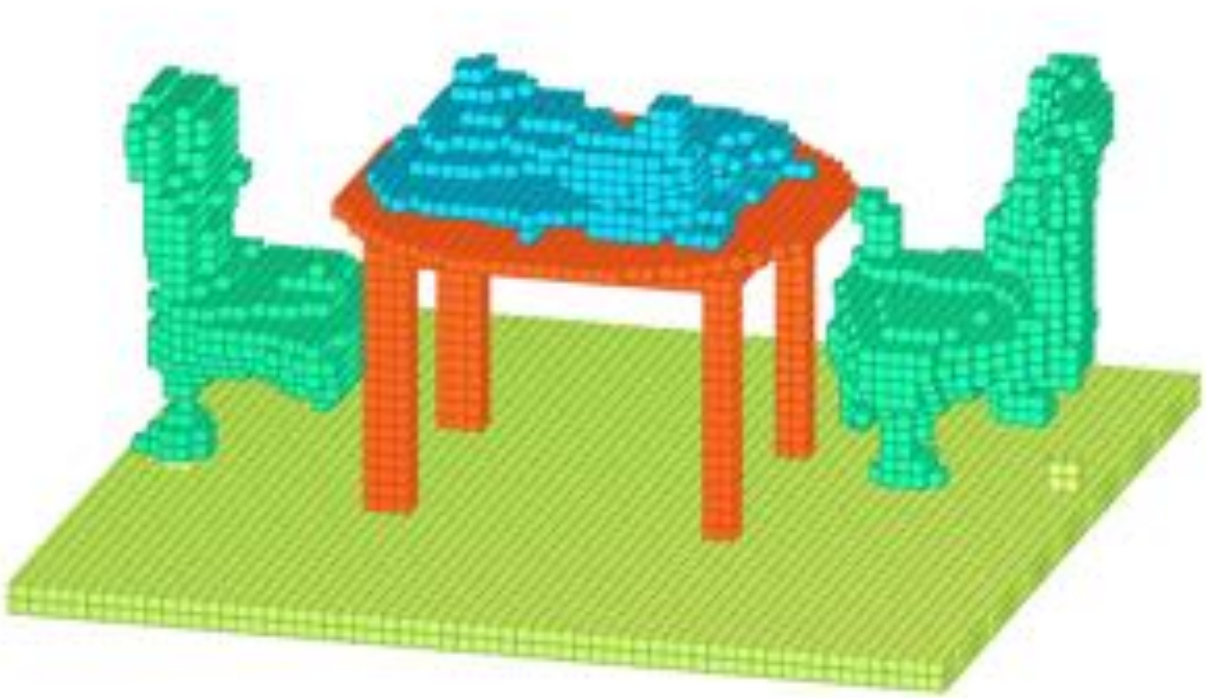
Scene refinement



Predictive and Generative Neural Networks for Object Functionality
[HYZ∗18]

SIGGRAPH ASIA 2020 VIRTUAL

Scene refinement



Predictive and Generative Neural Networks for Object Functionality

[HYZ∗18]

SIGGRAPH ASIA 2020 VIRTUAL

Final results

Predictive and Generative Neural Networks for Object Functionality
[HYZ∗18]

SIGGRAPH ASIA 2020 VIRTUAL

Final results

Predictive and Generative Neural Networks for Object Functionality [HYZ∗18]

Geometry + interaction methods

- Handcrafted descriptors
  - Atemporal interaction
  - Time-varying interaction
- **Supervised learning**
  - Object-level functionality
    - Discriminative recognition
    - Generative modeling
  - **Part-level functionality**
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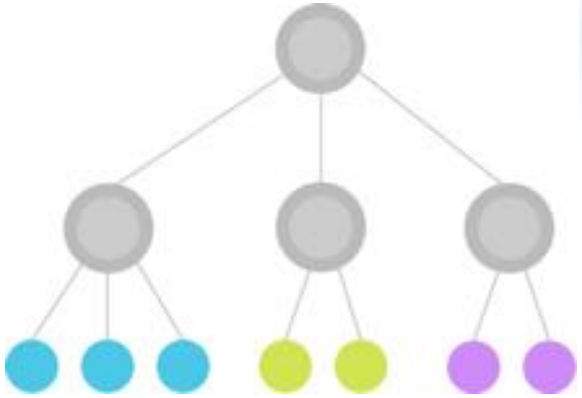
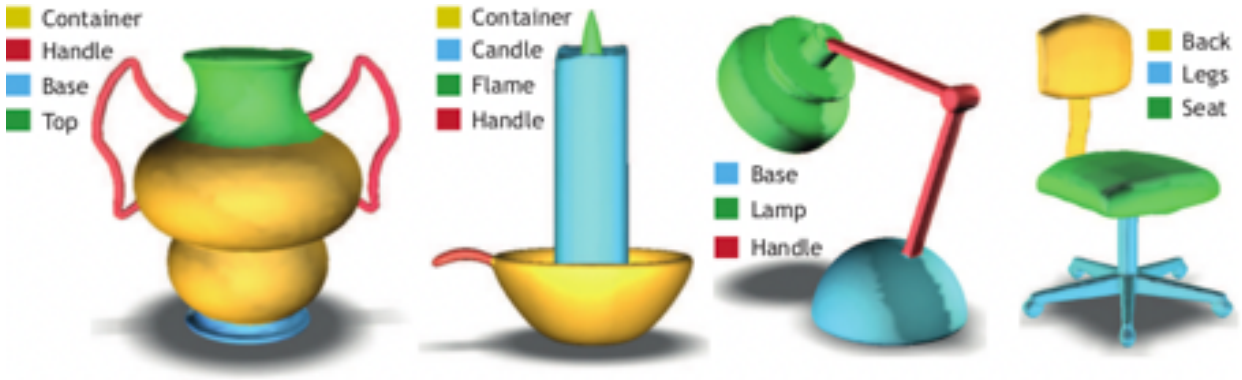
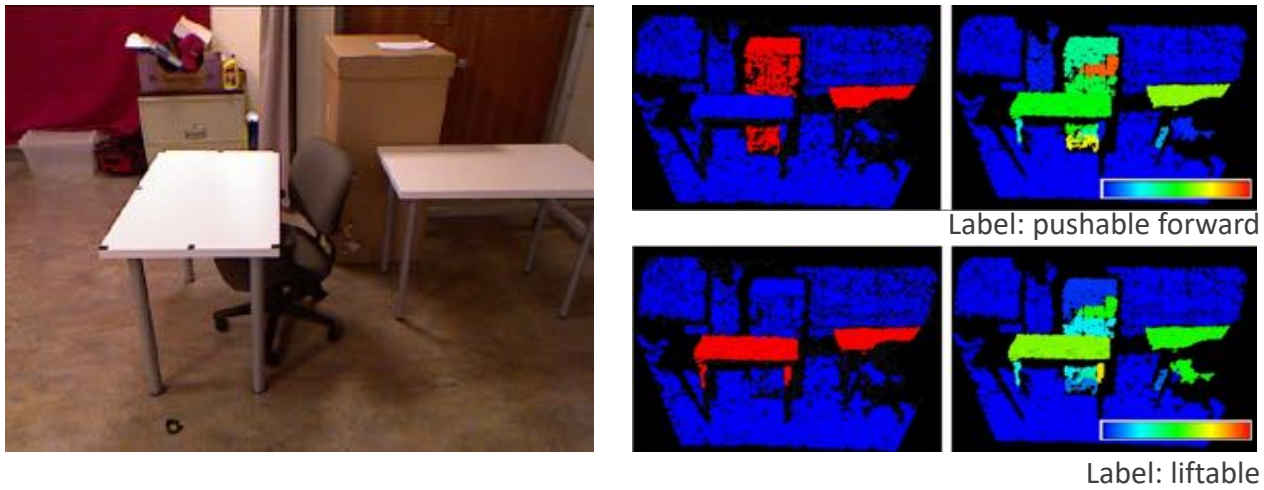


[HZvK*15]

Part-level semantic labeling (atemporal)

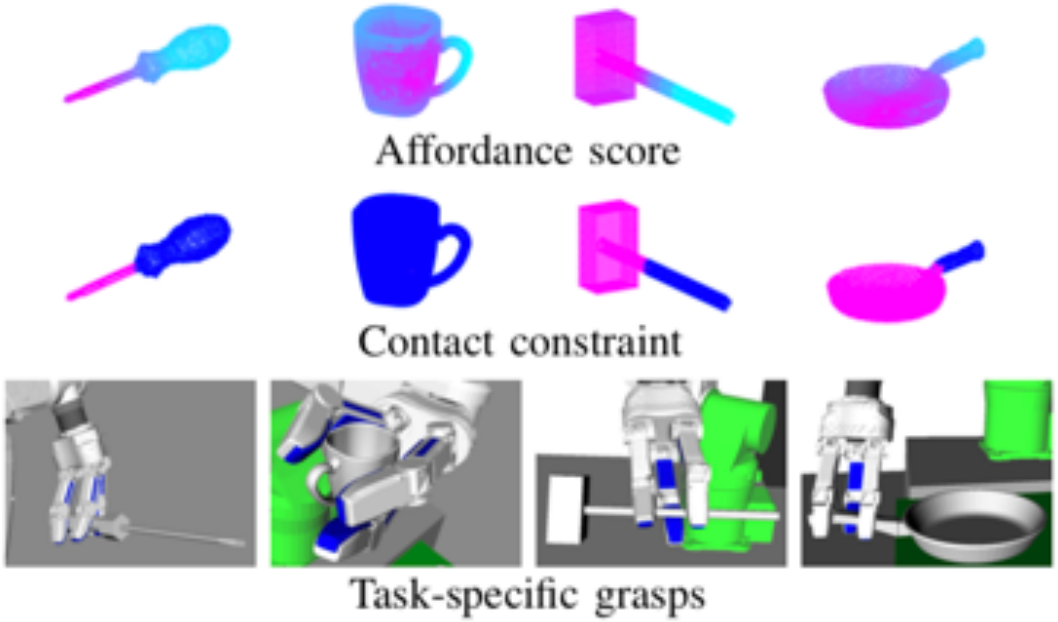


Segmentation and semantic labeling
[LMS13]

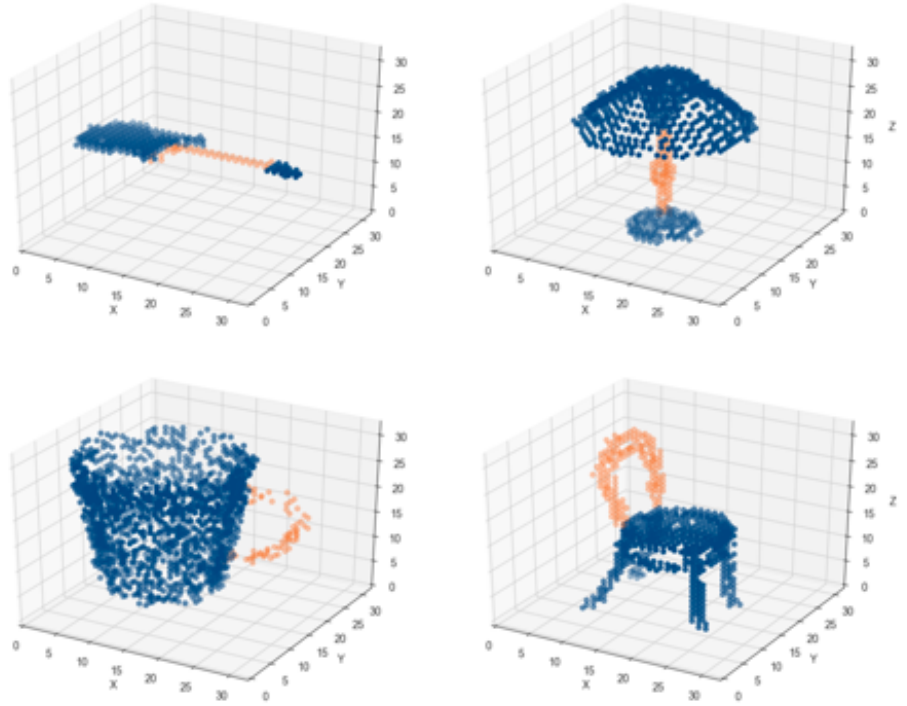


Semantic labeling with object affordance
[KS14]

Part-level grasping affordance prediction (atemporal)



Affordance detection for task-specific grasping
[KSHK17]



Learning to grasp 3d objects
[LSK20]

Part-level mobility prediction (Time-varying interaction)

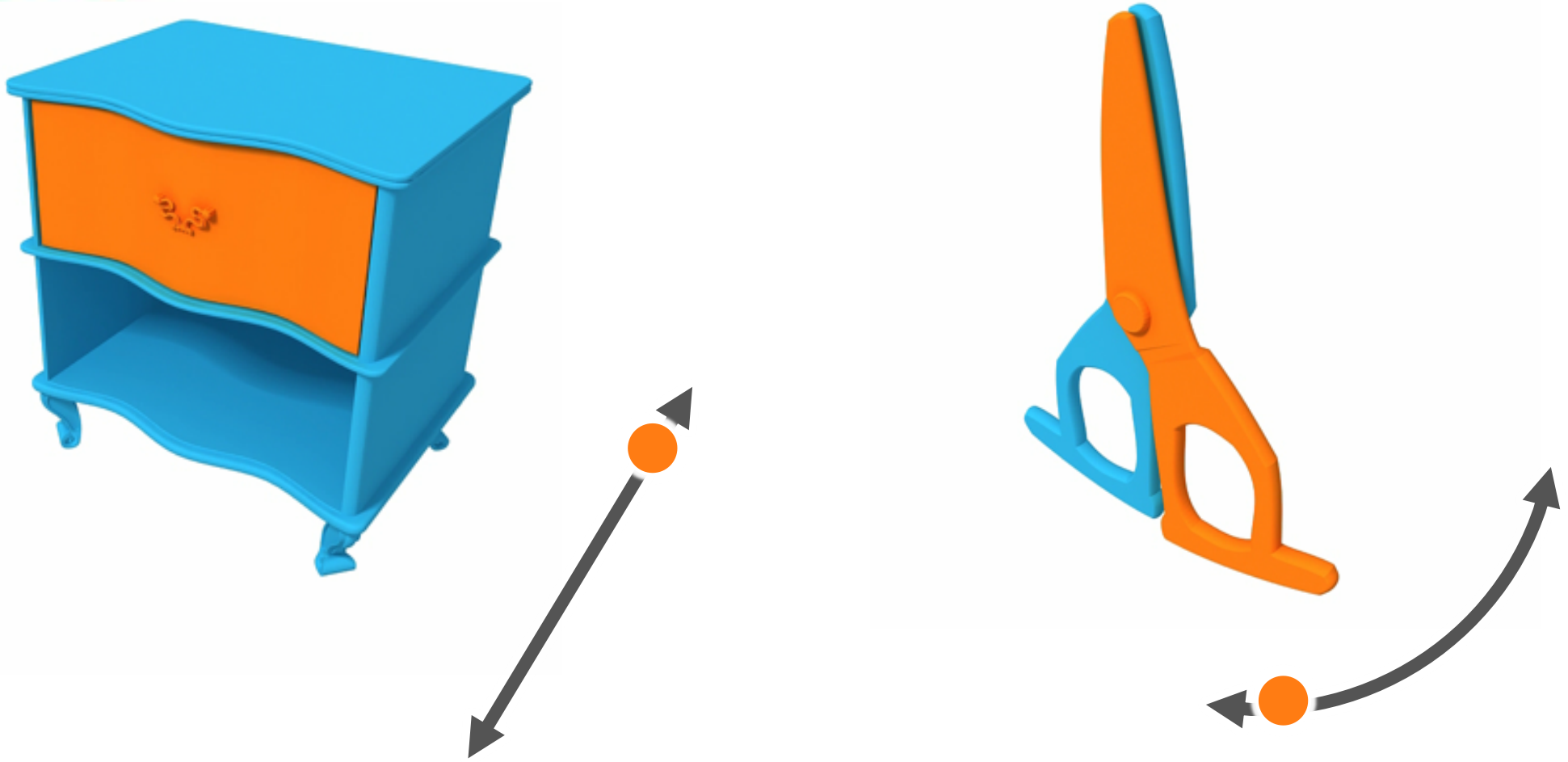
Pre-segmented input

Static shape

Dynamic motion

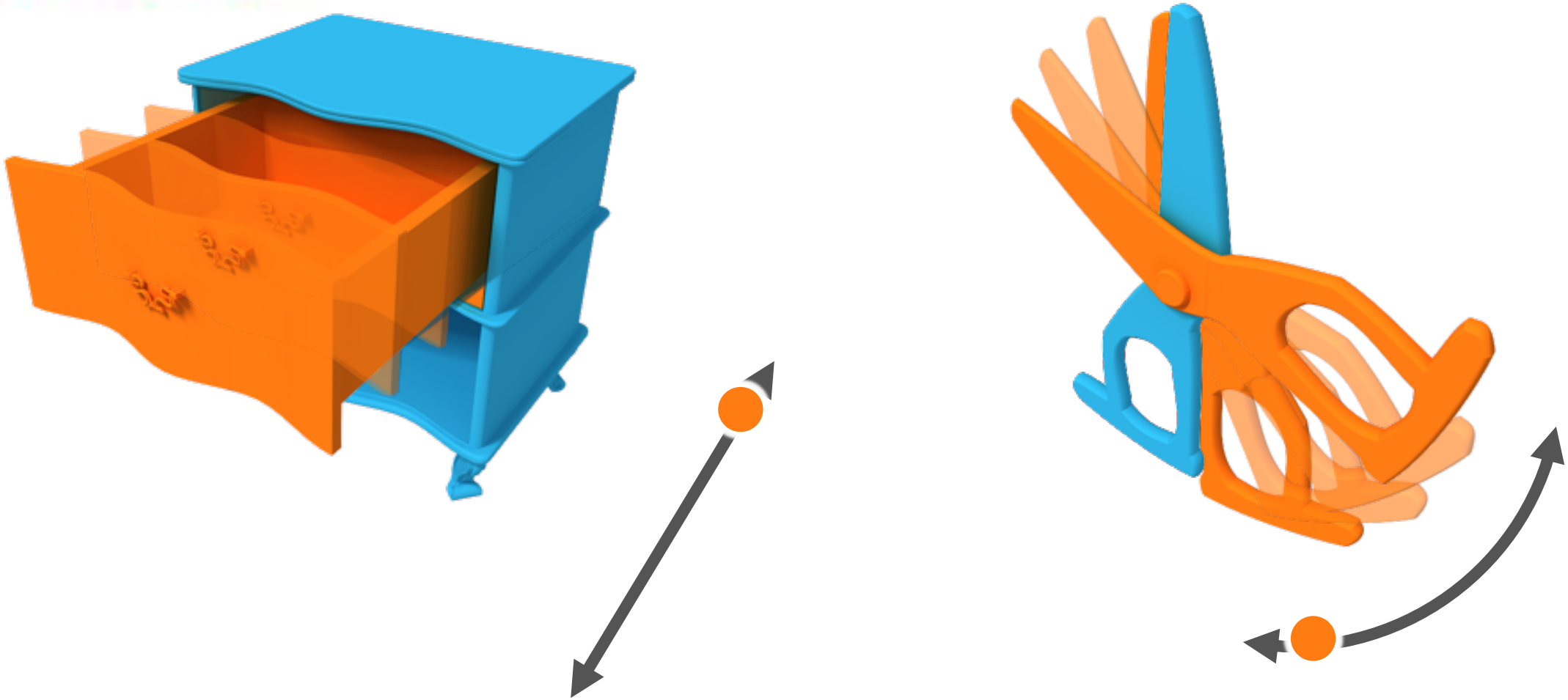
Learning to predict part mobility from a single static snapshot
[HLK*17]

Key observation: linearity of motion



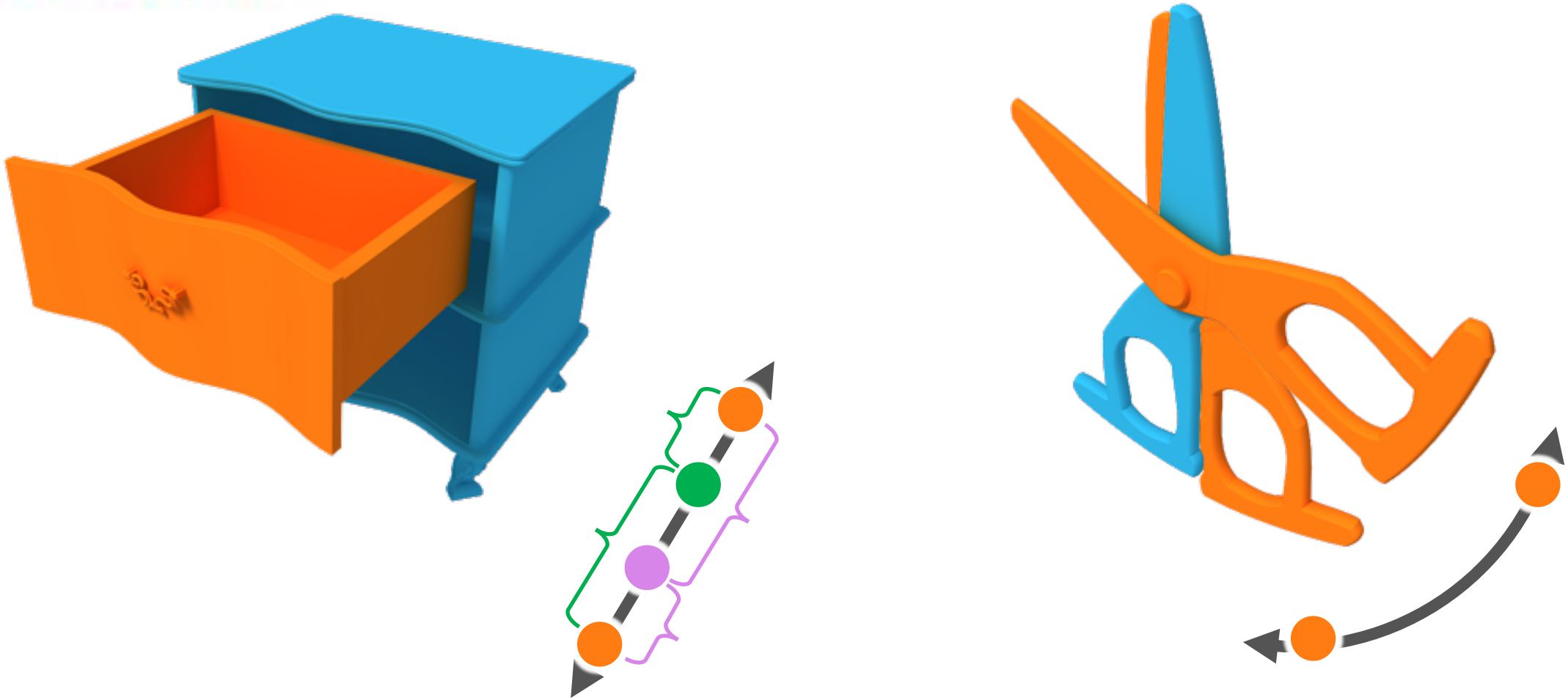
Learning to predict part mobility from a single static snapshot
[HLK*17]

Linearity of motion



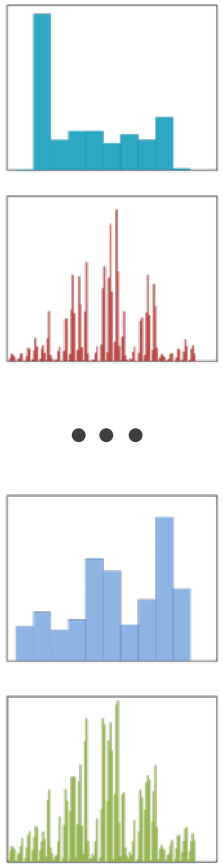
Learning to predict part mobility from a single static snapshot
[HLK*17]

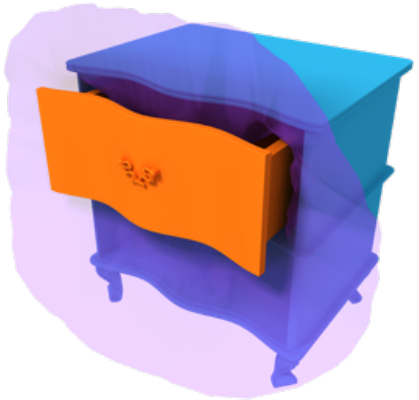
Start & end snapshots



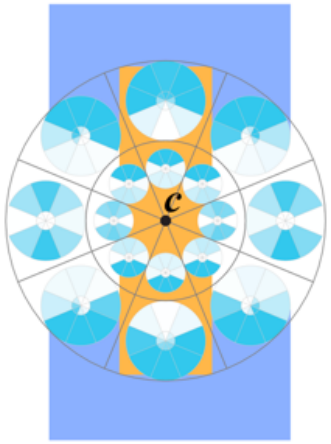
Learning to predict part mobility from a single static snapshot
[HLK*17]

Snapshot descriptor

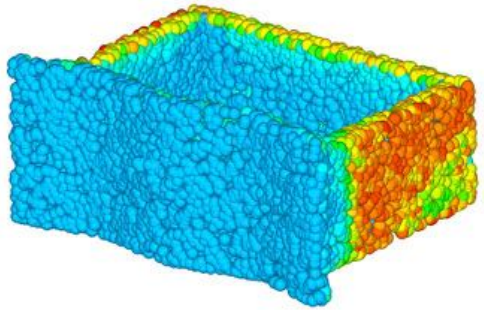




Interaction Bisector Surface
[Zhao et al. 2014]



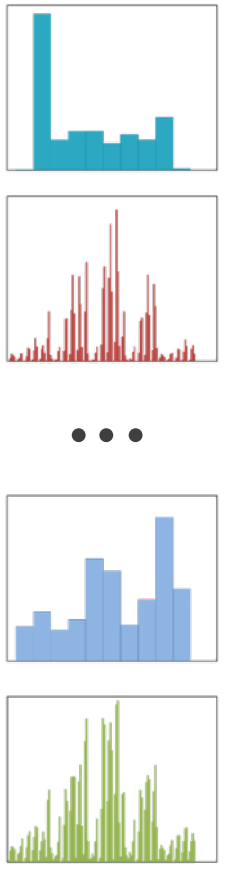
RAID-3D
[Guerrero et al. 2016]

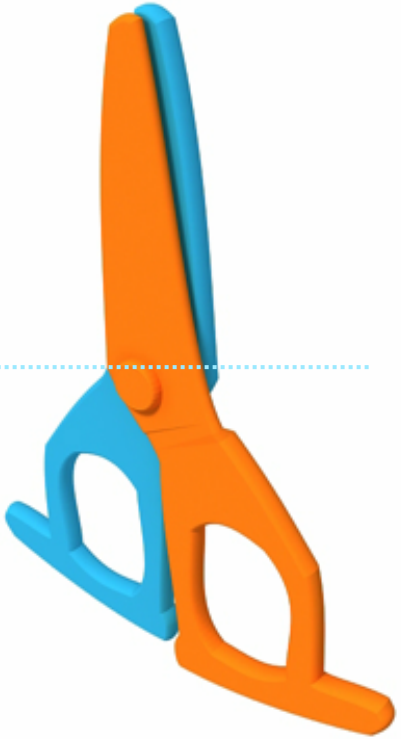


Interaction Region
[Hu et al. 2015]

Learning to predict part mobility from a single static snapshot
[HLK*17]

Snapshot-to-unit distance





Learning to predict part mobility from a single static snapshot
[HLK*17]

Nearest neighbor Retrieval

Learning to predict part mobility from a single static snapshot
[HLK*17]

Motion transfer

Learning to predict part mobility from a single static snapshot
[HLK*17]

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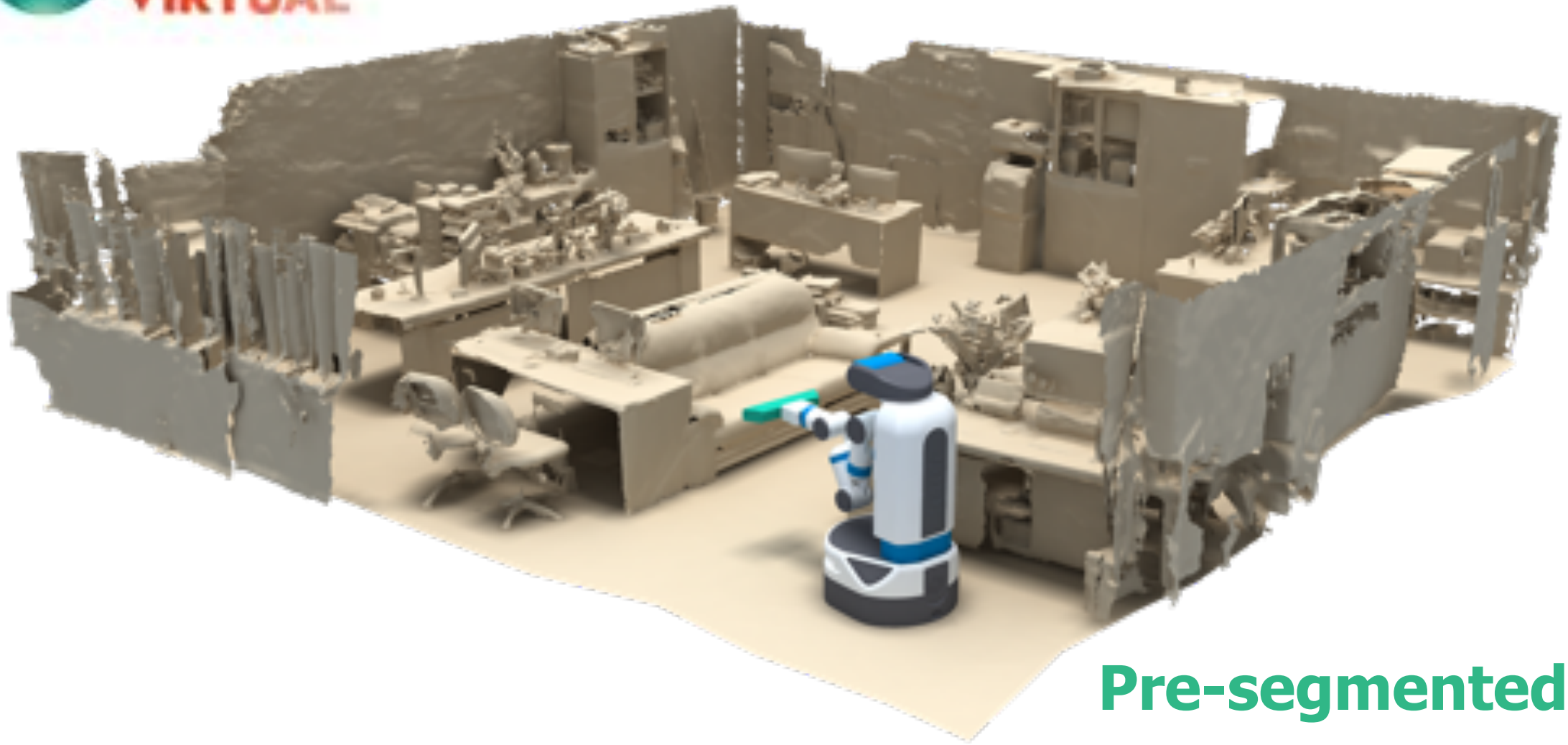
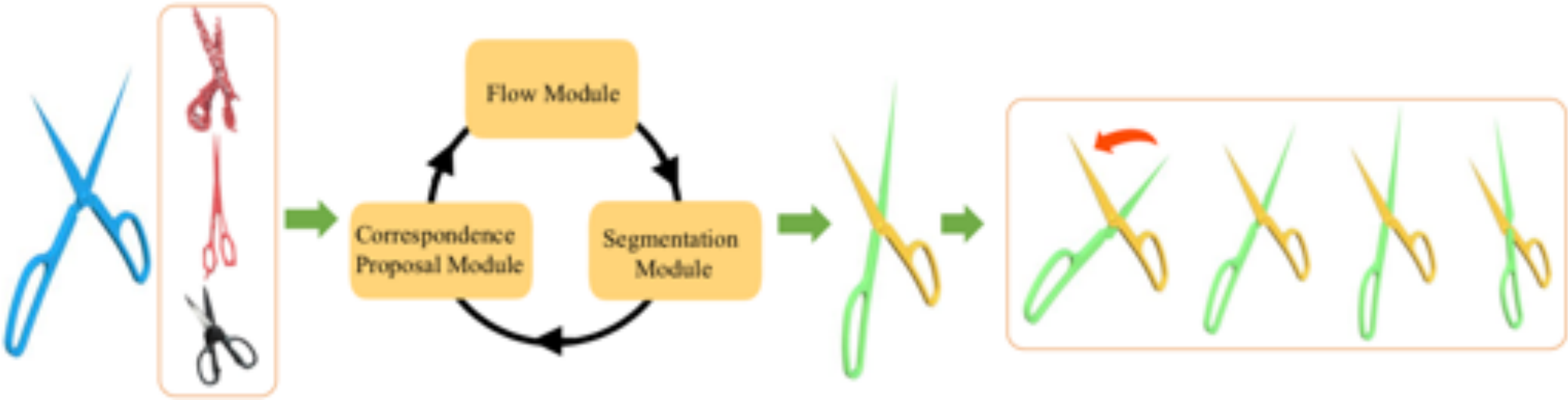
Limitation



Pre-segmented ✗

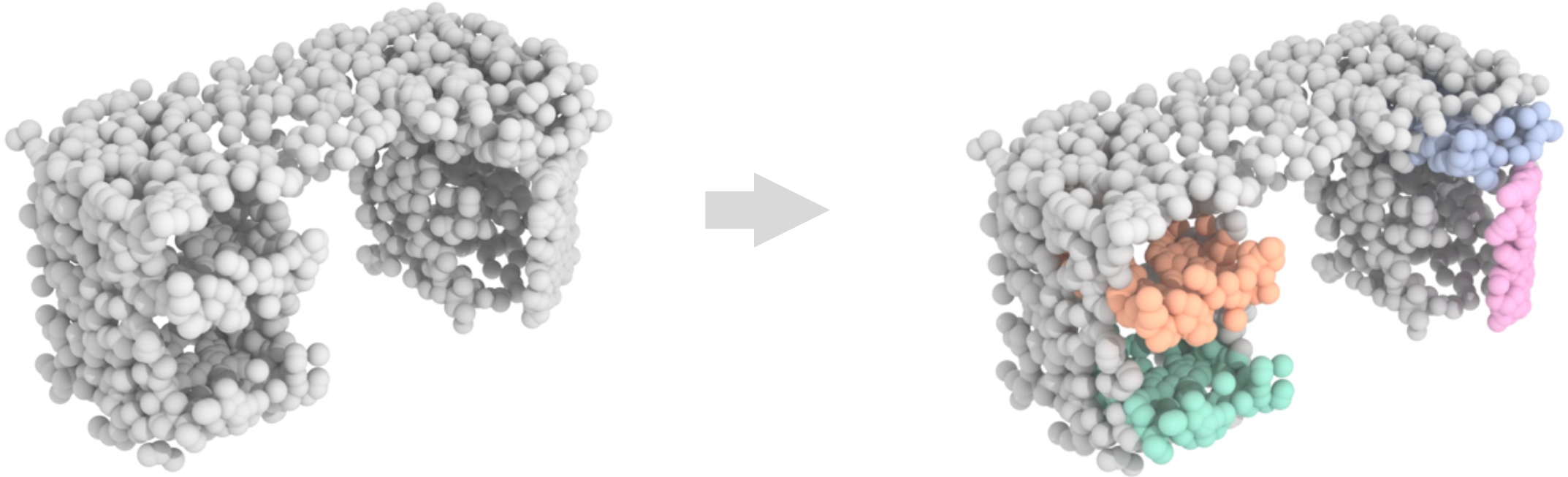
Part-level mobility prediction (Time-varying interaction)



Paired input

Deep part induction from articulated object pairs
[YHL*18]

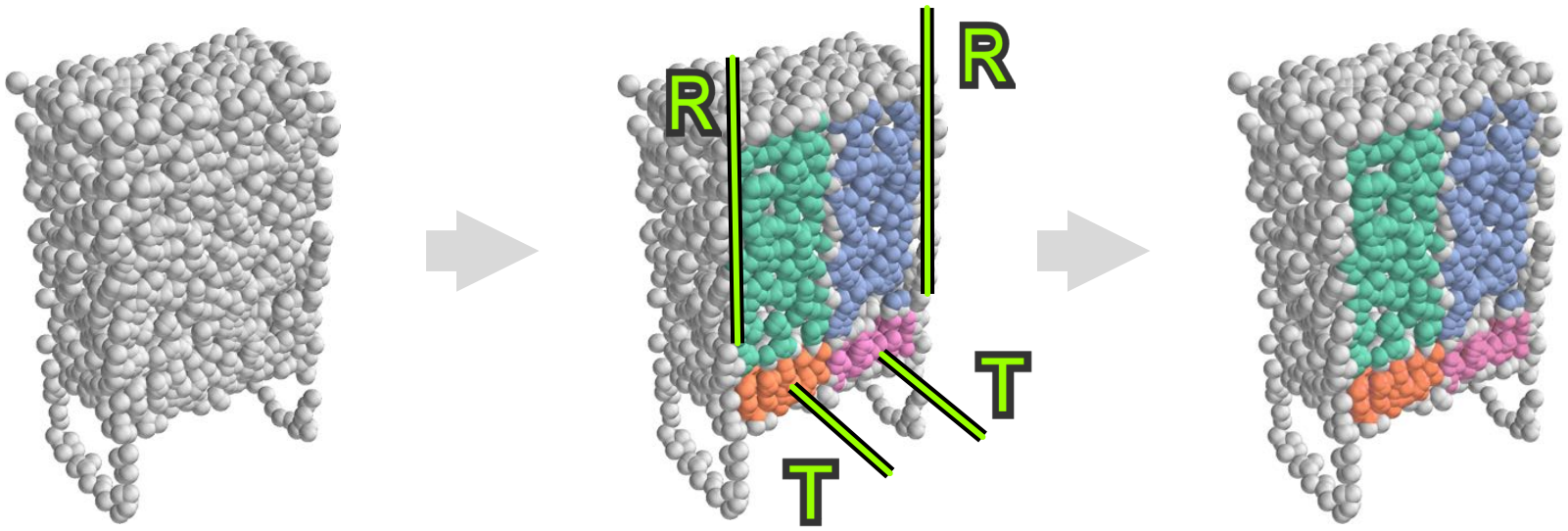
Part-level mobility prediction (Time-varying interaction)



single **un-segmented** **partial**

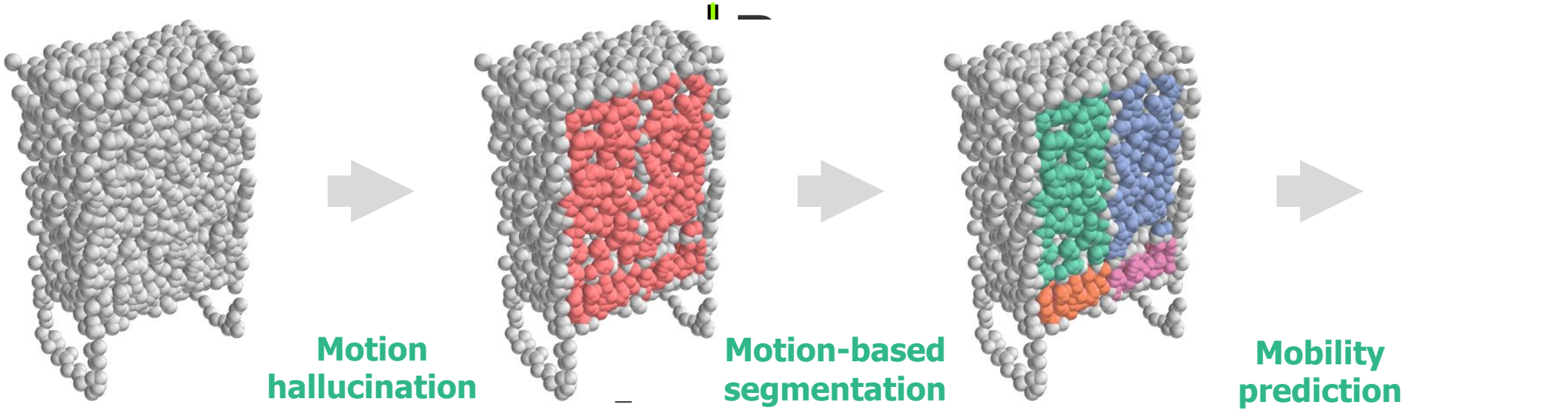
RPM-Net: recurrent prediction of motion and parts from point cloud
[YHY*19]

Direct mobility prediction



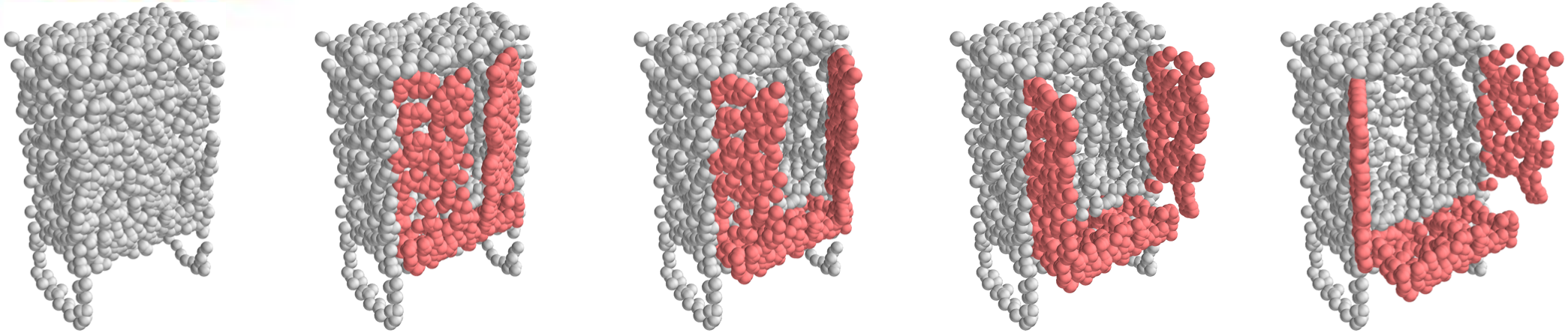
RPM-Net: recurrent prediction of motion and parts from point cloud
[YHY∗19]

Key contribution

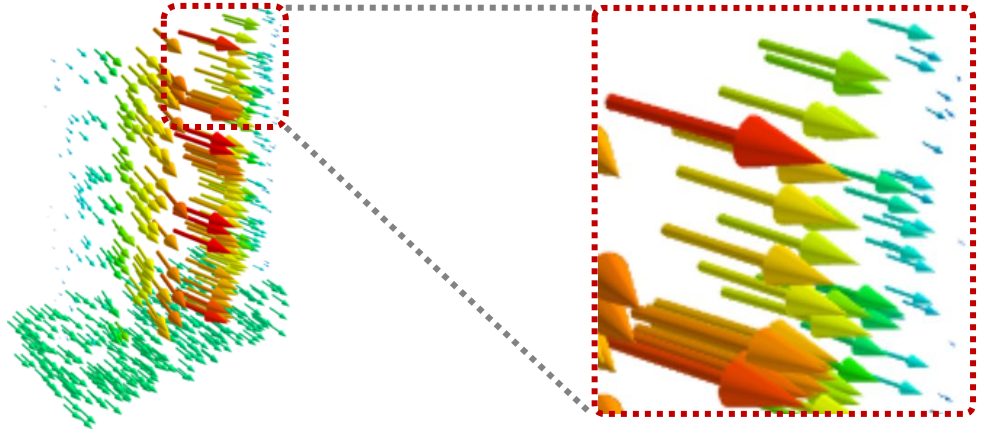


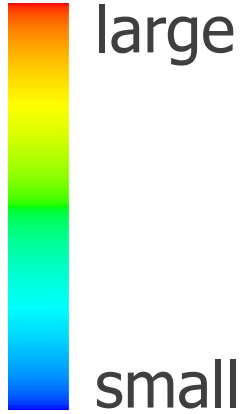
RPM-Net: recurrent prediction of motion and parts from point cloud
[YHY*19]

Motion displacement



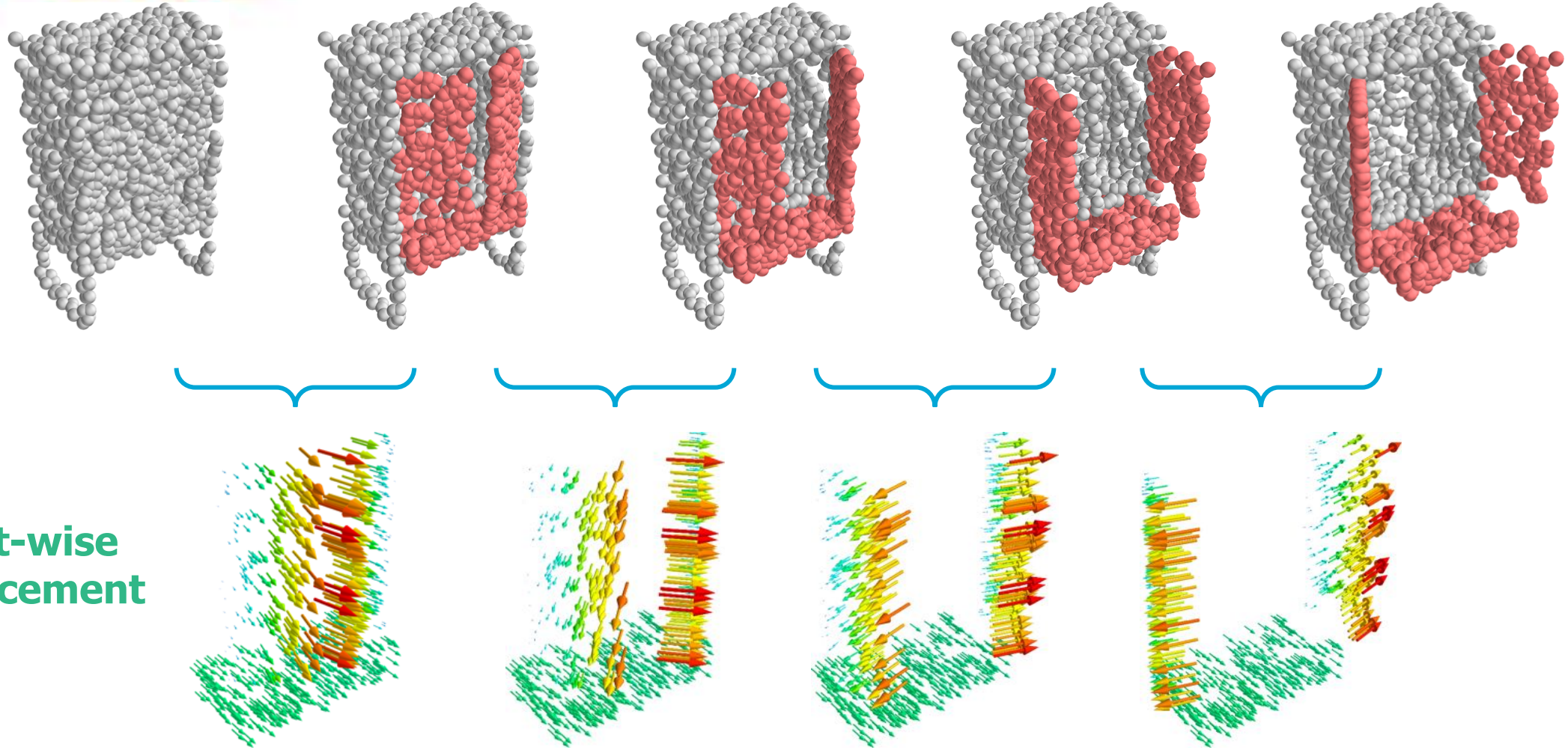
Point-wise displacement





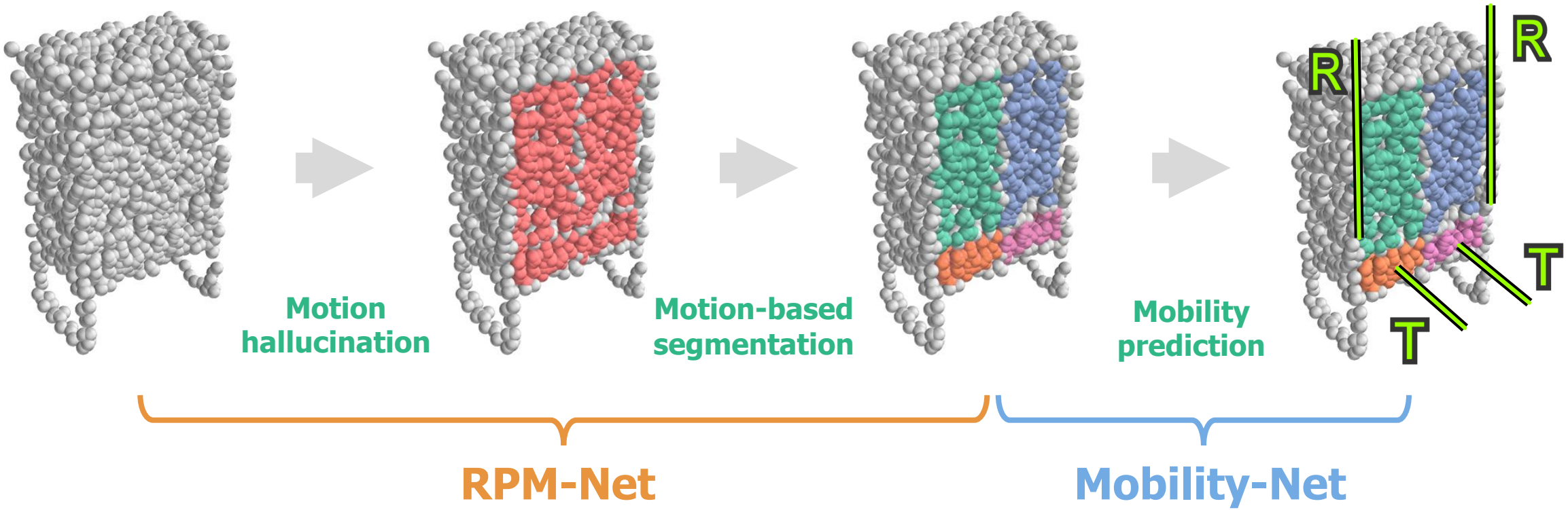
RPM-Net: recurrent prediction of motion and parts from point cloud
[YHY*19]

Motion displacement



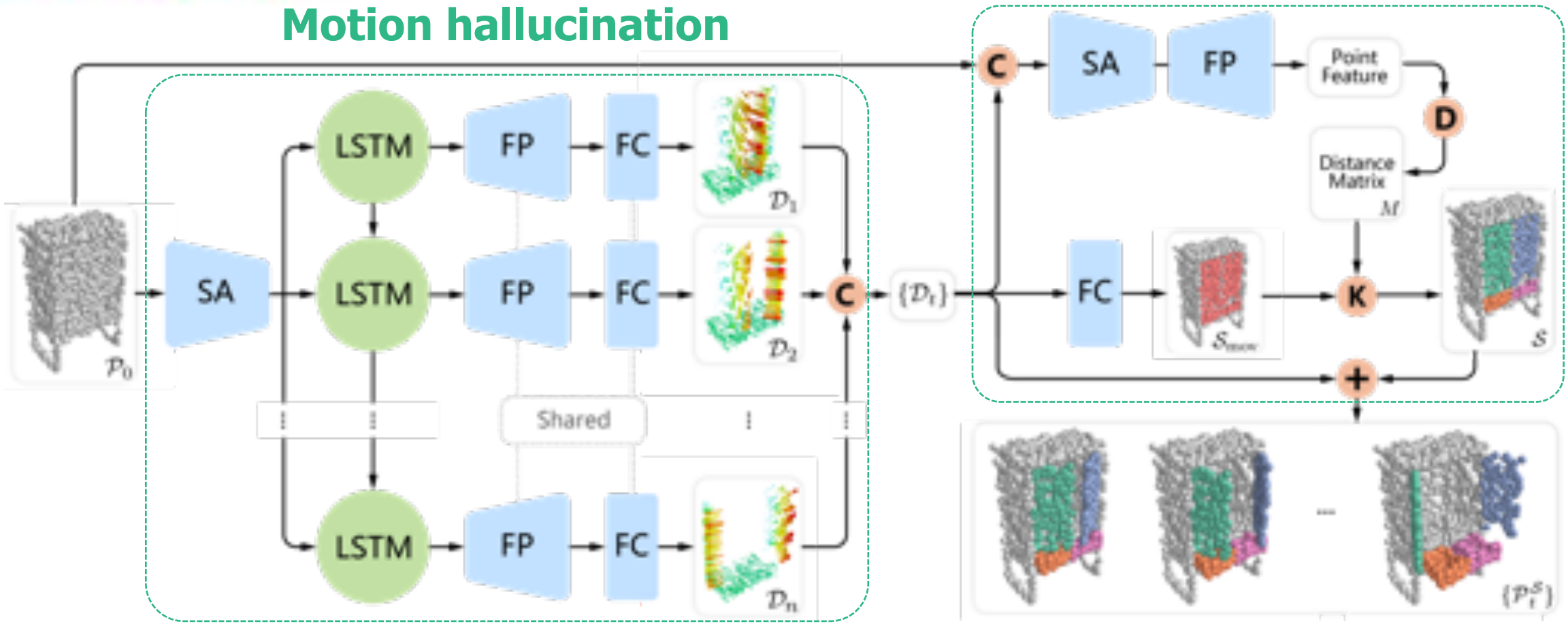
RPM-Net: recurrent prediction of motion and parts from point cloud
[YHY*19]

Overview



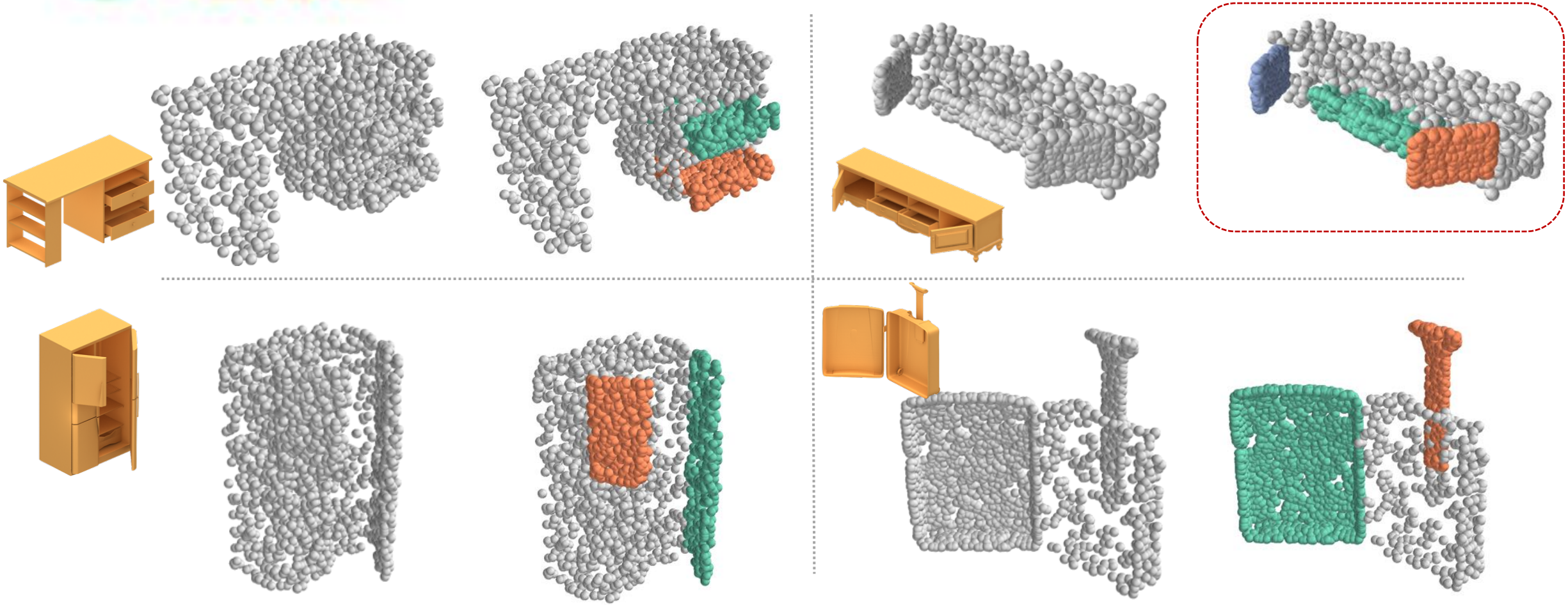
RPM-Net: recurrent prediction of motion and parts from point cloud
[YHY*19]

RPM-Net



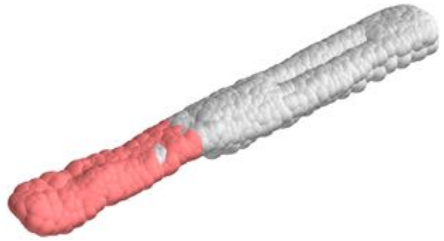
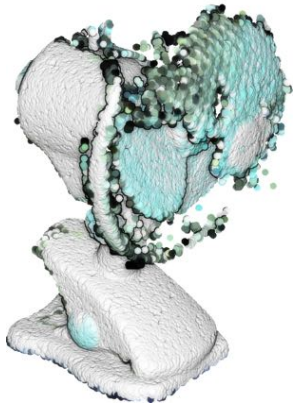
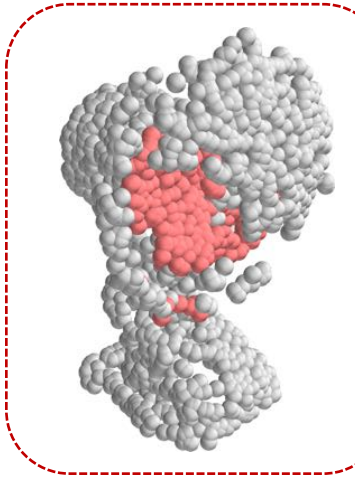
RPM-Net: recurrent prediction of motion and parts from point cloud
[YHY*19]

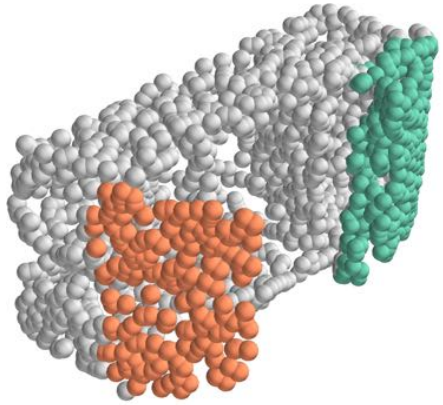
RPM-Net results

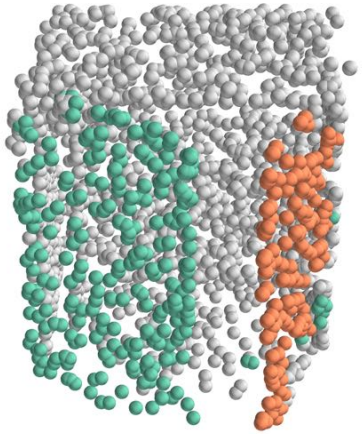


RPM-Net: recurrent prediction of motion and parts from point cloud
[YHY*19]

RPM-Net results

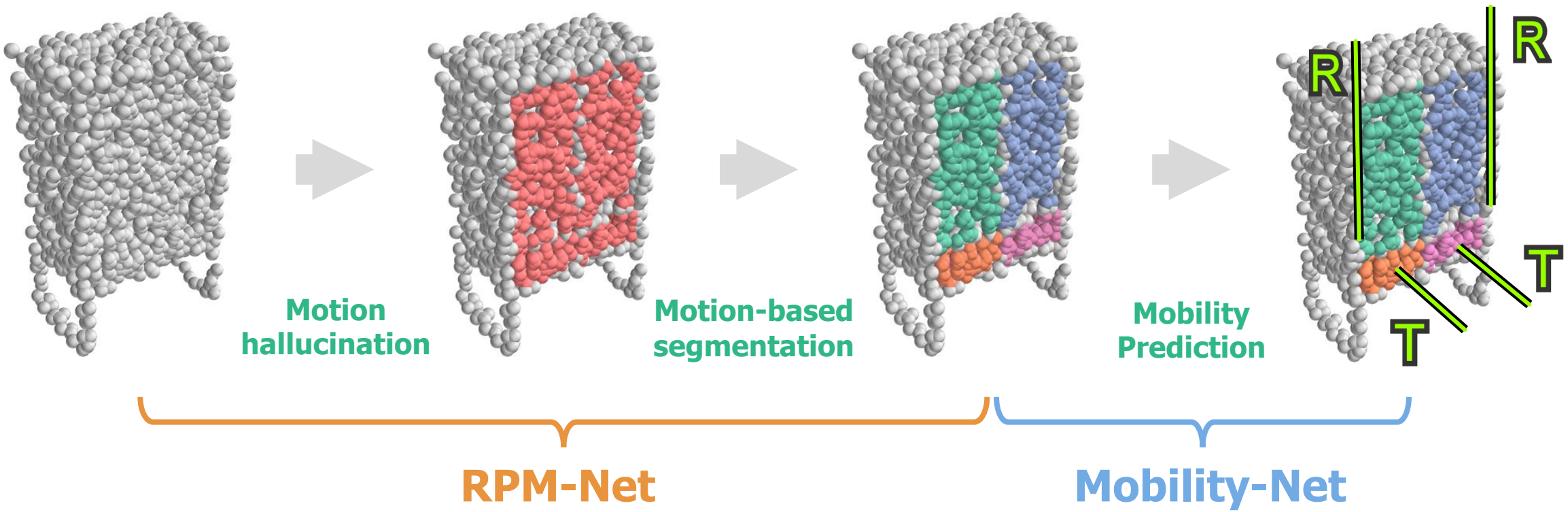









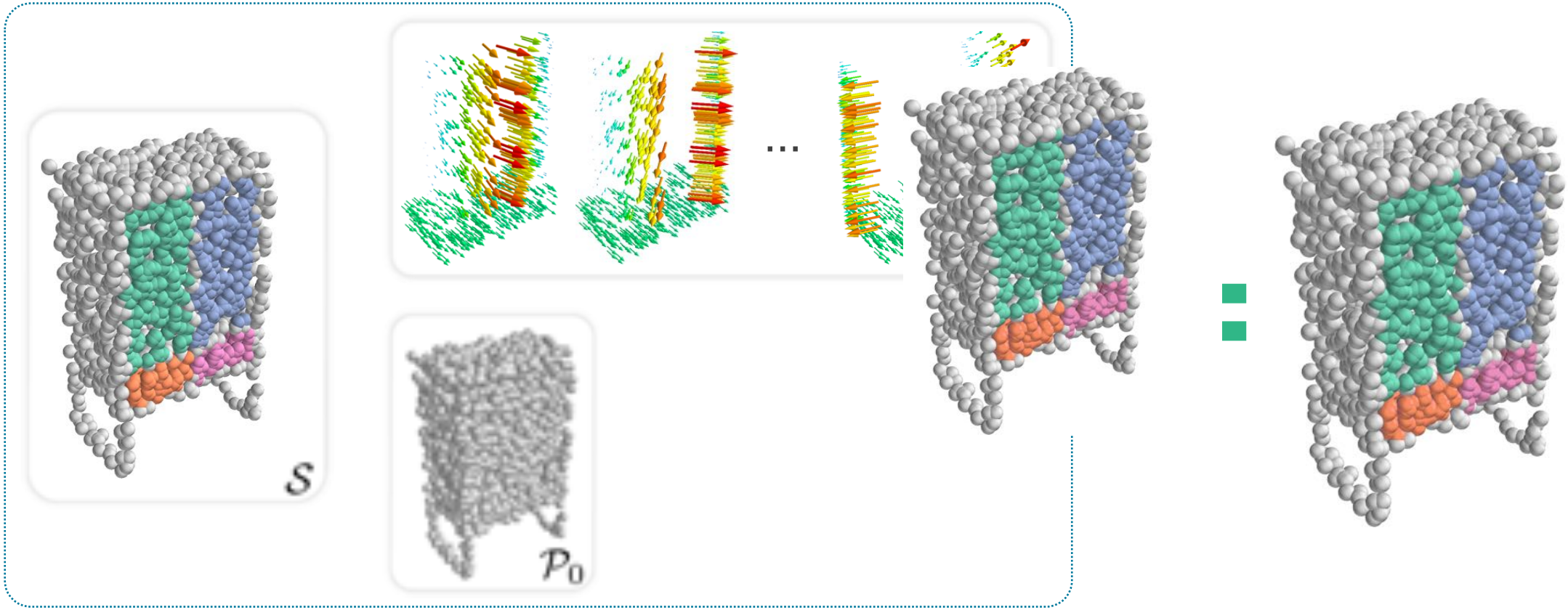
RPM-Net: recurrent prediction of motion and parts from point cloud
[YHY*19]

Overview



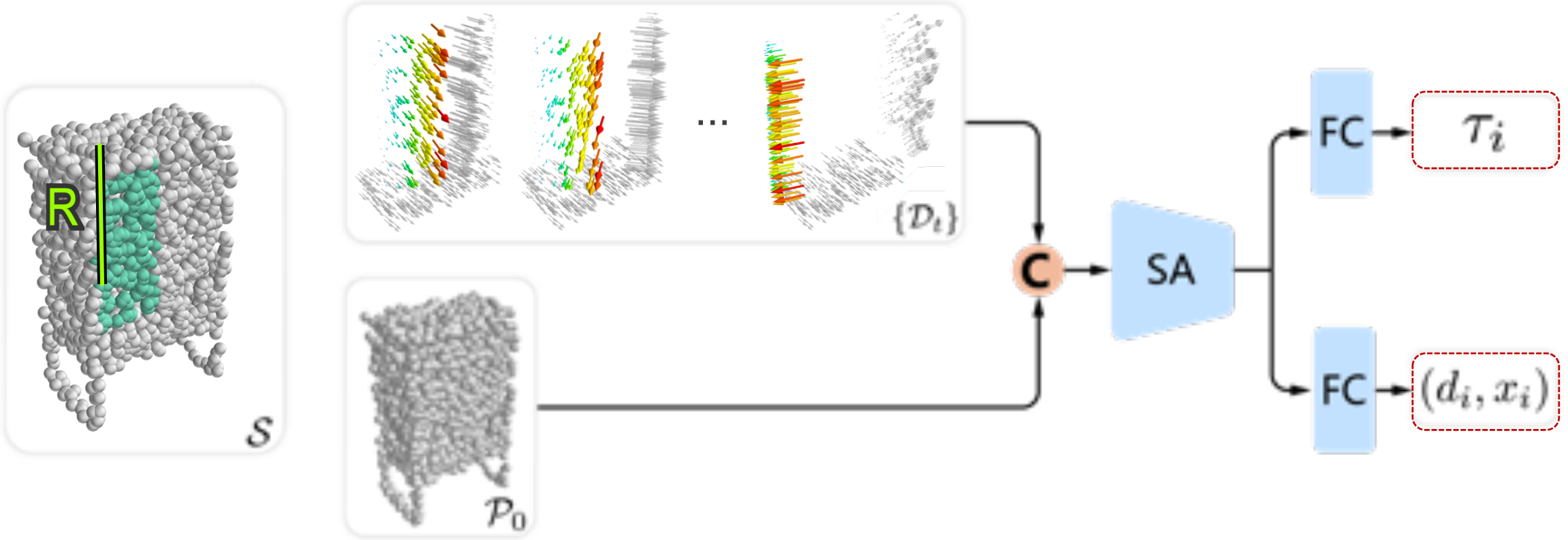
RPM-Net: recurrent prediction of motion and parts from point cloud
[YHY*19]

Mobility-Net: mobility prediction



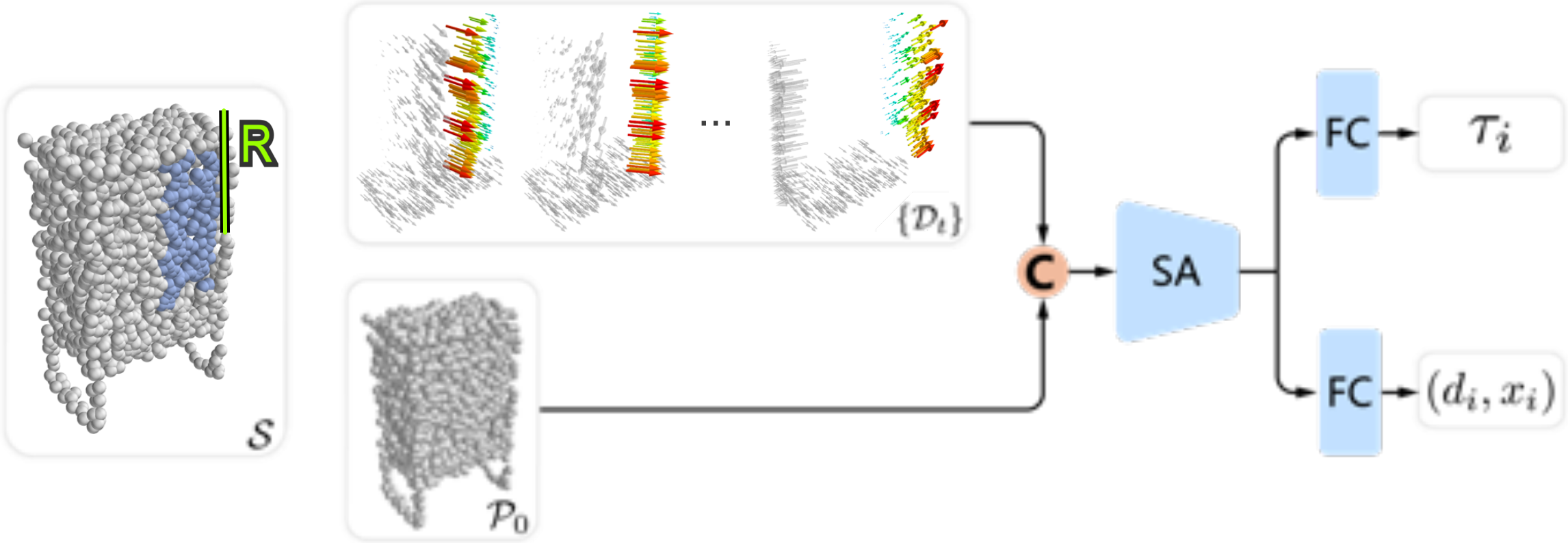
RPM-Net: recurrent prediction of motion and parts from point cloud
[YHY*19]

Mobility-Net: mobility prediction



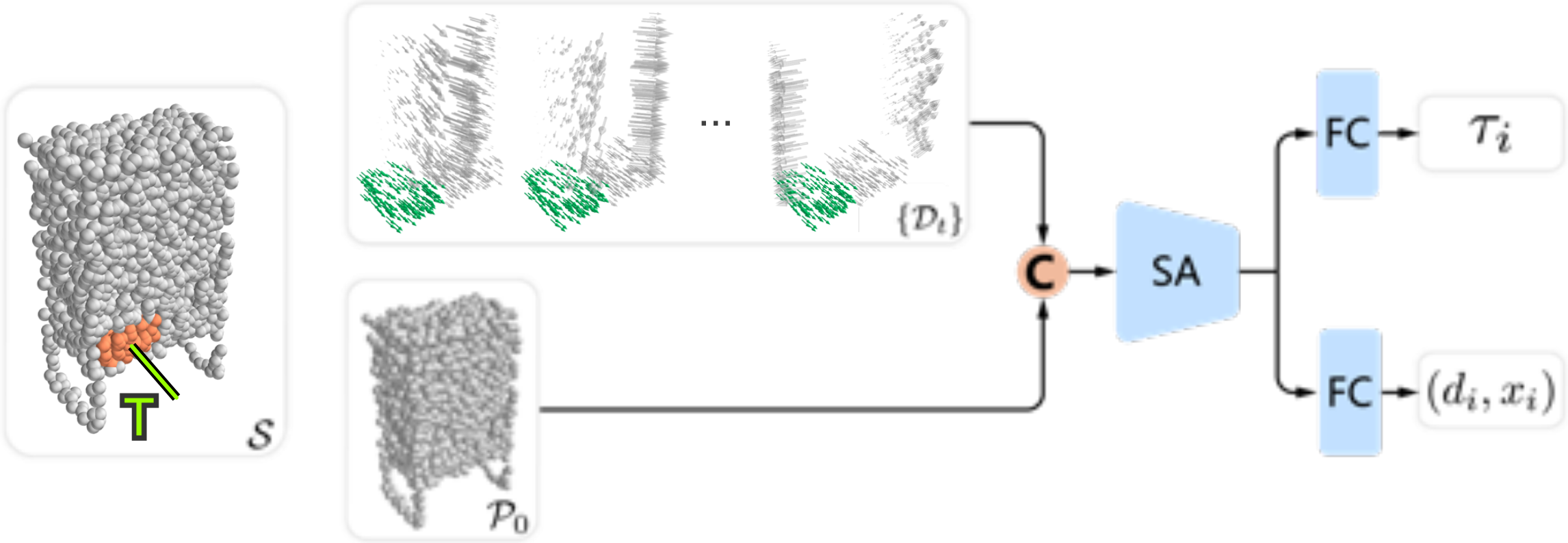
RPM-Net: recurrent prediction of motion and parts from point cloud
[YHY*19]

Mobility-Net: mobility prediction



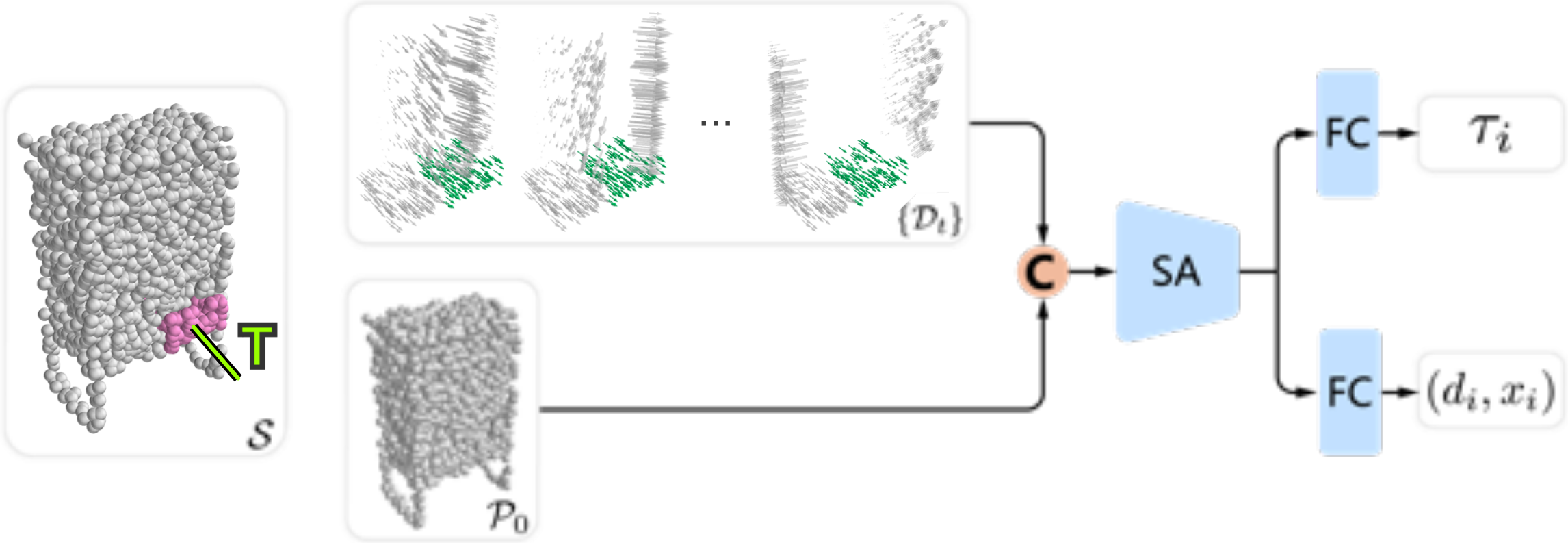
RPM-Net: recurrent prediction of motion and parts from point cloud
[YHY*19]

Mobility-Net: mobility prediction



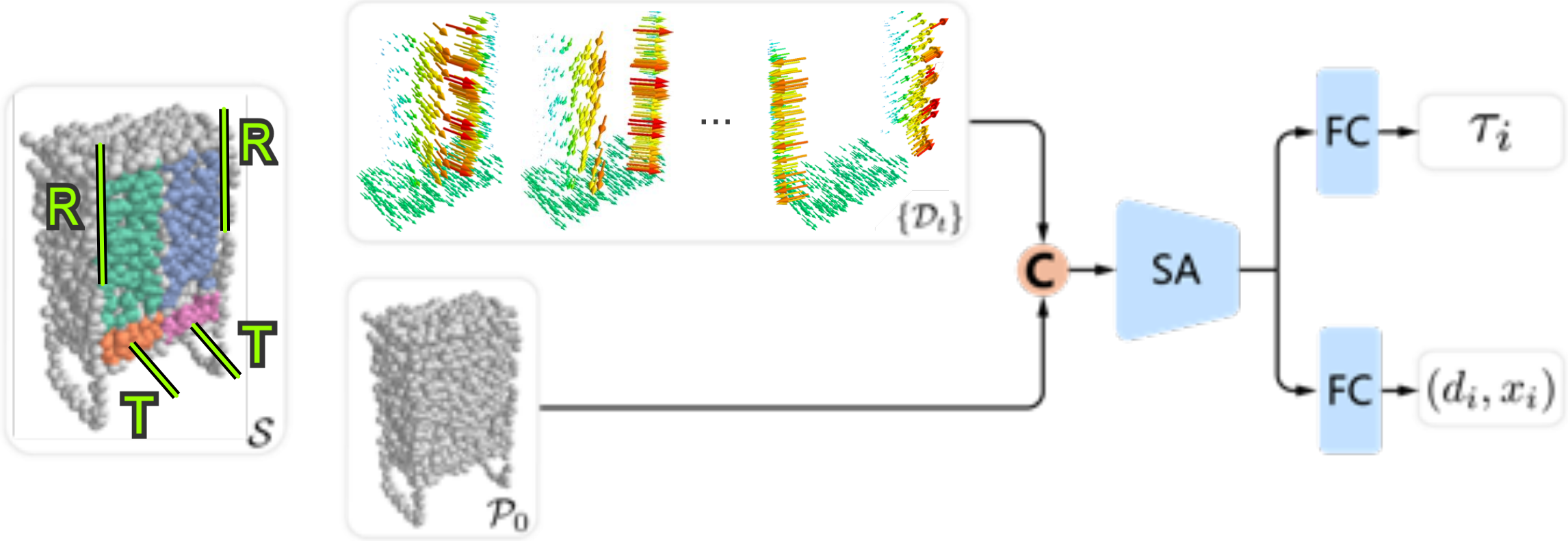
RPM-Net: recurrent prediction of motion and parts from point cloud
[YHY*19]

Mobility-Net: mobility prediction



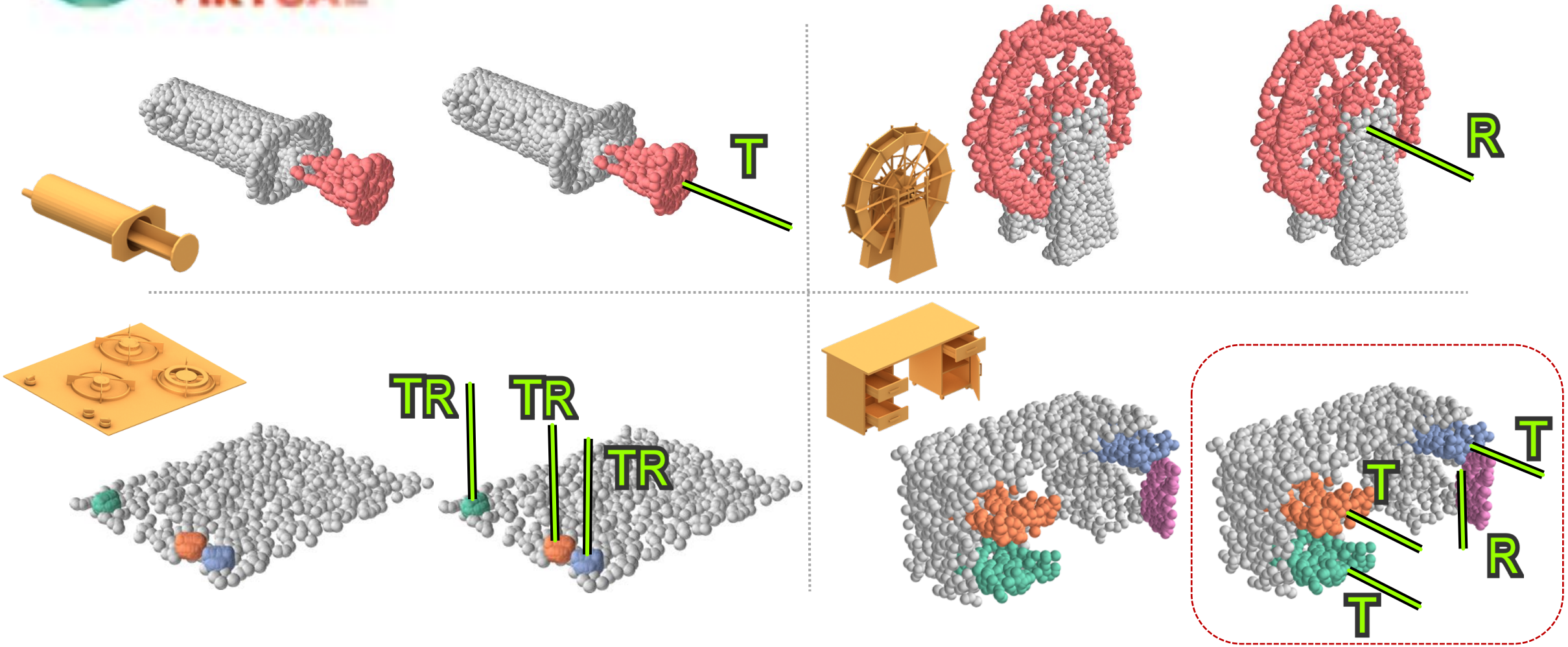
RPM-Net: recurrent prediction of motion and parts from point cloud
[YHY*19]

Mobility-Net: mobility prediction



RPM-Net: recurrent prediction of motion and parts from point cloud
[YHY*19]

Mobility-Net results

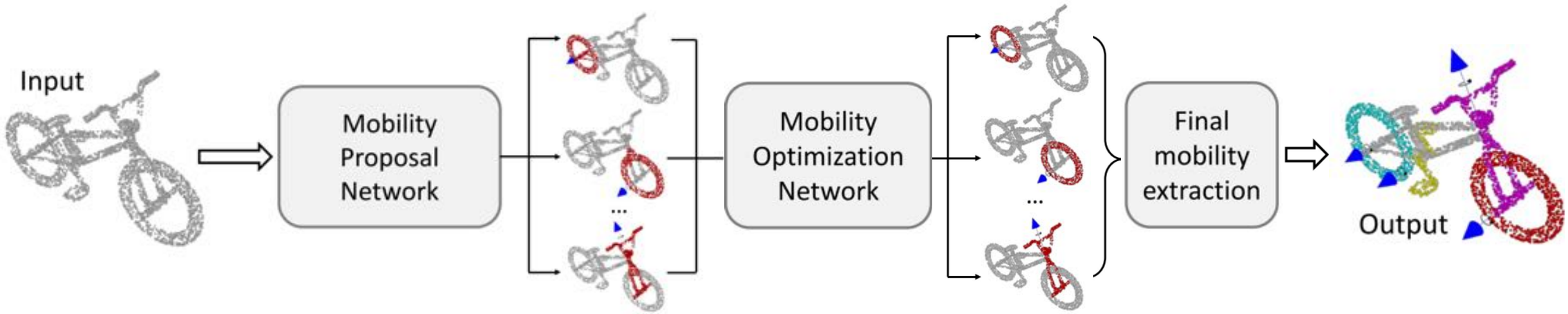


RPM-Net: recurrent prediction of motion and parts from point cloud
[YHY*19]

Mobility-Net results

RPM-Net: recurrent prediction of motion and parts from point cloud
[YHY*19]

Part-level mobility prediction (Time-varying interaction)

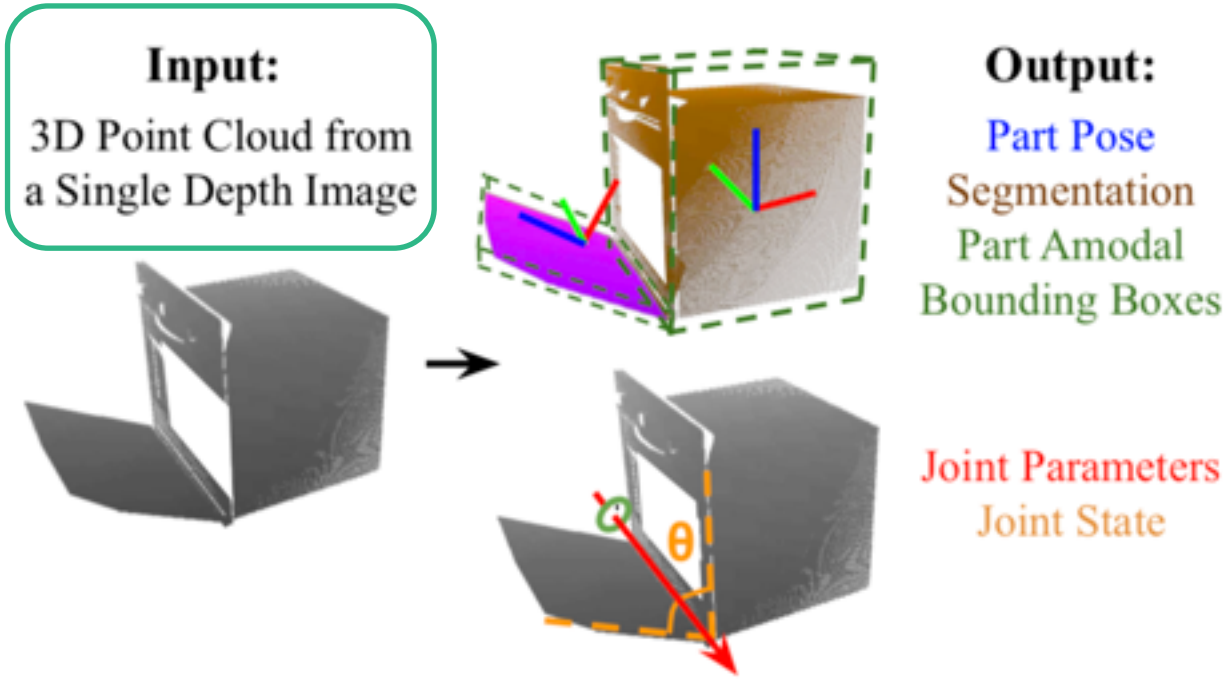


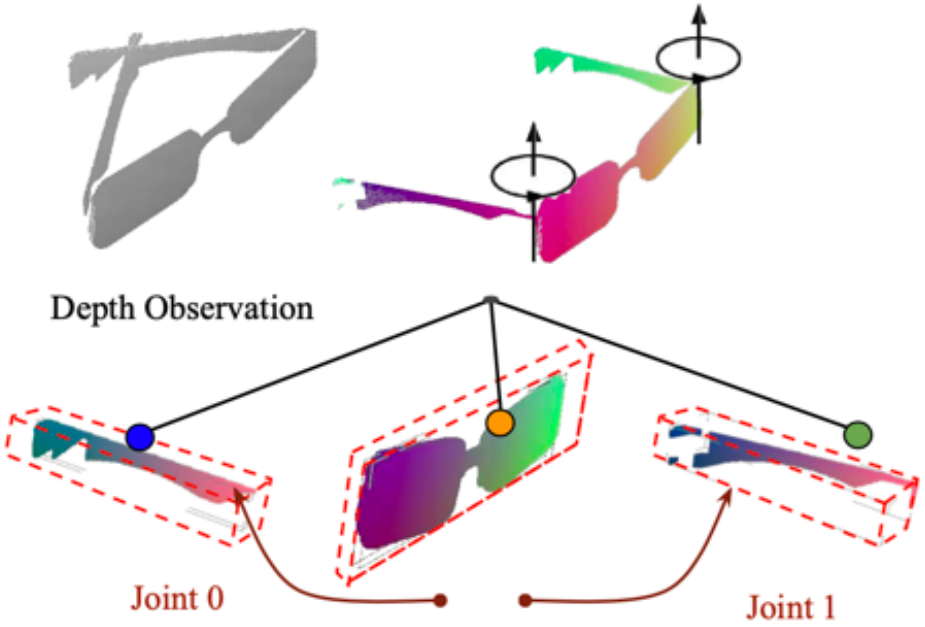
Single unsegmented input

Predict the segmentation and mobility parameters simultaneously

Shape2Motion: joint analysis of motion parts and attributes from 3D shapes
[WZS*19]

Part-level mobility prediction (Time-varying interaction)





Category-level articulated object pose estimation
[LWY∗20]

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Geometry + interaction methods

		Representation of geometry or interactions			Additional classification criteria		
Works	Functional entity	Component / interacting entity	Dynamicity	Relations	Input	Approach	Model type
Geometry+interaction (GI)							
Hu et al. [HZvK*15]	object	stat-inter	stat	BR	pcl	handcrafted	discriminative
Hu et al [HvKW*16]	object	stat-inter	stat	BR	pcl	supervised	discriminative
Pirk et al. [PKH*17]	object	dyn-inter	dyn	VF	mesh	handcrafted	discriminative
Myers et al. [MTFA15]	part	stat-inter	stat	SA	rgbd	supervised	discriminative
Kim et al. [KS14]	part	stat-inter	stat	SA	rgbd	supervised	discriminative
Laga et al. [LMS13]	part	stat-inter	stat	SA+SG	mesh	supervised	discriminative
Hu et al. [HLK*17]	part	stat-inter	dyn	SA+BR	pcl	supervised	discriminative
Xiang et al. [XQM*20]	part	stat-inter	dyn	SA	mesh	supervised	discriminative
Hu et al. [HYZ*18]	object	stat-inter	stat	SA+BR	vol	supervised	generative
Yi et al. [YHL*18]	part	stat-inter	dyn	SA	pcl	supervised	discriminative
Wang et al. [WZS*19]	part	stat-inter	dyn	SA	pcl	supervised	discriminative
Yan et al. [YHY*19]	part	stat-inter	dyn	SA	pcl	supervised	discriminative
Li et al. [LWY*20]	part	stat-inter	dyn	SA	pcl	supervised	discriminative
Kokic et al. [KSHK17]	part	stat-inter	dyn	SA	pcl	supervised	generative
Li et al. [LSK20]	part	stat-inter	dyn	SA	pcl	supervised	generative

Discussion

- Focus on **object** and **part** level functionalities
- Start with **handcrafted** functionality descriptors
- Recent learning-based methods for **prediction** and **generation**
- Both **atemporal** and **time-varying** interactions

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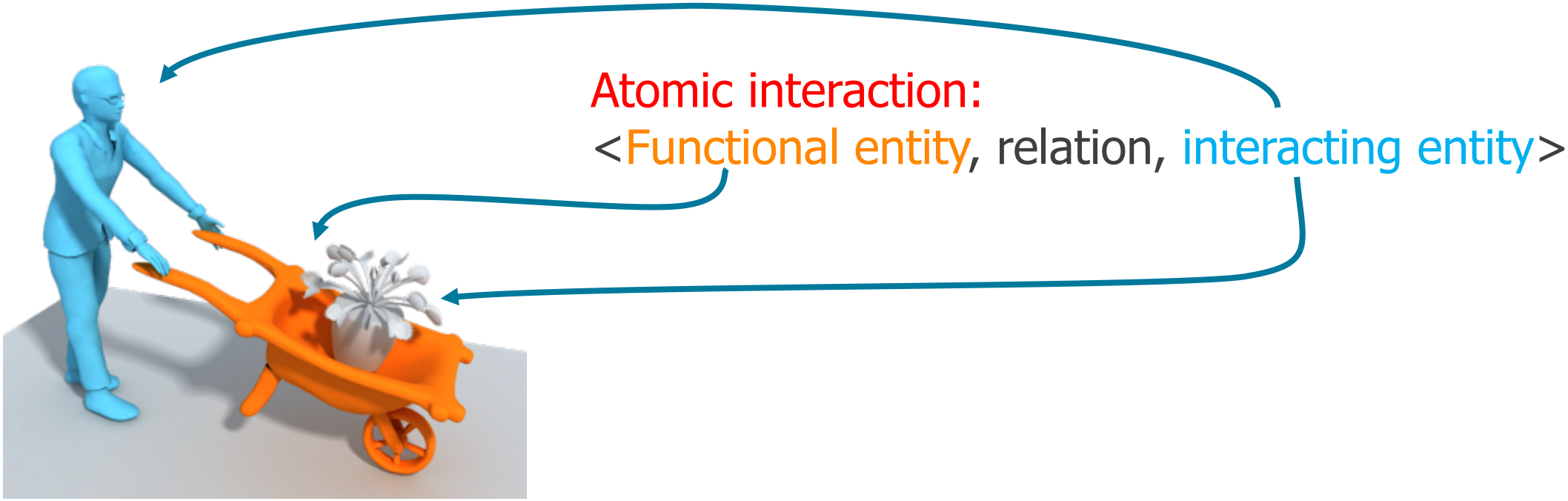
Geometry + Agent

Our definition of functionality

Functionality = Geometry + Interaction



Geometry + agent methods

- Interaction with (humanoid) agent
- Can be special case of geometry + interaction methods
- Critical for human-centric functionality
- Recent interest in applications for fabrication, VR/AR

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Much recent work

		Representation of geometry or interactions			Additional classification criteria		
Works	Functional entity	Component / interacting entity	Dynamicity	Relations	Input	Approach	Model type
Geometry+agent (GA)							
Grabner et al. [GGVG11]	scene	agent-inter	stat	HA	mesh	supervised	generative
Savva et al. [SCH*14]	scene	agent-inter	stat	SA+HA	mesh	supervised	discriminative
Zhu et al. [ZJZ*16]	scene	agent-inter	stat	SA	mesh	supervised	generative
Jiang et al. [JKS13]	multi-object	agent-inter	stat	SA	rgbd	supervised	discriminative
Wang et al. [WLY17]	multi-object	agent-inter	stat	SA+HA	mesh	supervised	discriminative
Fisher et al. [FSL*15]	multi-object	agent-inter	stat	SA+HA	mesh	supervised	generative
Savva et al. [SCH*16]	multi-object	agent-inter	stat	SA+HA	mesh	supervised	generative
Ma et al. [MLZ*16]	multi-object	agent-inter	dyn	SA+HA	mesh	unsupervised	generative
Zheng et al. [ZLDM16]	object	agent-inter	stat	SA	mesh	handcrafted	generative
Kim et al. [KCGF14]	object	agent-inter	stat	SA	mesh	supervised	generative
Bar-Aviv & Rivlin [BAR06]	object	agent-inter	stat	SA+HA	mesh	handcrafted	discriminative
Zhu et al. [ZZCZ15]	object	agent-inter	dyn	SA+HA	rgbd	supervised	discriminative
Zhao et al. [ZCK17]	object	agent-inter	dyn	SA+HA	mesh	handcrafted	discriminative
Lee et al. [LCL06]	object	agent-inter	dyn	SA	mesh	supervised	generative
Li et al. [LLK*19]	scene	agent-inter	stat	SA+HA	rgbd	supervised	generative
Zhang et al. [ZHN*20]	scene	agent-inter	stat	SA+HA	rgbd	supervised	generative
Mao et al. [MZX*19]	object	agent-inter	stat	SA	mesh	supervised	generative
Fu et al. [FFY*20]	scene	agent-inter	stat	SA+HA	mesh	supervised	discriminative
Monszpart et al. [MGC*19]	scene	agent-inter	stat	SA	rgbd	supervised	generative
Ruiz et al. [RMC19]	scene	agent-inter	stat	SA+BR	mesh	supervised	generative
Starke et al. [SZKS19]	object	agent-inter	dyn	SA	vol	supervised	generative
Akizuki et al. [AA18]	object	agent-inter	dyn	SA+HA	rgbd	supervised	discriminative

Axes of variation

- Representation focus: agent-centric or functional entity-centric
- Functional entity level
- Relation type: time-varying or not
- Generation: agent(s) ←→ scene
- Discrimination: scene quality metrics and object understanding

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Axes of variation

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Fisher et al. [FSL*15]	multi-object	agent-inter	stat	SA+HA	mesh	supervised	generative
Savva et al. [SCH*16]	multi-object	agent-inter	stat	SA+HA	mesh	supervised	generative
Ma et al. [MLZ*16]	multi-object	agent-inter	dyn	SA+HA	mesh	unsupervised	generative
Zheng et al. [ZLDM16]	object	agent-inter	stat	SA	mesh	handcrafted	generative
Kim et al. [KCGF14]	object	agent-inter	stat	SA	mesh	supervised	generative
Bar-Aviv & Rivlin [BAR06]	object	agent-inter	stat	SA+HA	mesh	handcrafted	discriminative
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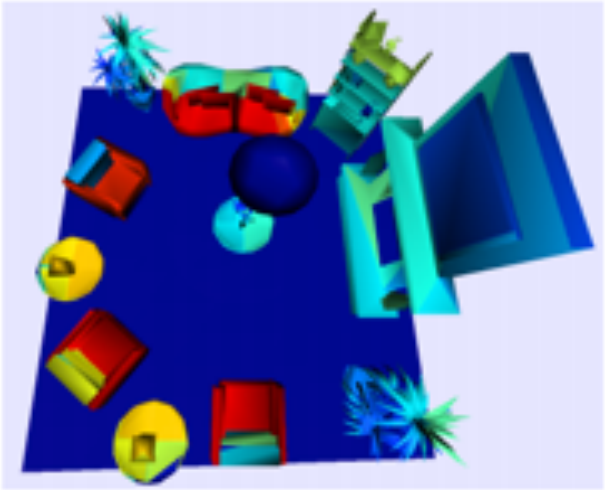
Lee et al. [LCL06]	object	agent-inter	dyn	SA	mesh	supervised	generative
Li et al. [LLK*19]	scene	agent-inter	stat	SA+HA	rgbd	supervised	generative
Zhang et al. [ZHN*20]	scene	agent-inter	stat	SA+HA	rgbd	supervised	generative
Mao et al. [MZX*19]	object	agent-inter	stat	SA	mesh	supervised	generative
Fu et al. [FFY*20]	scene	agent-inter	stat	SA+HA	mesh	supervised	discriminative
Monszpart et al. [MGC*19]	scene	agent-inter	stat	SA	rgbd	supervised	generative
Ruiz et al. [RMC19]	scene	agent-inter	stat	SA+BR	mesh	supervised	generative
Starke et al. [SZKS19]	object	agent-inter	dyn	SA	vol	supervised	generative
Akizuki et al. [AA18]	object	agent-inter	dyn	SA+HA	rgbd	supervised	discriminative

Representation focus

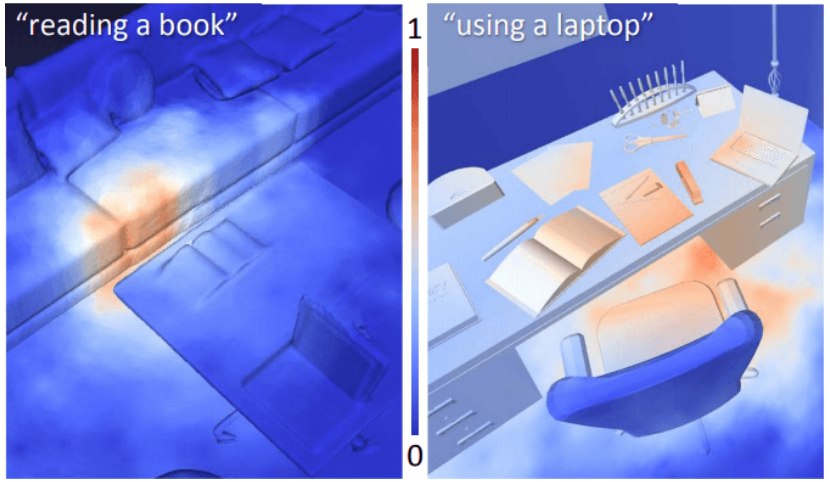
Geometry-centric

Agent-centric

Geometry-centric representations



Sittability prediction
[GGVG11]

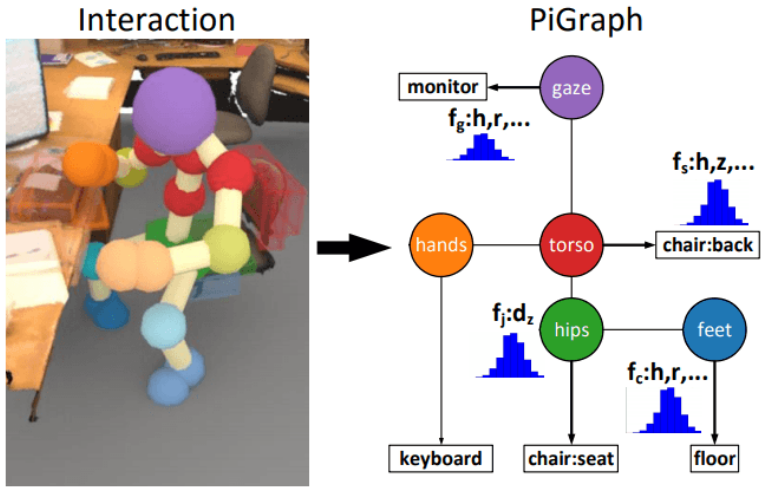


Action maps
[SCH*14]

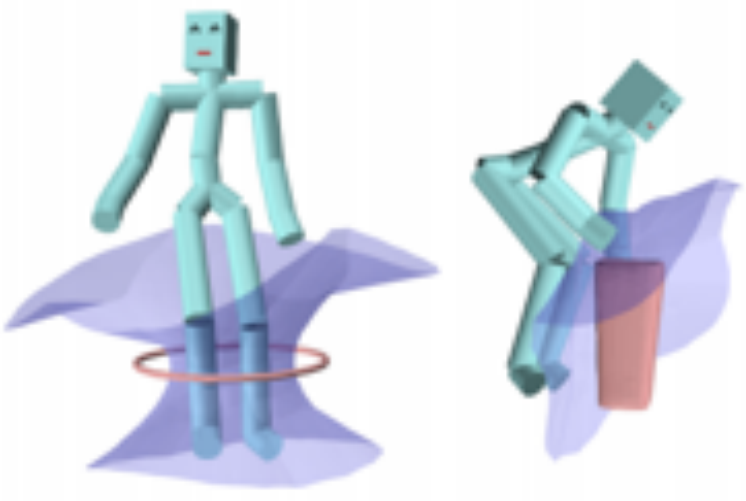
Object interactions
[FSL*15]

Agent-centric representations

Shape2pose
[KCGF14]



PiGraphs
[SCH*16]



Character-object IBS
[ZCK17]

Functional entity level

Scene

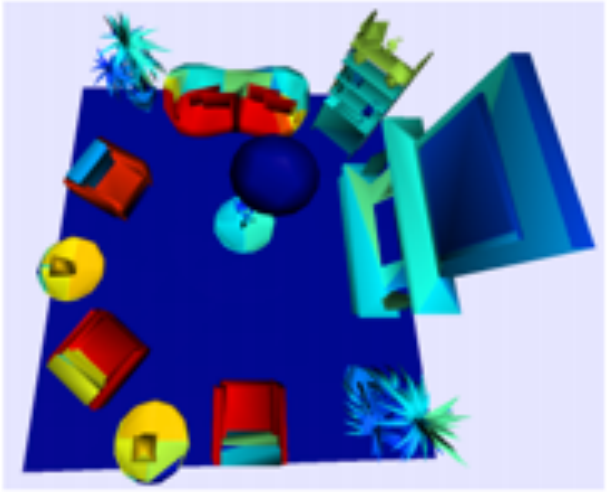
Multi-object

Object

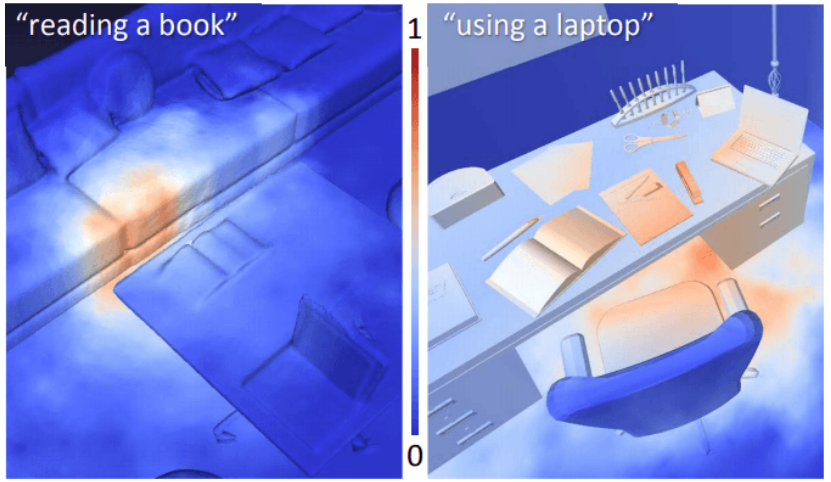
Multi-part

Part

Functional entity level: scene



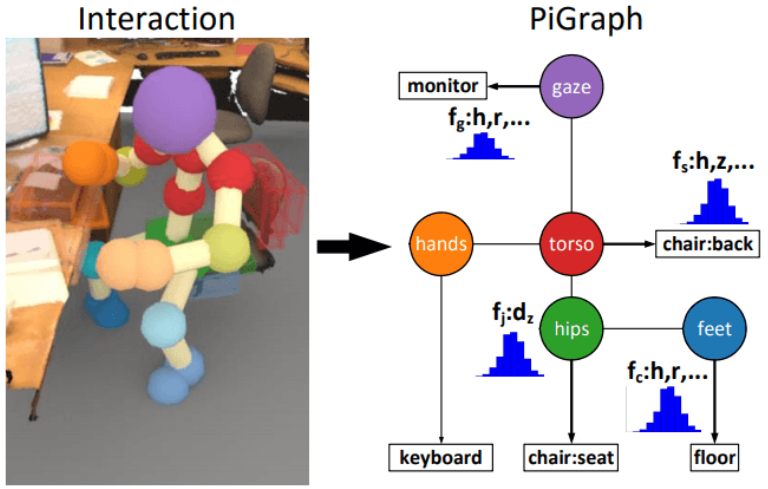
Sittability prediction
[GGVG11]



Action maps
[SCH*14]

Functional entity level: multi-object

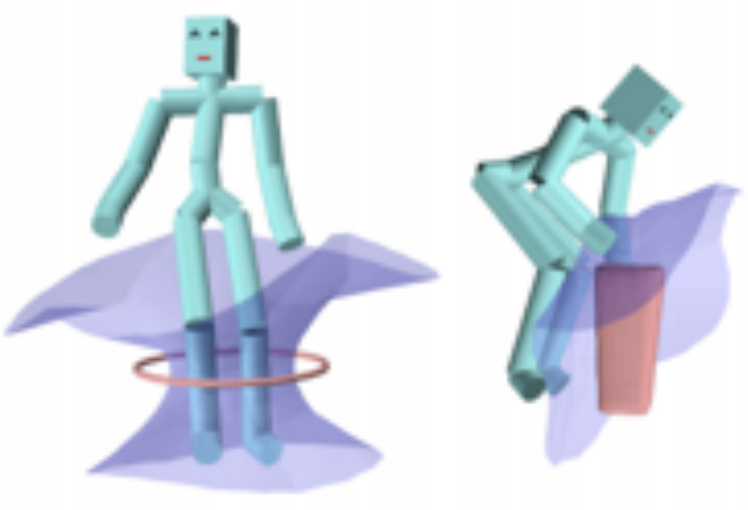
Object interactions
[FSL*15]



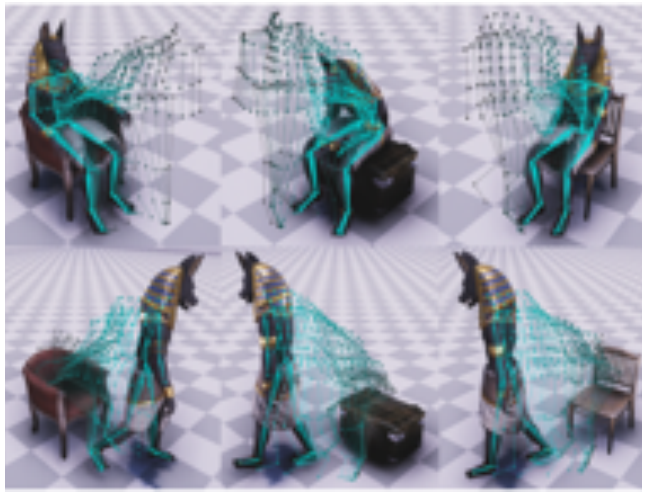
PiGraphs
[SCH*16]

Functional entity level: object

Shape2pose
[KCGF14]



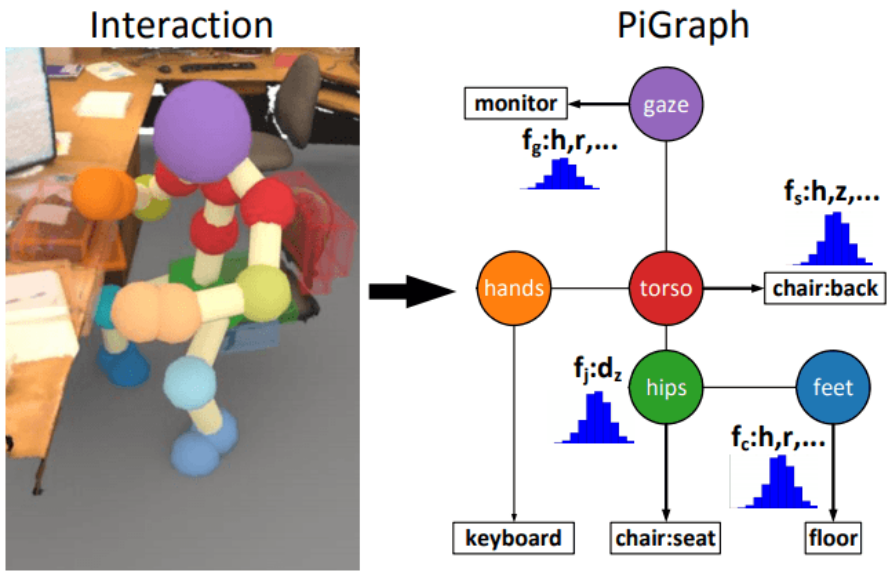
Character-object IBS
[ZCK17]



Character interactions
[SZKS19]

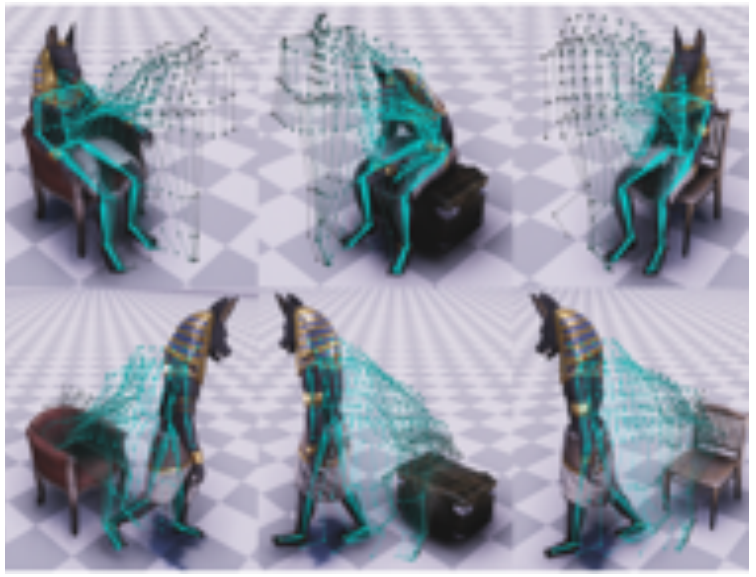
Relation type

Atemporal



[SCH*16]

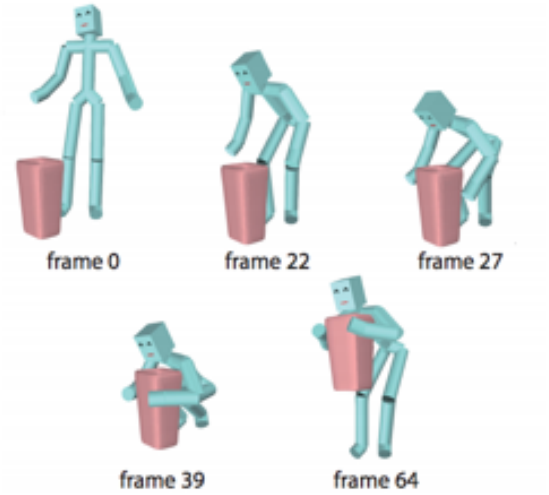
Time-varying



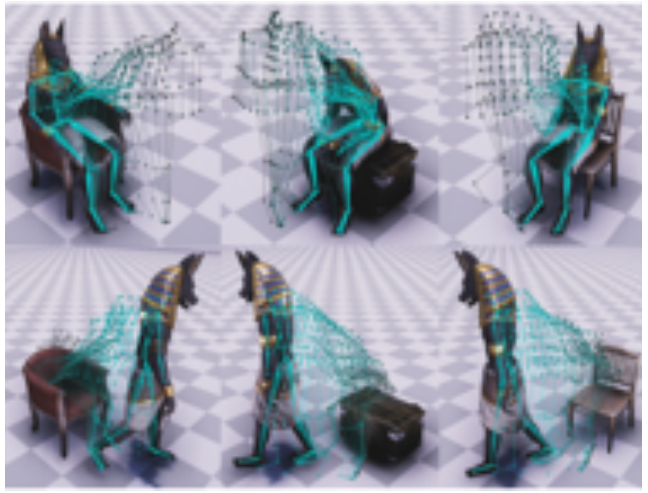
[SZKS19]

Relation type: time-varying

Motion patches
[LCL06]



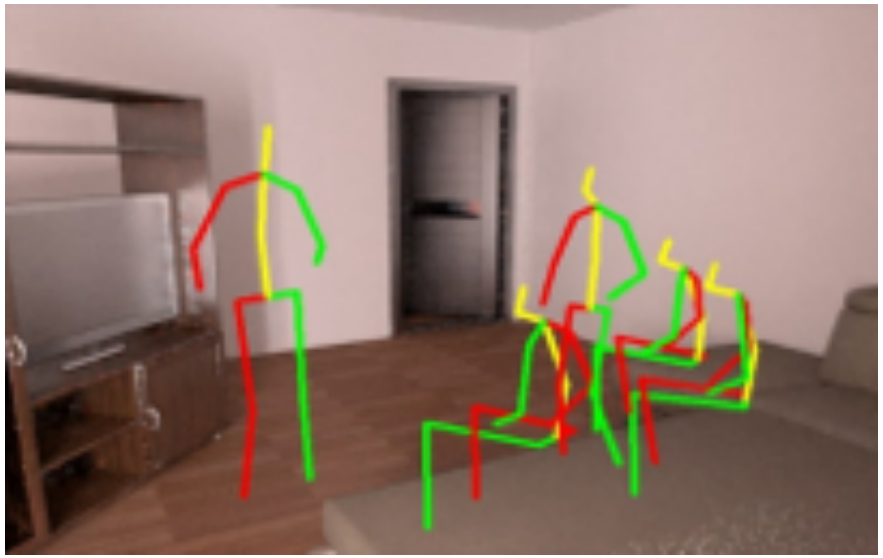
Character-object IBS
[ZCK17]



Character interactions
[SZKS19]

Generation: scene → agent(s)

Generating 3D people
[ZHN*20]

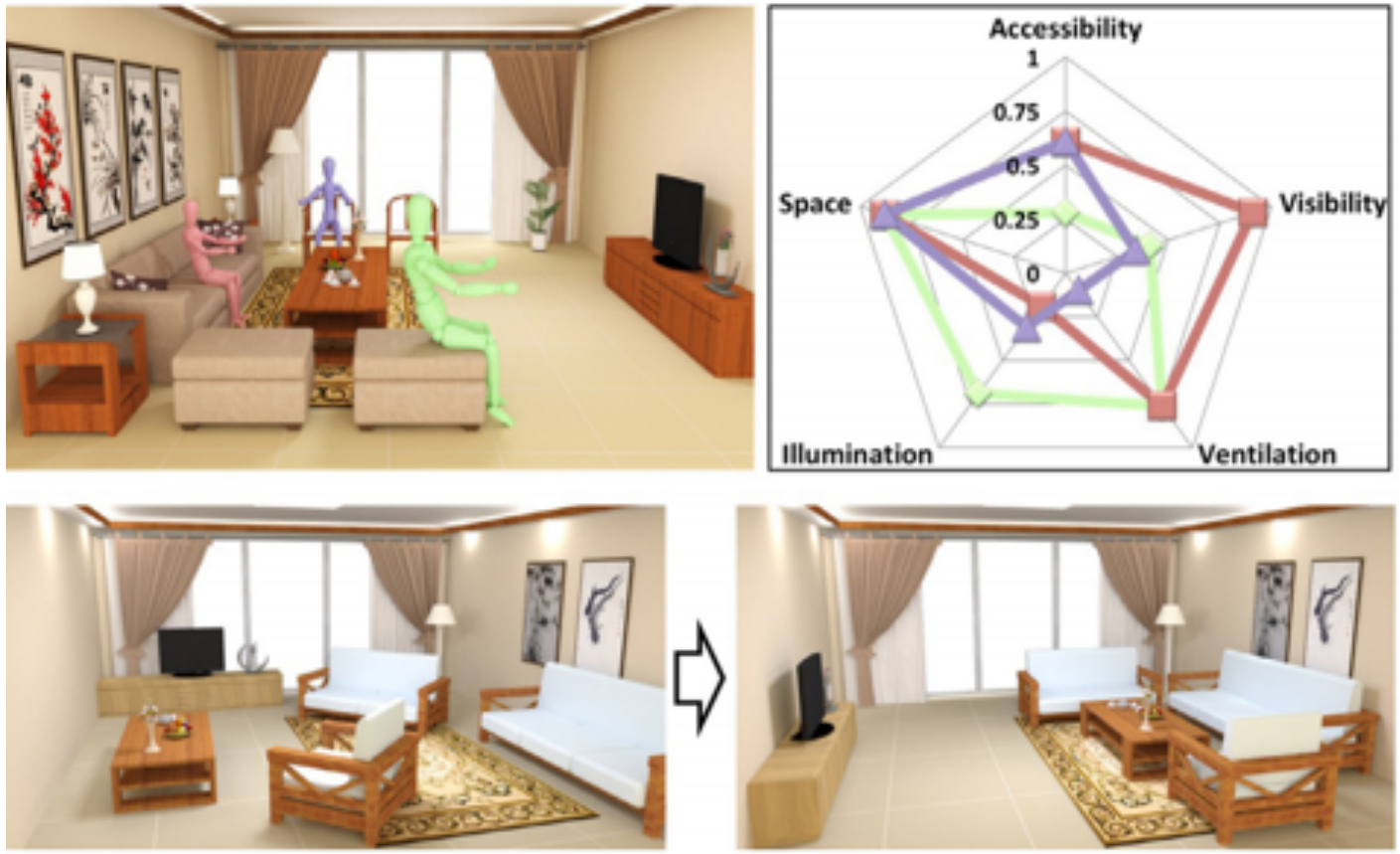


Putting humans in a scene
[LLK*19]

Generation: agent → scene

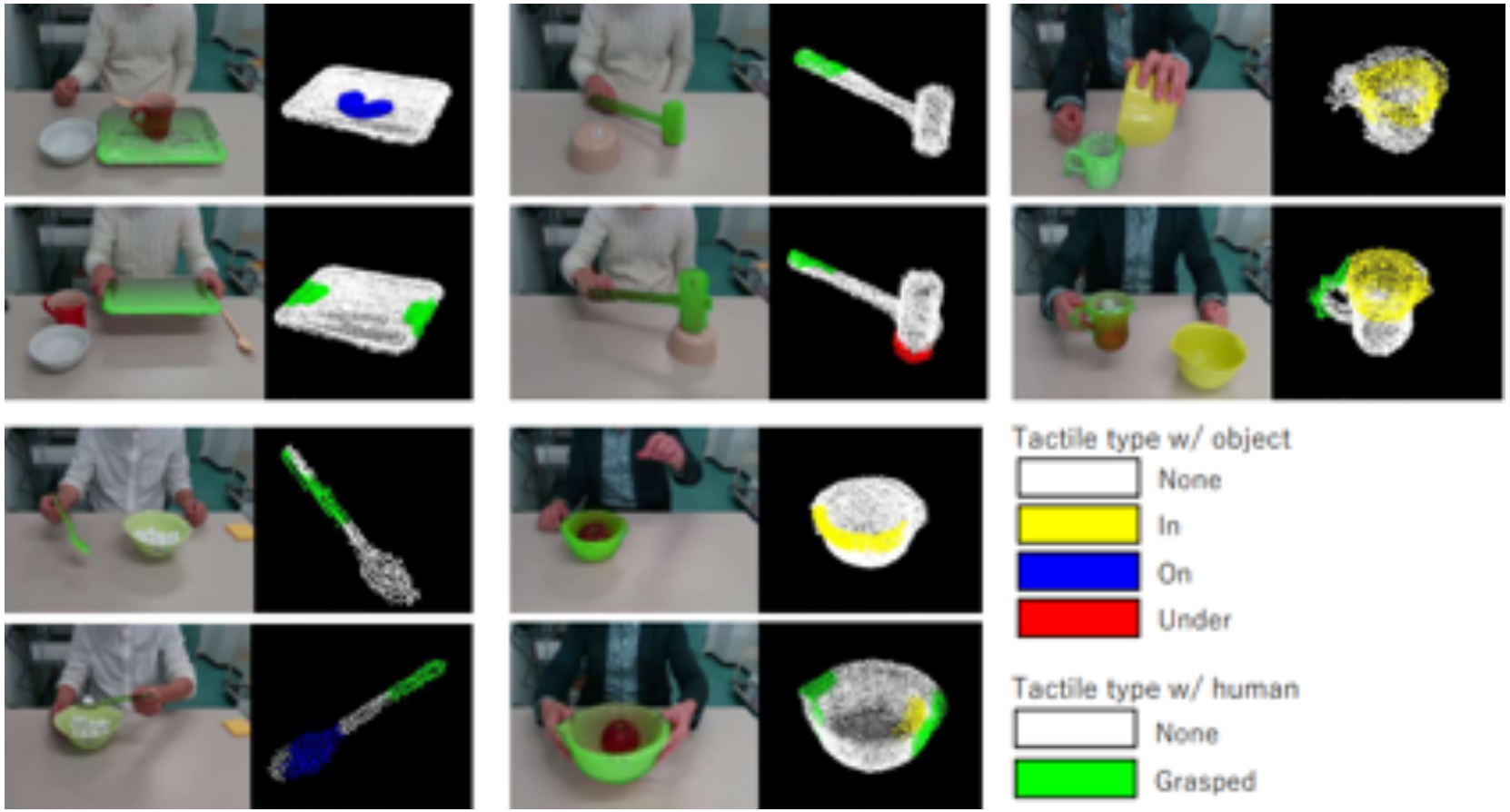
iMapper
[MGC*19]

Discrimination: scene quality metrics



Human-centric scene assessment metrics [FFY*20]

Discrimination: object understanding



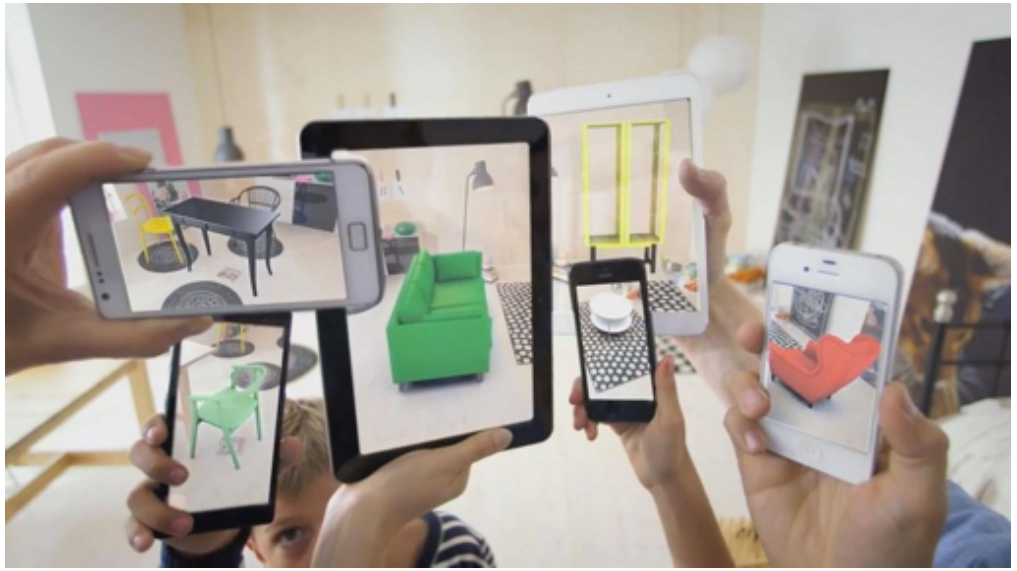
Tool use classification
[AA18]

Future directions for geometry + agent methods

- Finer scale actions
- Social actions and hierarchical actions
- Time-varying relations in time-varying scenes
- Connections with robotics, computer vision, embodied AI

Summary: geometry + agent methods

Virtual and augmented reality



[image source: https://commons.wikimedia.org/wiki/File:Augmented-reality.jpg]

Fabrication

[image source: https://commons.wikimedia.org/wiki/File:GENERATIC-collection-by-Emmanuel_Touraine-for-VENTURY-027.jpg]

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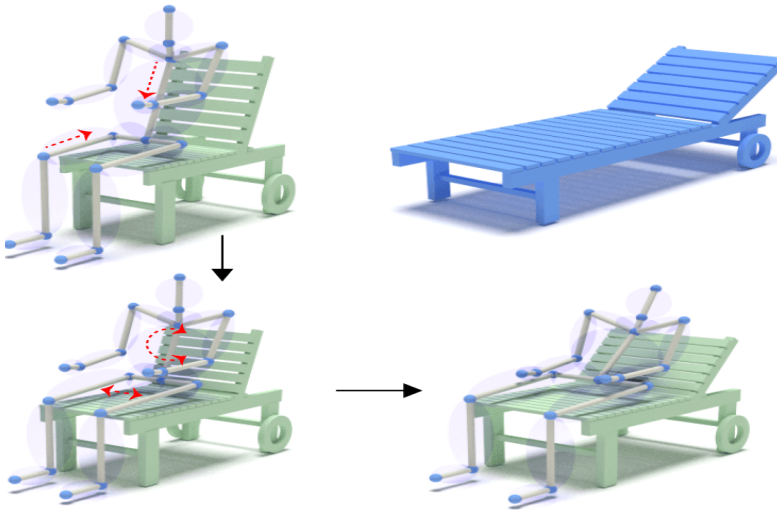
Applications

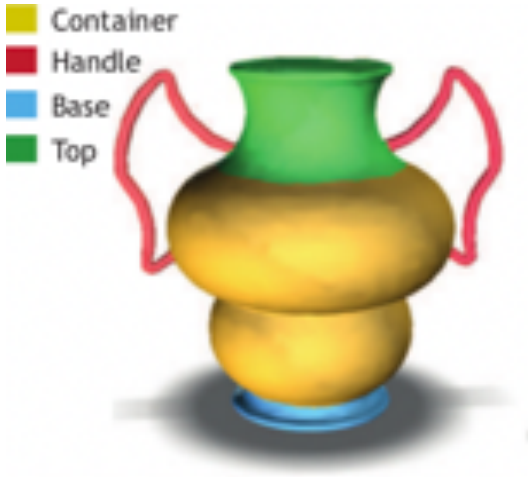


Application domains

- Classification, segmentation, and labeling
- Retrieval
- Synthesis
- Modeling and editing
- Visualization and fabrication
- Robotics and AI

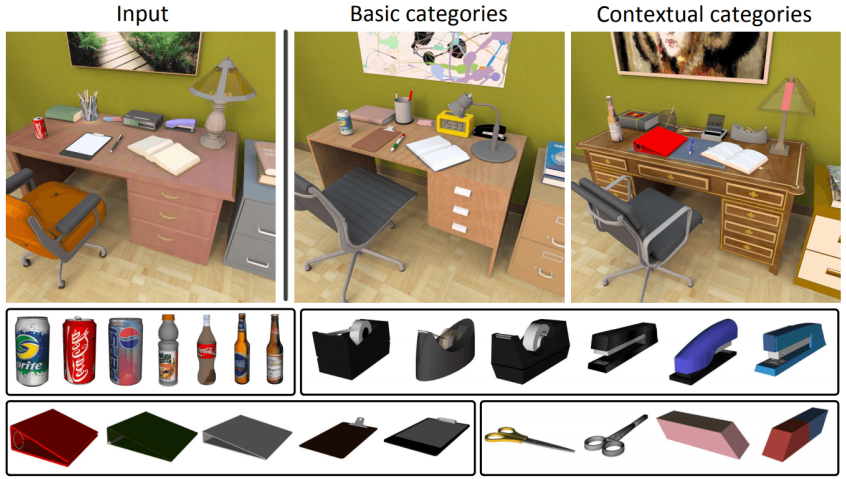
Classification, segmentation, labeling

Part classification



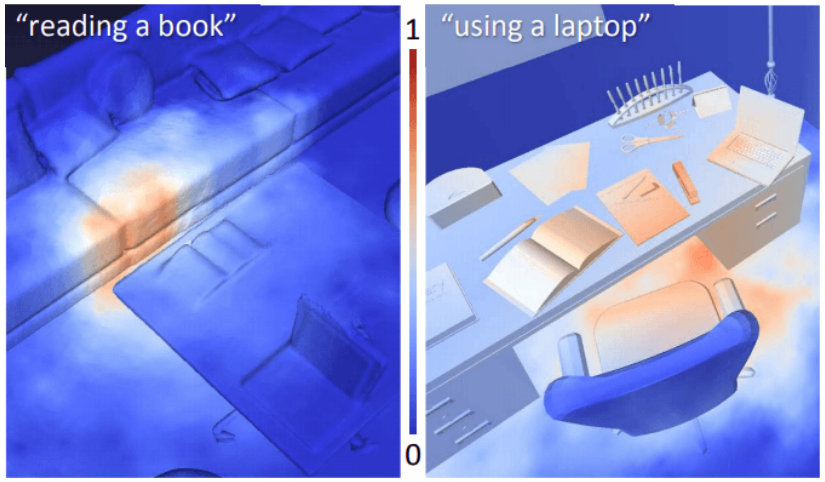
[LMS13]

Object classification



[FRS*12]

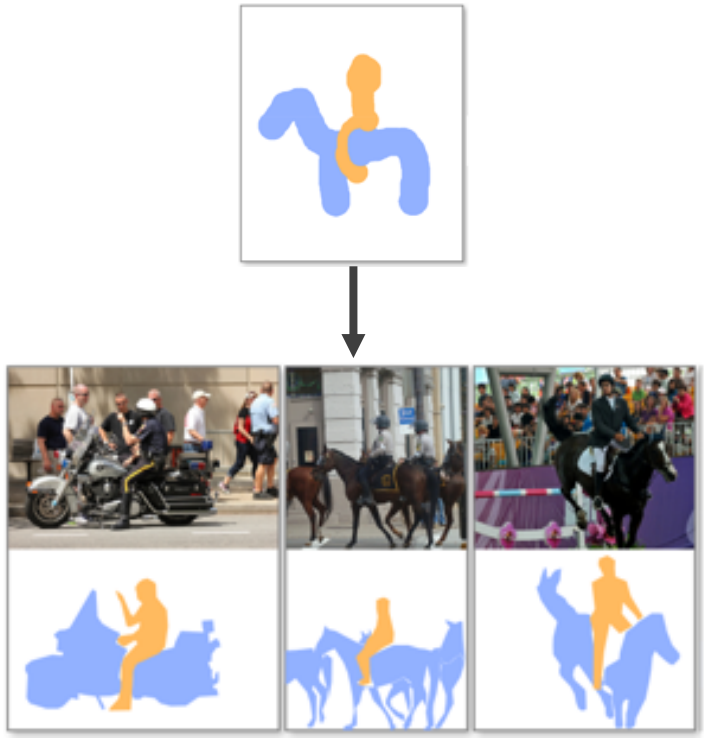
Scene classification



[SCH*14]

Retrieval

Part retrieval

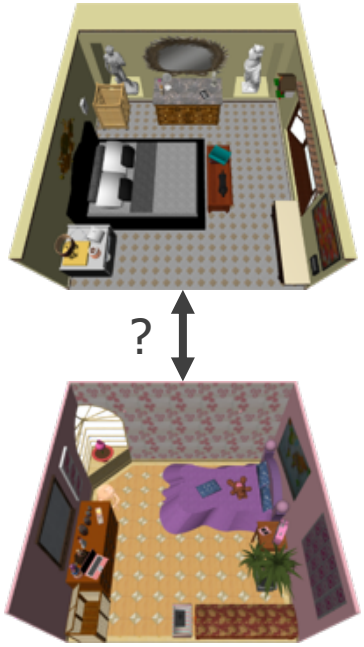


[GMW16]

Object-in-scene retrieval

[HZvK*15]

Scene retrieval



[SCH*14]

Synthesis

3D scene synthesis

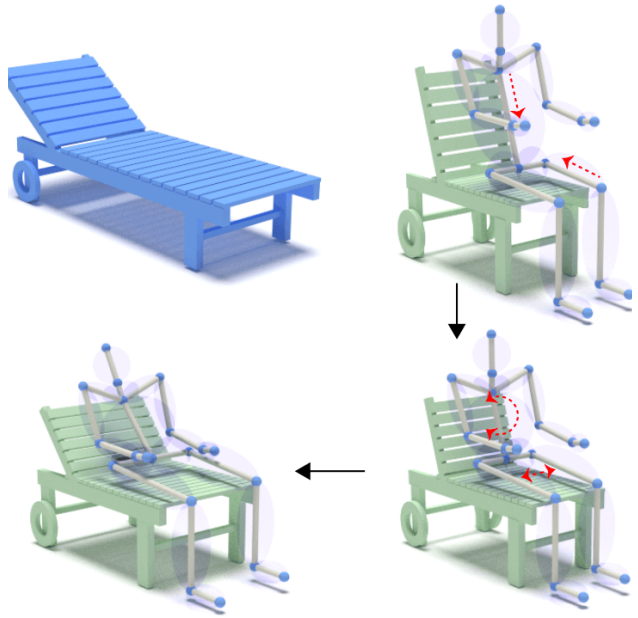
[FSL*15]

Human interaction synthesis

[SCH*16]

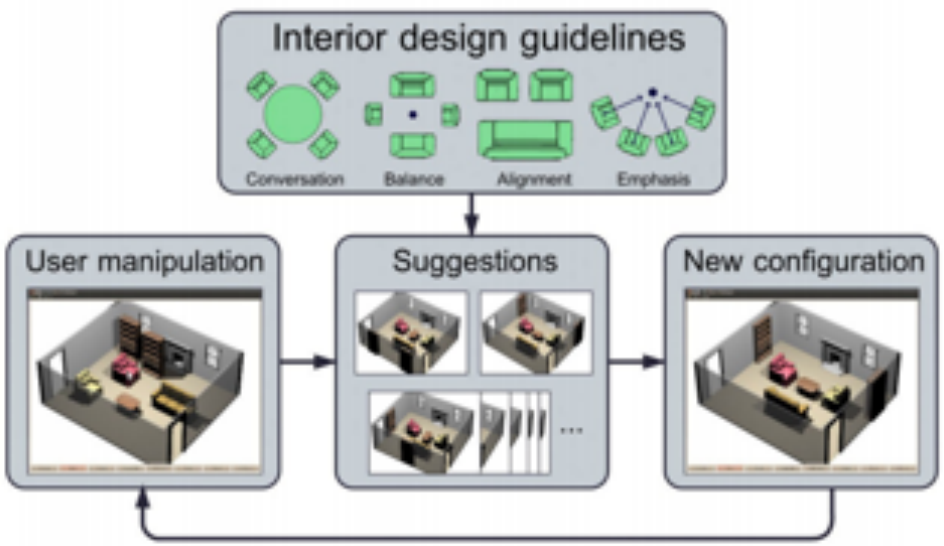
Modeling and editing

Object modeling



[ZLDM16]

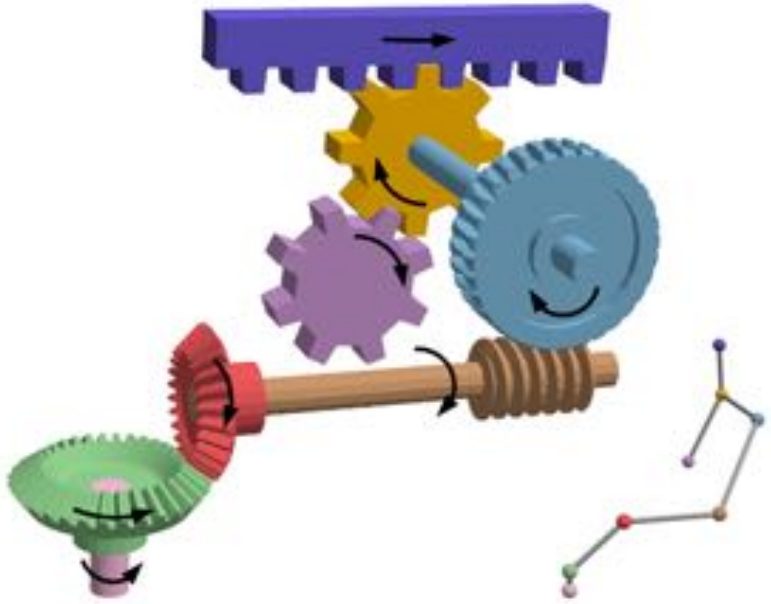
Scene editing



[MSL*11]

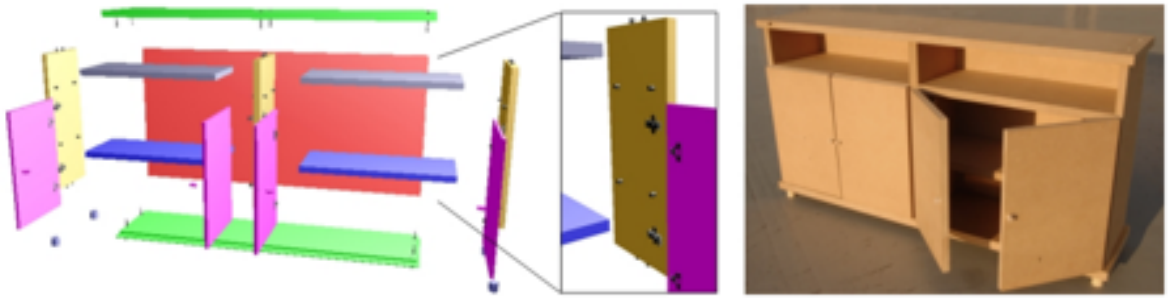
Visualization and fabrication

Assembly visualization



[MYY*10]

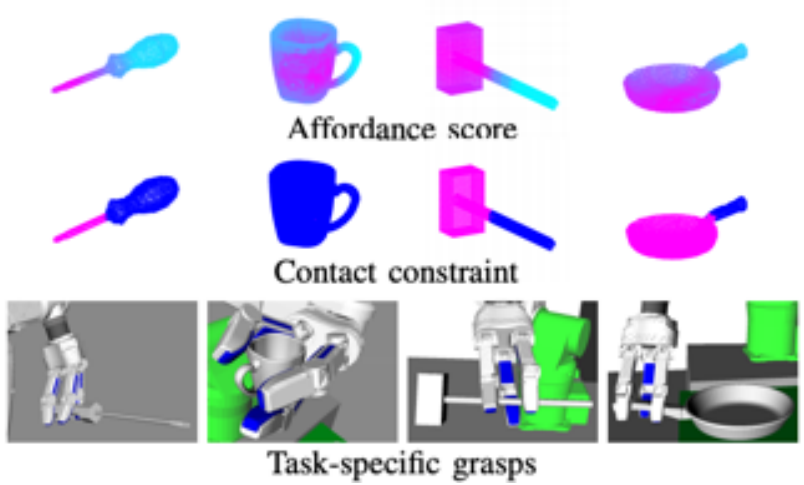
Fabrication



[LOMI11]

Robotics and AI

Affordance detection for grasping



[KSHK17]

SAPIEN: interactive 3D simulation

[XQM*20]

Applications: summary

- Many application domains
- Functionality critical for both analysis and synthesis tasks
- Despite much recent work, open research questions abound

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Future Directions

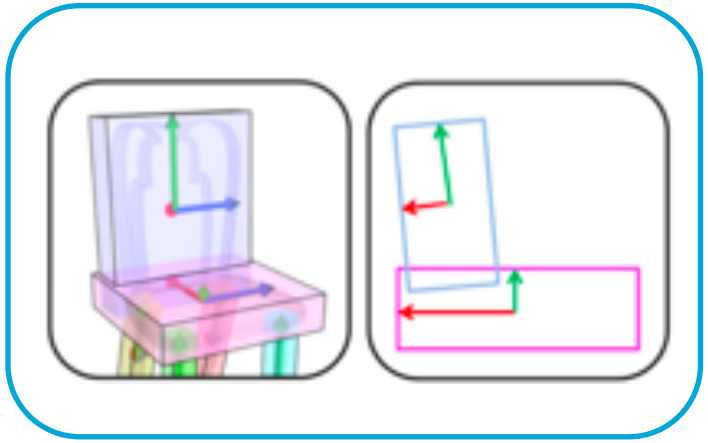
Different levels of functional entities

(a) Scene (b) Object-union (c) Object (d) Part-union (e) Part

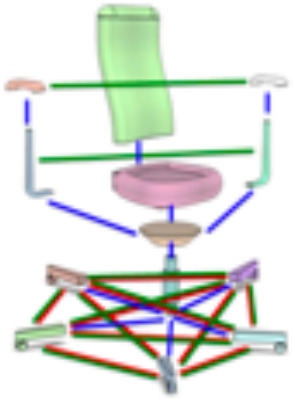
Multi-level treatment?

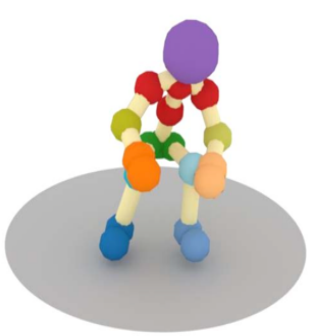
Hierarchical representation?

Interaction representation



More informative representation?

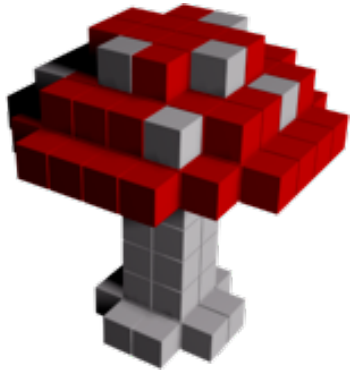




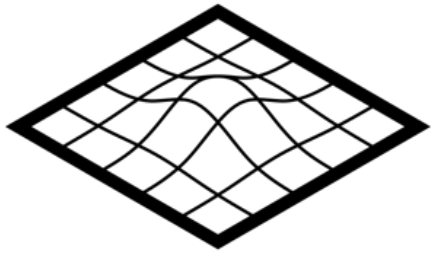
Input data type

Mesh [HLK*17]

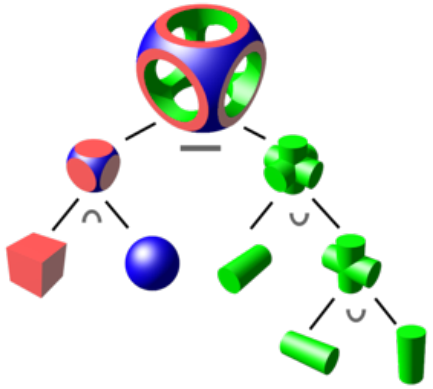
Point cloud [ZWK14]



Volumetric data



Parametric surface



Constructive solid geometry

Raw scan [FSL*15]

incomplete / partially regions

presence of noise

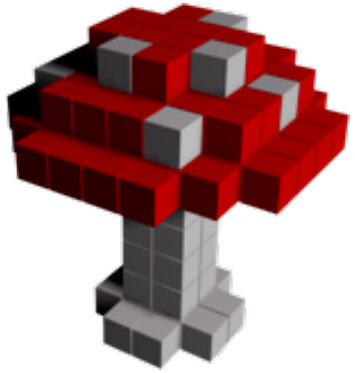
imperfect registration

...

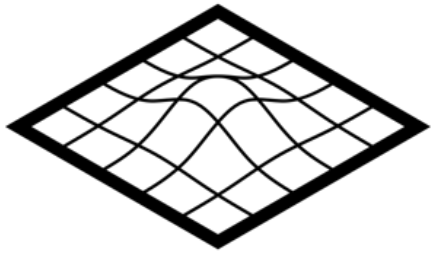
Input data type

Mesh [HLK*17]

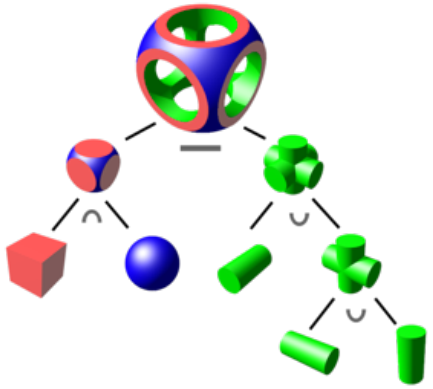
Point cloud [ZWK14]



Volumetric data



Parametric surface

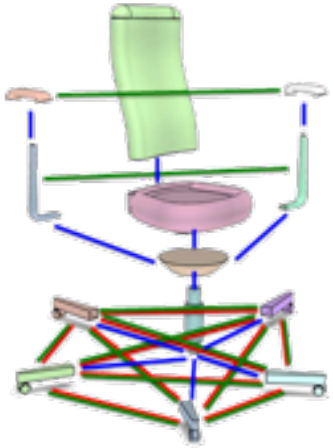


Constructive solid geometry

Raw scan [FSL*15]

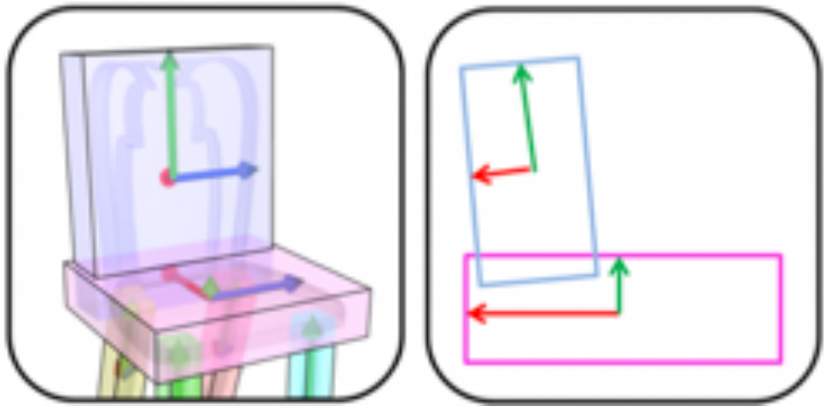
RGB image [ZFFF14]

Static vs. dynamic

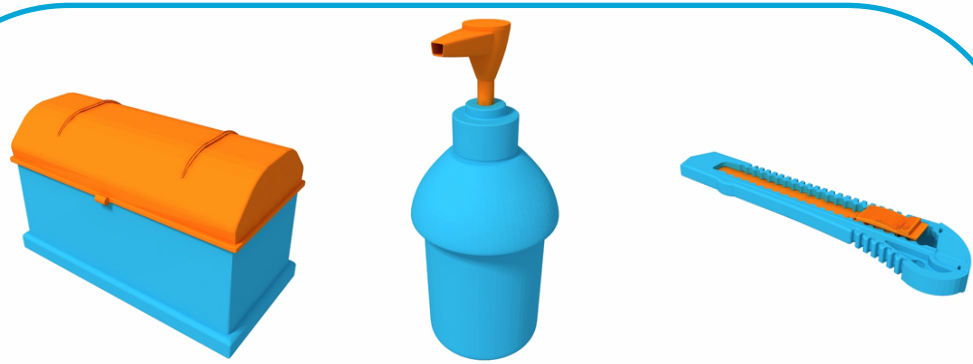


[WXL*11]

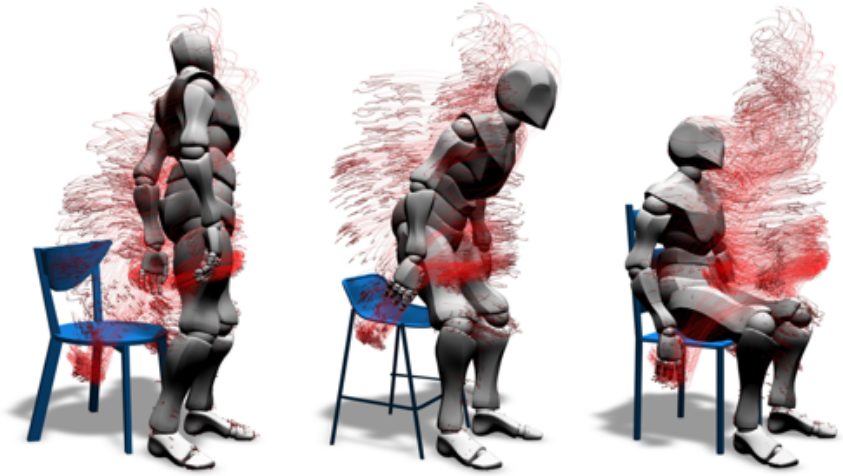
[FSL*15]



[FAvK*14]



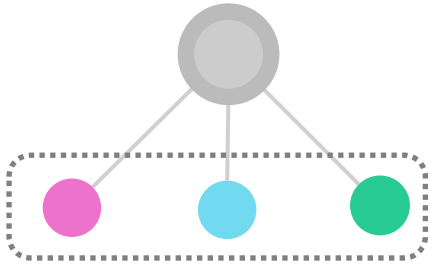
[HLK*17]



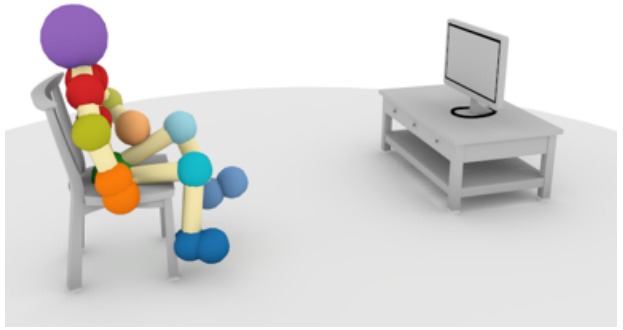
[PKH*17]

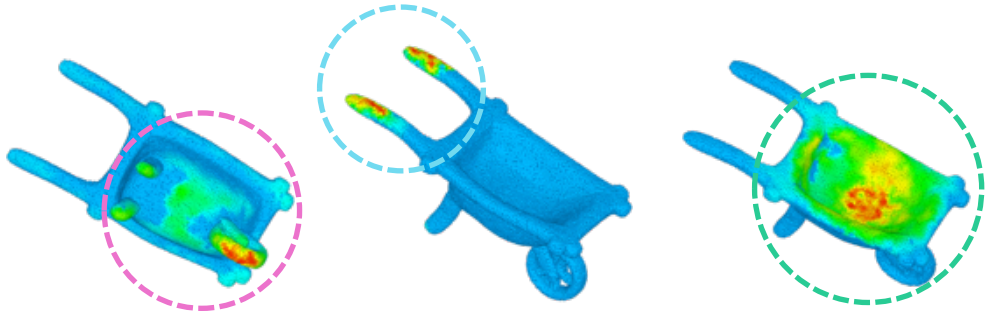
Real data collection?

Handcrafted vs. data-driven



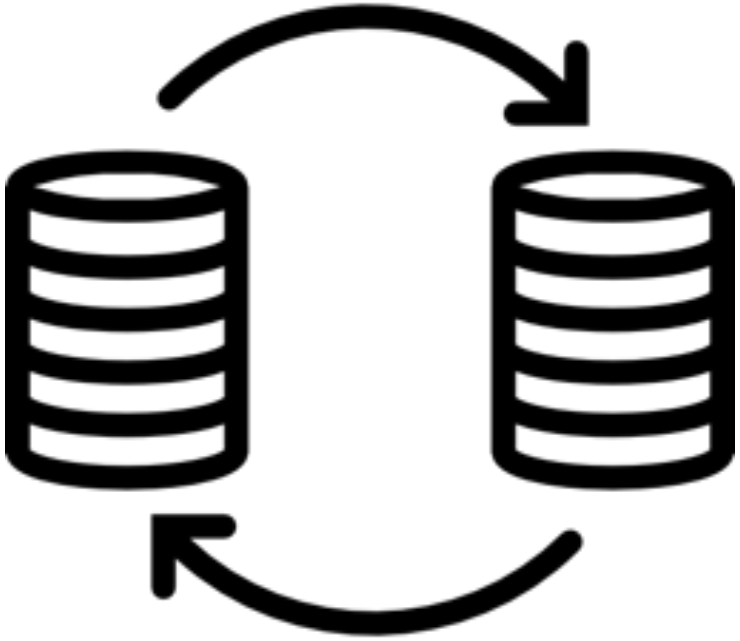
prior knowledge

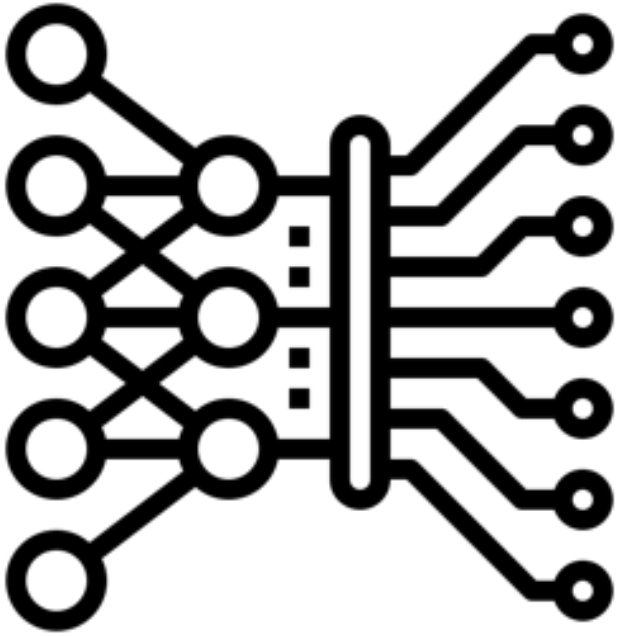




handcrafted features

Handcrafted vs. data-driven





Large-scale 3D functionality dataset

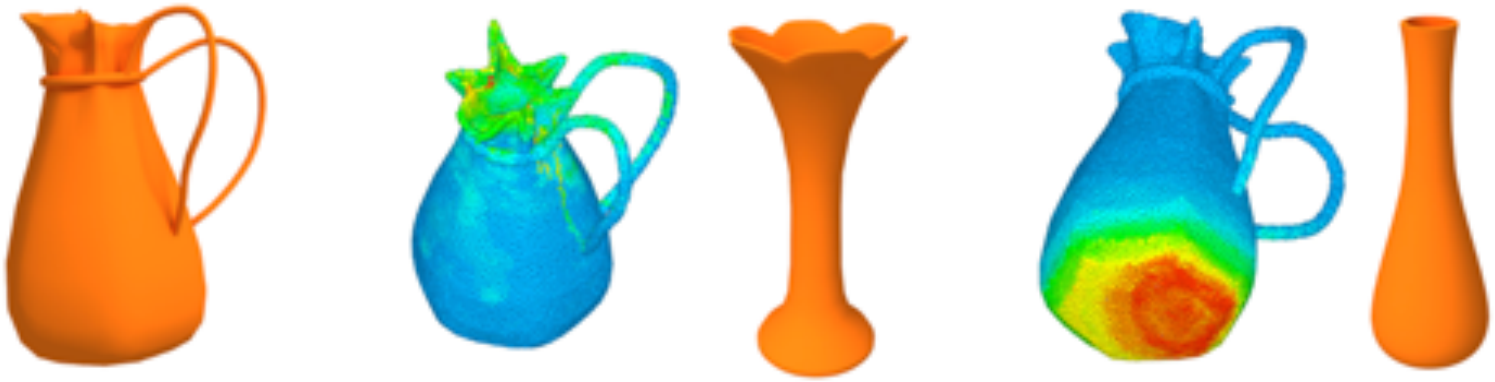
[Image source: Icons made by Pause08 www.flaticon.com]

Machine learning advances

[Image source: Icons made by Becris www.flaticon.com]

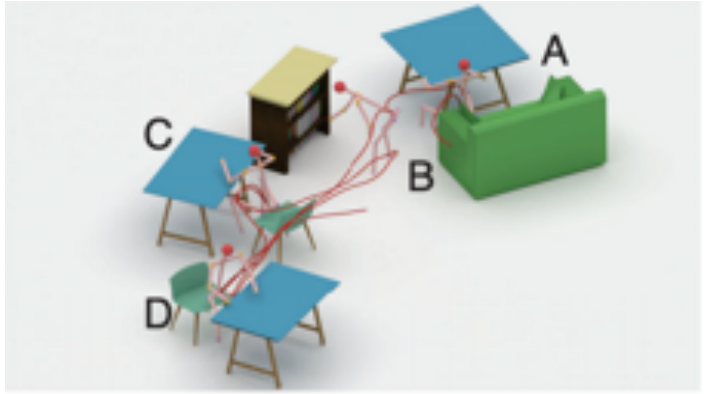
Beyond geometry

- Materials for physical reasoning
- Acoustic properties for sound-based functions

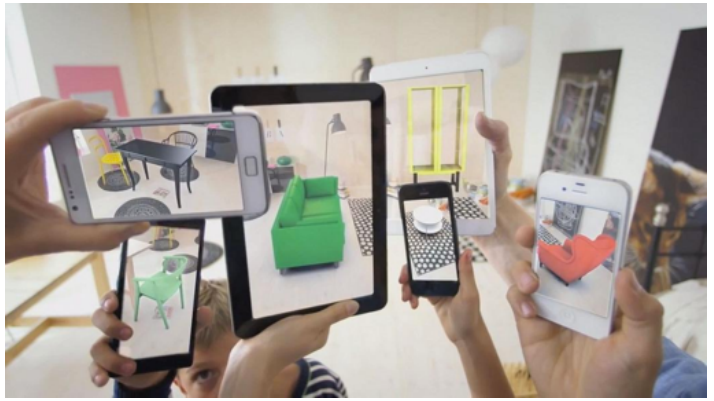


Emerging applications

- Functionality-guided scene synthesis
- Functionality-driven AR/VR
- Functionality-driven interactive 3D simulation



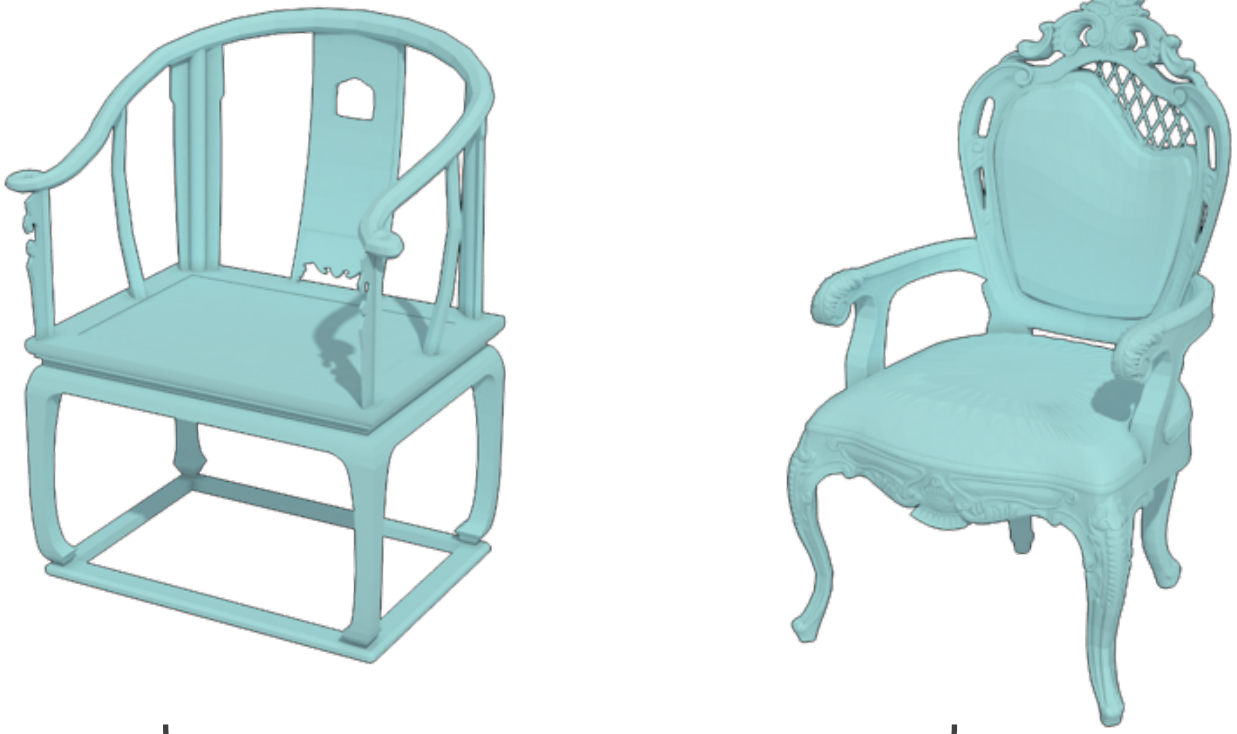
[MGC*19]



[image source: https://commons.wikimedia.org/wiki/File:Augmented-reality.jpg]

[XQM*20]

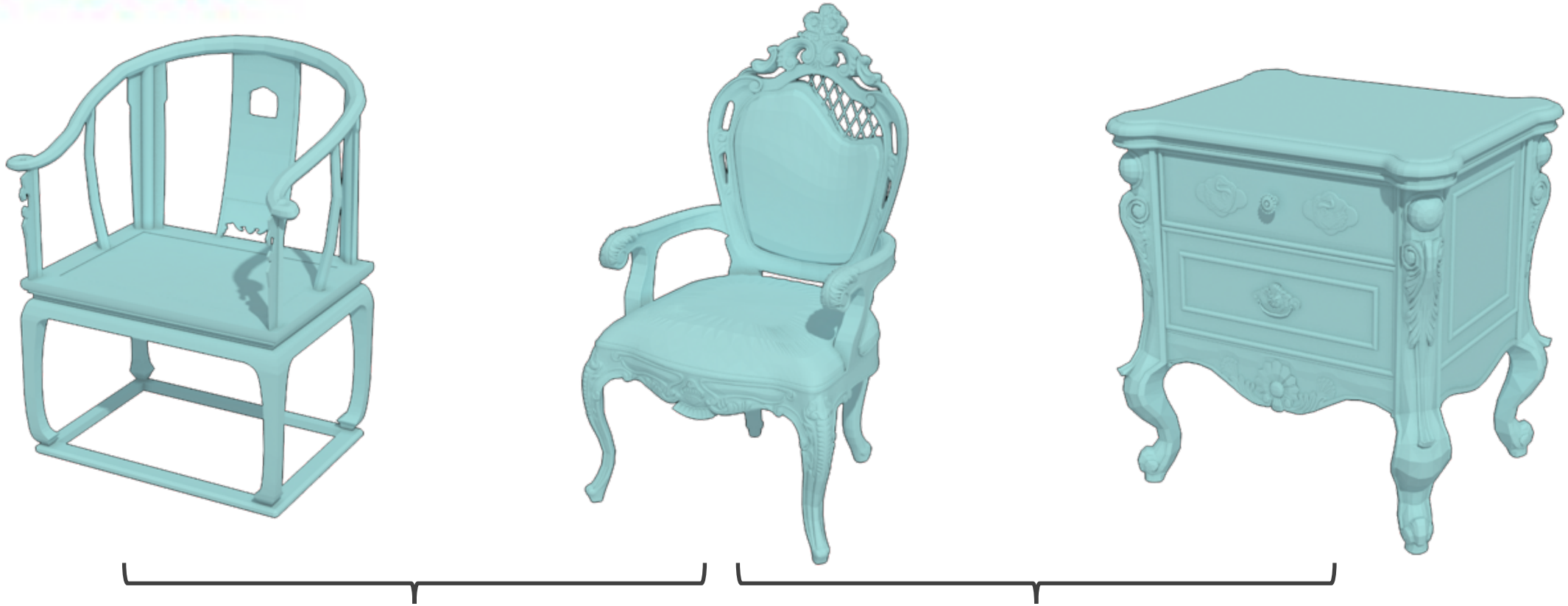
Full understanding of 3D shape



Same functionality

- Material
- Weight
- Size
- ⋮

Full understanding of 3D shape



Same functionality

Same style

“Grand challenge”

- Model covering a range of functionality aspects
  - Human-object
  - Object-object
  - Dynamic settings
  - Physical properties
  - …
- Use the model for analysis and synthesis
- E.g., realistic shape and scene synthesis

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Conclusion

Summary

- Comprehensive survey of work on functionality
- Definition of functionality: geometry + interaction
- Three classes of methods:
  geometry-only, geometry + interaction, geometry + agent
- Factorization into intrinsic and extrinsic properties

Limitations

- Functionality definition is not complete or perfect
- What are other ways of encoding functionality?
- What are the fundamental properties of parts, objects, scenes?
- Key question: form from function or function from form?

Thank you!

- Reasoning about functionality is ubiquitous
- Emerging connections between applications in graphics, vision, robotics, and AI
- Check out the course website for more information and for our contact details!

https://learn3dfunc.github.io/