CSC2457 3D & Geometric Deep Learning

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Learning Generative Models of 3D Structures

- S. Chaudhuri, D. Ritchie, J. Wu, K. Xu, H. Zhang
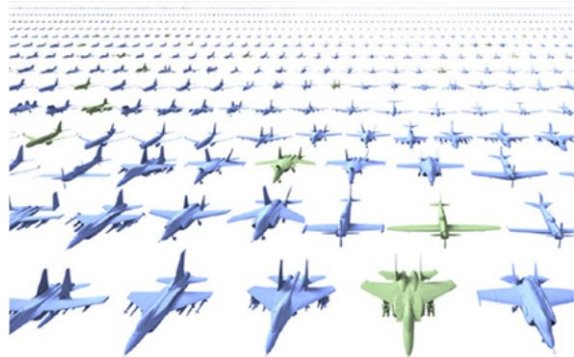
July 2020

Motivation
Learning Generative Models of 3D Content

Motivation
Learning Generative Models of 3D Content

➢ Generative models
 ○ generative: P(X)   vs.   discriminative: P(Y|X)

Contributions

➢ Educational report

➢ Survey historical work and recent progress

➢ Show representations of 3D shapes and scenes
   ○ voxel grids, point cloud, implicit representations, triangle mesh

➢ Present prominent methodologies
   ○ probabilistic models, deep generative models, program synthesis, etc.

➢ Describe structure-aware synthesis
   ○ structure-aware: express 3D shapes and scenes using abstractions that allow manipulation of their high-level structure

Structure-Aware Representations

Structure-Aware Representations

Scope: *learned* generative models of *structured* 3D content

➢ Learned:
  ○ **Determined with data**   <->   By hand or rules

➢ Structured:
  ○ **3D shapes and scenes that are decomposed into sub-structures**
  ○ <->
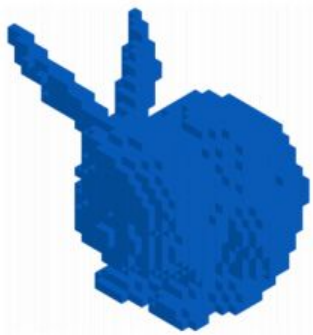 ○ a monolithic chunk of geometry
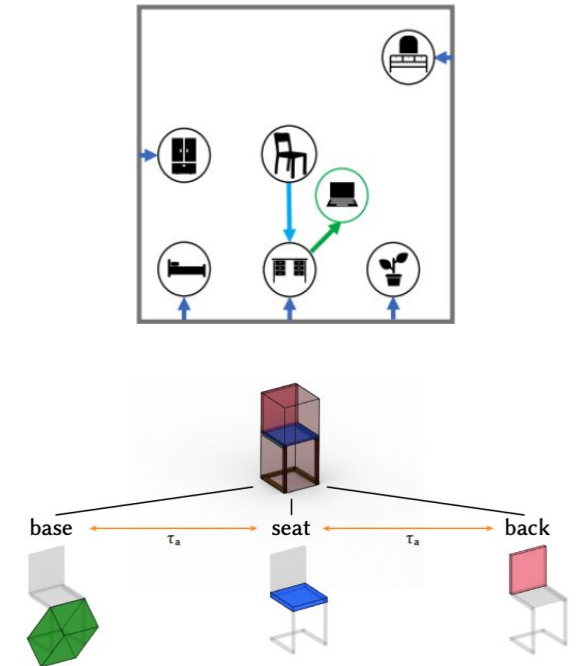
Structure-Aware Representations

➢ Express 3D shapes and scenes using abstractions that allow manipulation of their high-level structure

   ○ represent the geometry of the atomic structural elements

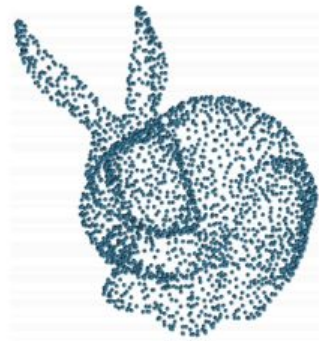   ○ represent the structural patterns
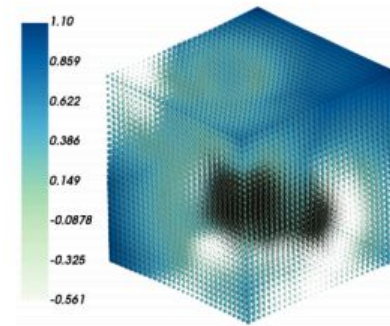
Structure-Aware Representations

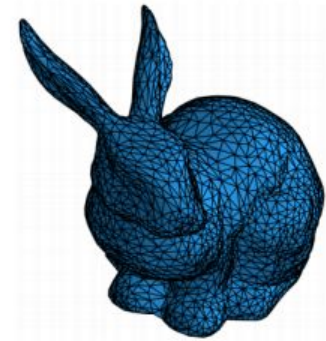➢ Representations of Part/Object Geometry
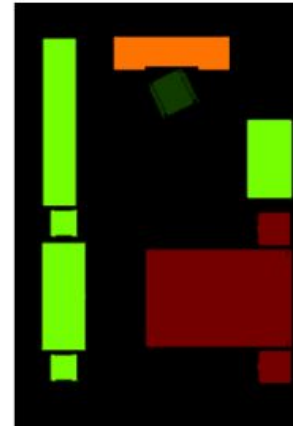

Voxel Grid

Point Cloud

Implicit Surface

Triangle Mesh

Structure-Aware Representations

➢ Representations of Part/Object Geometry

➢ Representations of Structure

Structure-Aware Representations

➢ Representations of Part/Object Geometry

➢ **Representations of Structure**

　　○ **Segmented geometry**
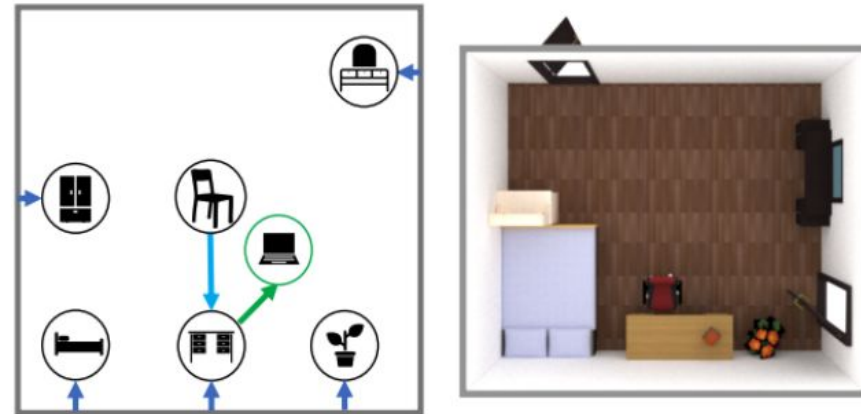
Structure-Aware Representations

➢ Representations of Part/Object Geometry

➢ **Representations of Structure**

- ○ Segmented geometry
- ○ **Part sets**
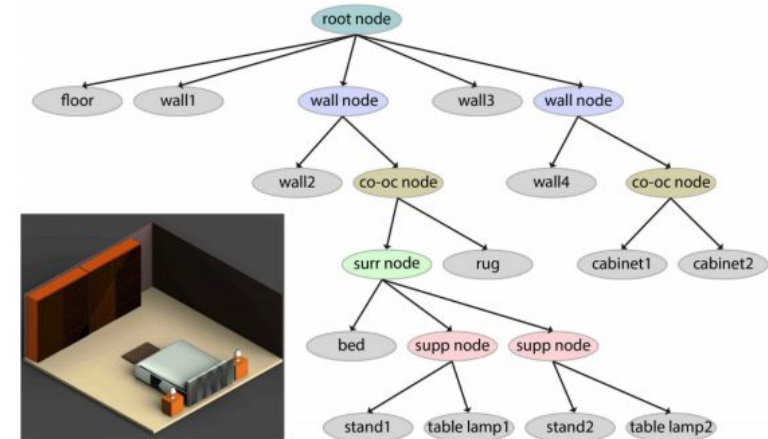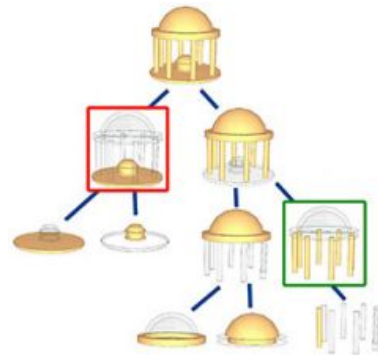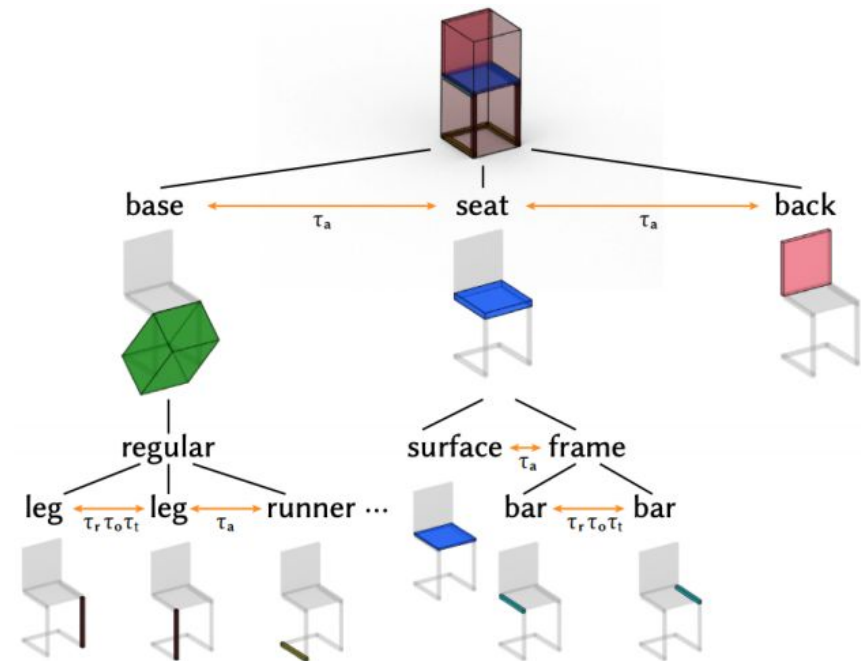 - ■ an unordered set of atoms

Structure-Aware Representations

➢ Representations of Part/Object Geometry

➢ Representations of Structure

  ○ Segmented geometry
  ○ Part sets
  ○ **Relationship graphs**

Structure-Aware Representations

➢ Representations of Part/Object Geometry

➢ **Representations of Structure**

  ○ Segmented geometry
 ○ Part sets
  ○ Relationship graphs
  ○ **Hierarchies**

Structure-Aware Representations

➢ Representations of Part/Object Geometry

➢ Representations of Structure

- ○ Segmented geometry
- ○ Part sets
- ○ Relationship graphs
- ○ Hierarchies
- ○ **Hierarchical graphs**

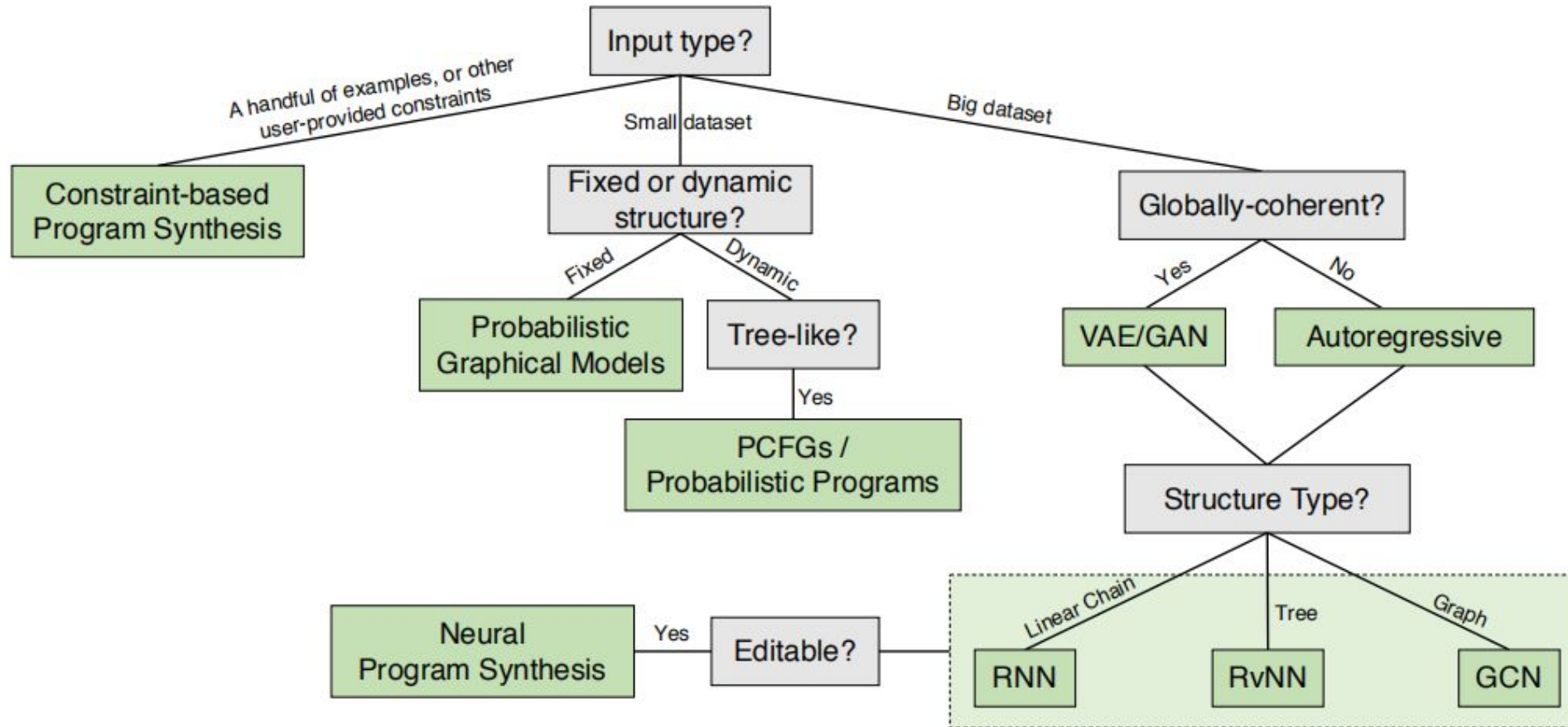# Structure-Aware Representations

➢ Representations of Part/Object Geometry

➢ **Representations of Structure**

  ○ Segmented geometry
  ○ Part sets
  ○ Relationship graphs
  ○ Hierarchies
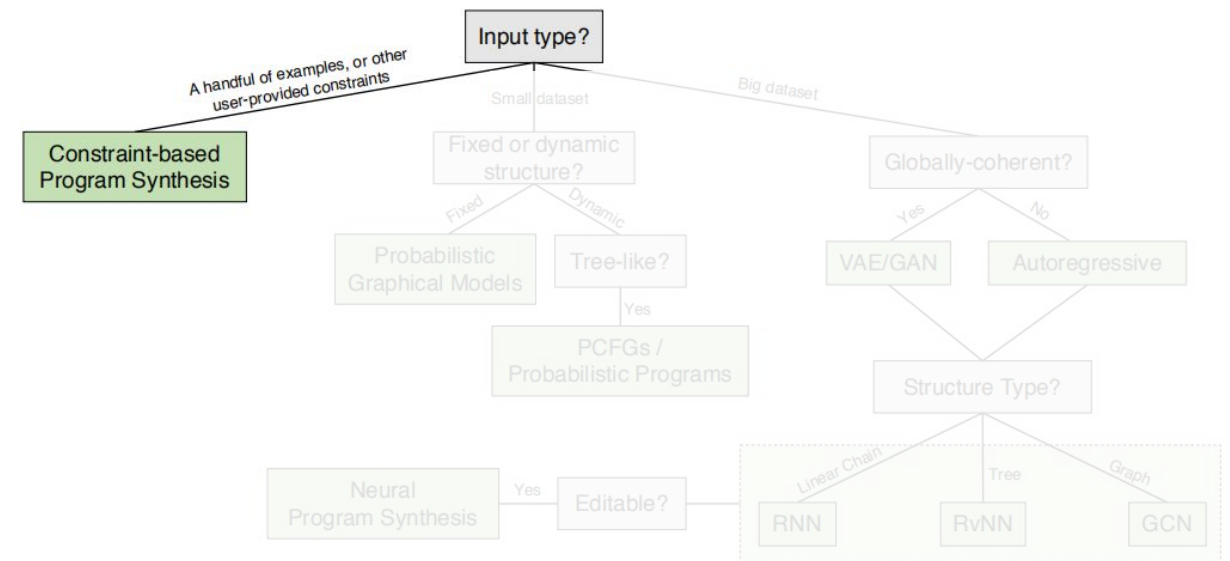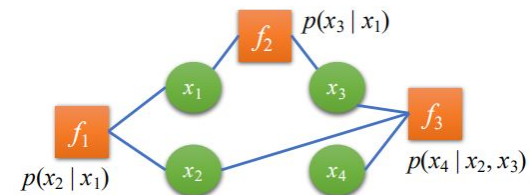 ○ Hierarchical graphs
  ○ **Programs**
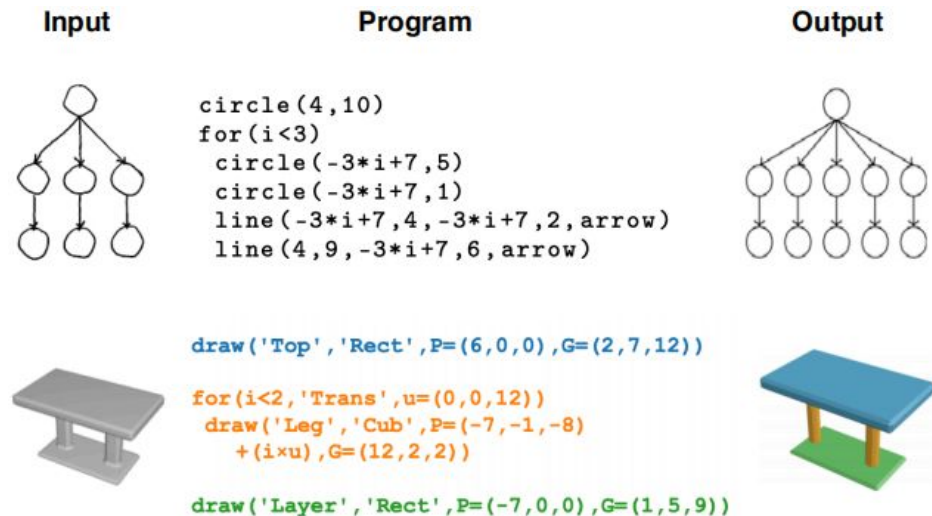
Methodologies

Methodologies

➢ Program synthesis

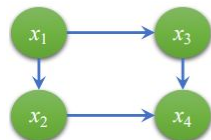 ○ Constraint-based program synthesis

Methodologies

➢ Classical Probabilistic Models
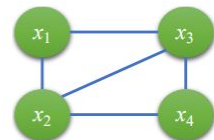
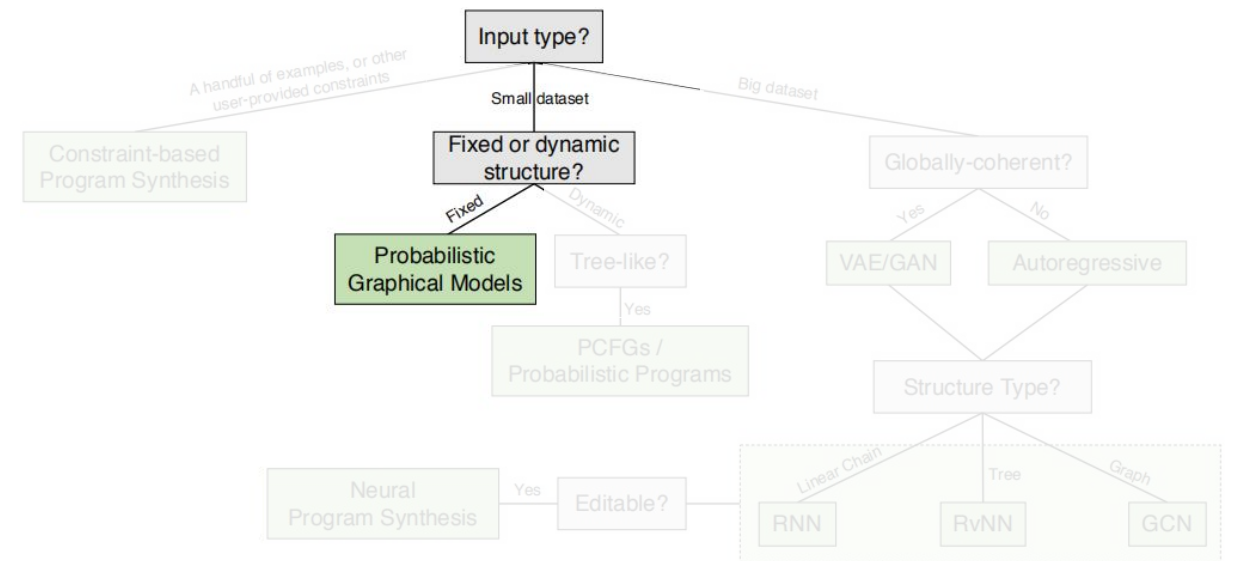○ Probabilistic graphical models

Methodologies

➢ **Classical Probabilistic Models**

- ○ Probabilistic graphical models
- ○ **Probabilistic grammars**
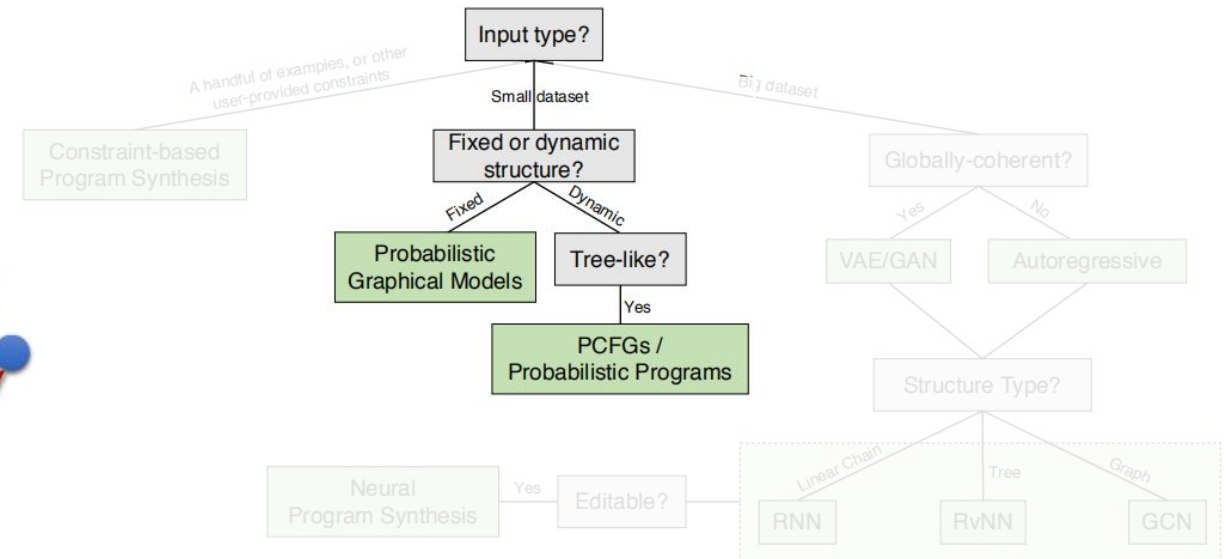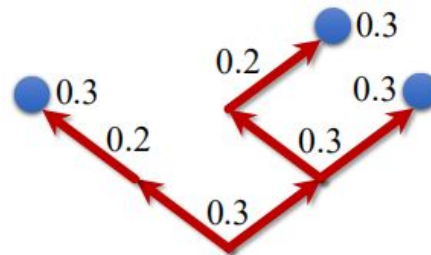 - ■ Context-free grammar (CFG)
  - ■ Probabilistic CFG (PCFG)

Methodologies

➢ Deep Generative Models

○ Autoregressive models
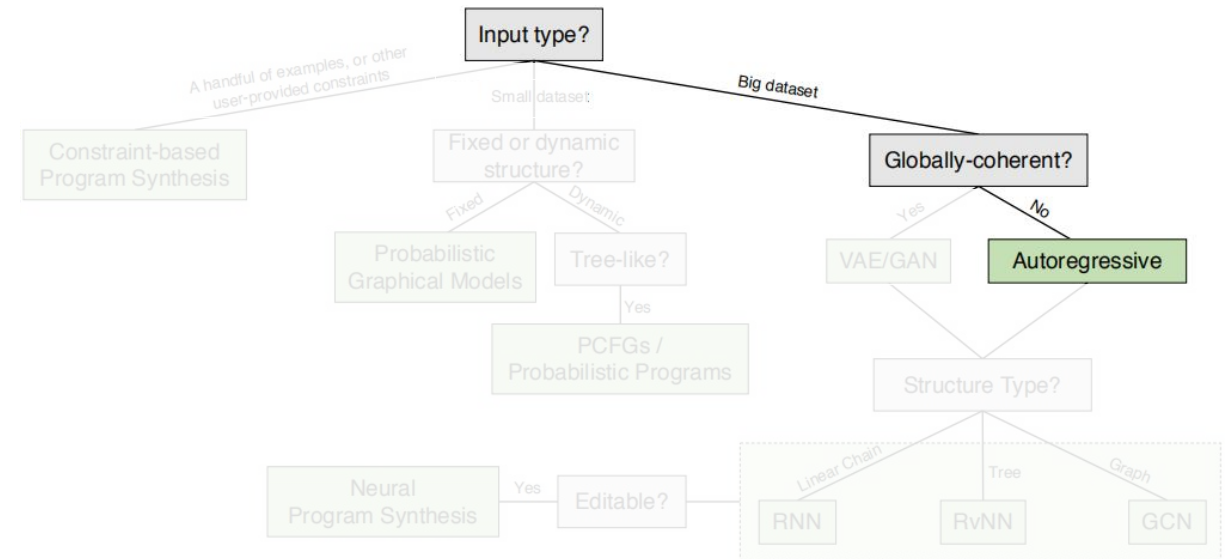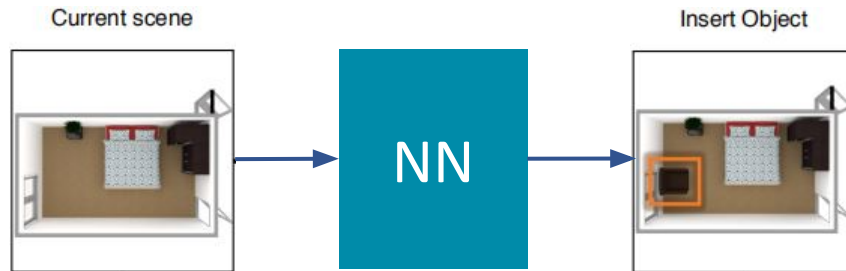
Methodologies

➢ Deep Generative Models

○ Autoregressive models

○ Deep latent variable models

■ VAE

■ GAN
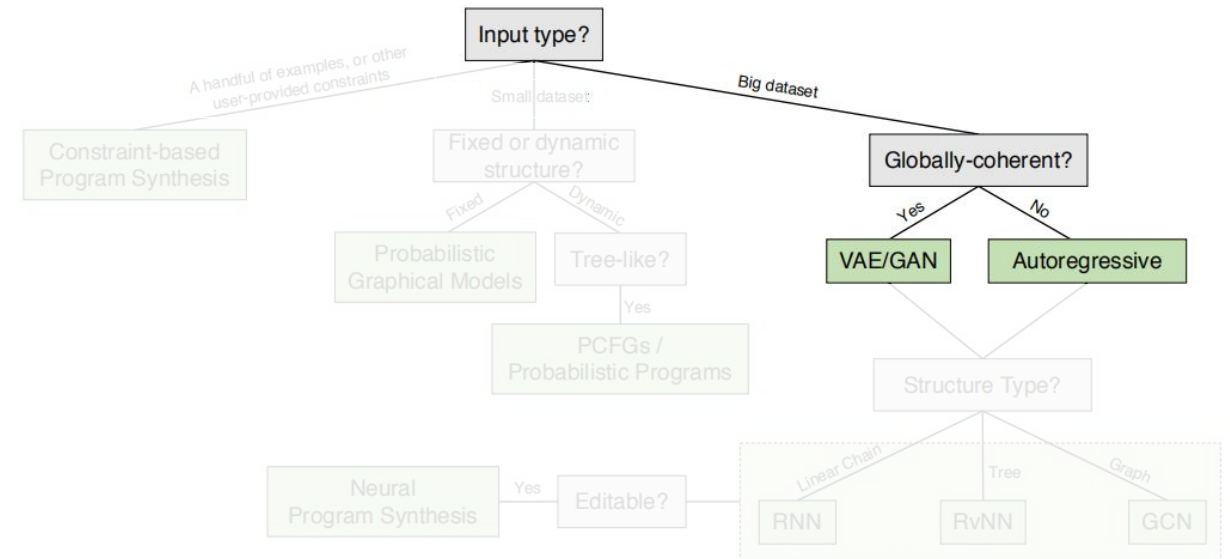
Methodologies

➢ Neural Networks for Different Structure Types

- Chains: recurrent neural networks (RNN)
- Trees: recursive neural networks (RvNN)
- Graphs: graph convolutional networks (GCN)

➢ Program synthesis

- Constraint-based program synthesis
- Neural program synthesis
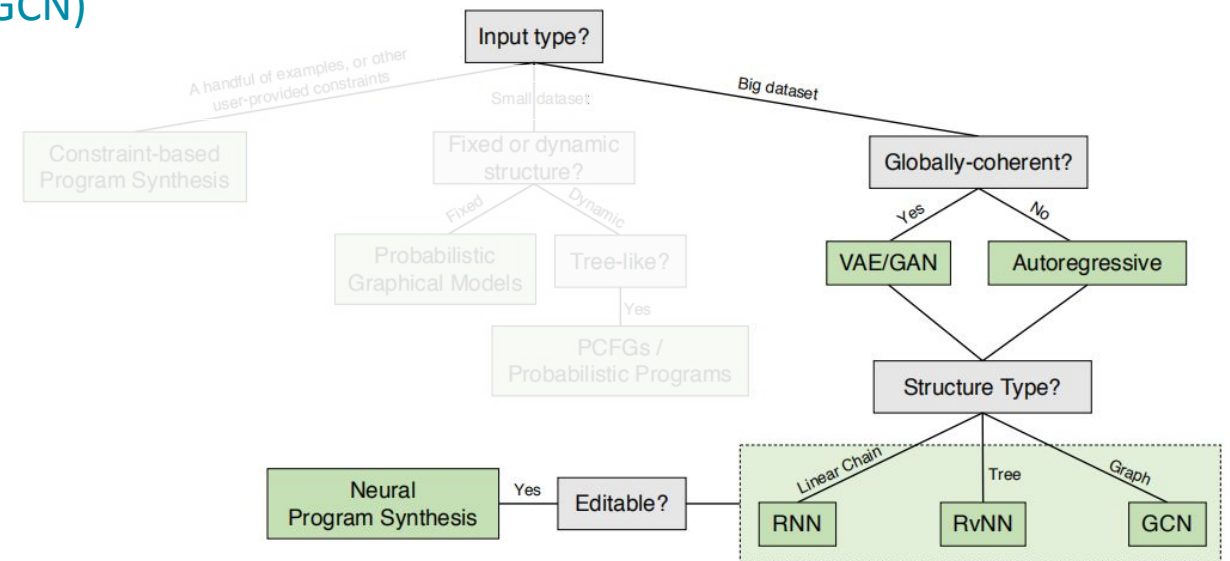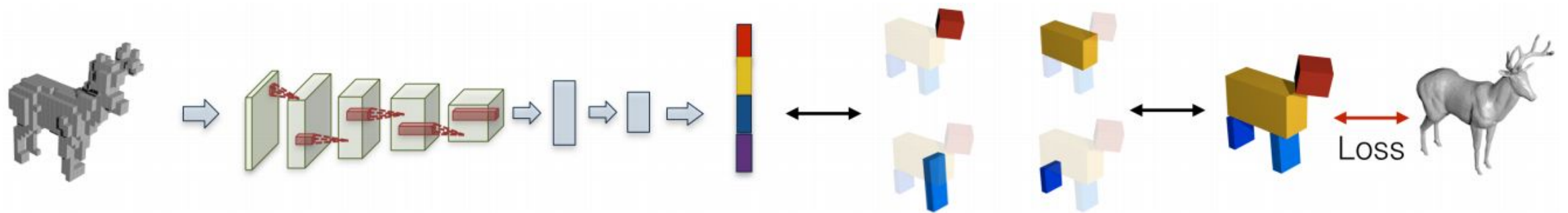
Application: Visual Program Induction

Synthesize a plausible program that recreates an existing piece of 3D content

Recover shape-generating programs from an existing 3D shape

Recover shape-generating programs from an existing 3D shape

➢ Tulsiani et al. 2017

Loss

Recover shape-generating programs from an existing 3D shape

➢ Tulsiani et al. 2017

Loss

➢ Tian et al. 2019


```
Draw("Top", "Circle", position, geometry)

for(i < 2, "translation", a)
    for(j < 2, "translation", b)
        Draw("Leg", "Cub", position + i*a + j*b, geometry)

for(i < 2, "translation", c)
    Draw("Layer", "Rec", position + i*c, geometry)
```
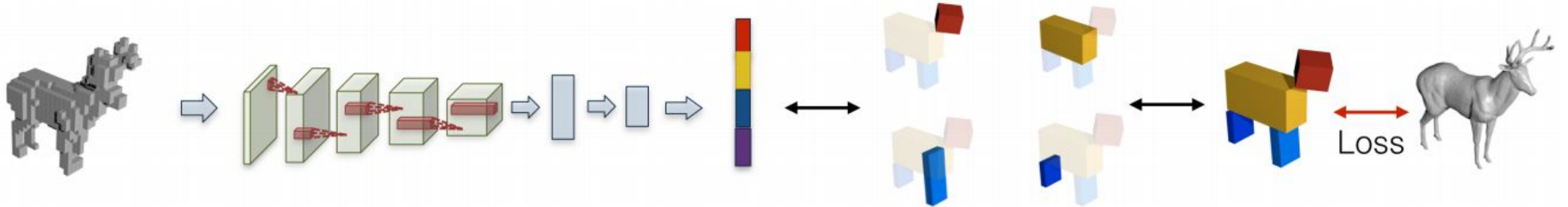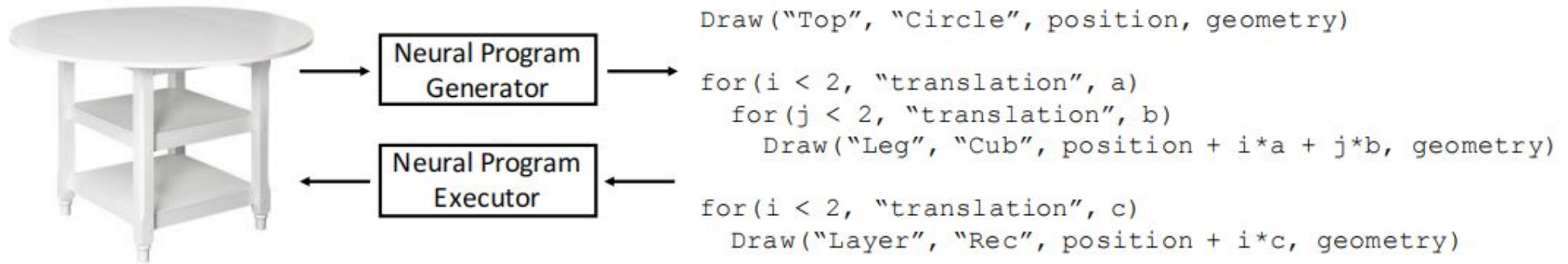
Perform visual program induction directly from 2D images

Perform visual program induction directly from 2D images

➢ Liu et al. 2019

Layout extrapolation
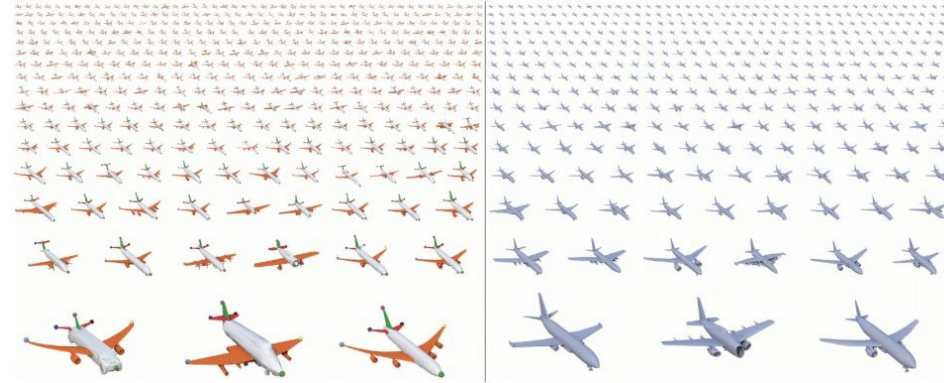

Input Image   Patches   Edited Image
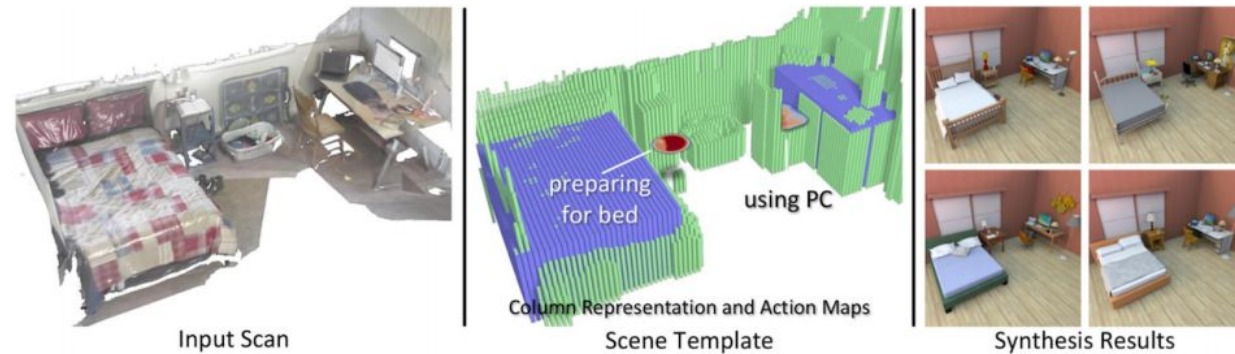
Applications

➤ **Part-based Shape Synthesis**
- Kalogerakis et al. 2012
- Huang et al. 2015: Deep Boltzmann Machine
- Sung et al. 2017: ComplementMe
- Li et al. 2017: GRASS
- etc.

➤ **Indoor Scene Synthesis**
- Xu et al. 2013: Sketch2Scene
- Savva et al. 2016: PiGraph
- Wang et al. 2019: PlanIt
- Li et al. 2019: GRAINS
- etc.

Input Scan Column Representation and Action Maps / Scene Template Synthesis Results

Recap

➢ Learning structure-aware generative models of 3D shapes and scenes

➢ Representations of individual structural atoms and structural patterns

➢ Different generative modeling methods

➢ Applications of generative technologies to 3D tasks