Pose Tracking: Object Pose Estimation and Tracking

CS 6334 Virtual Reality

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Tracking in VR

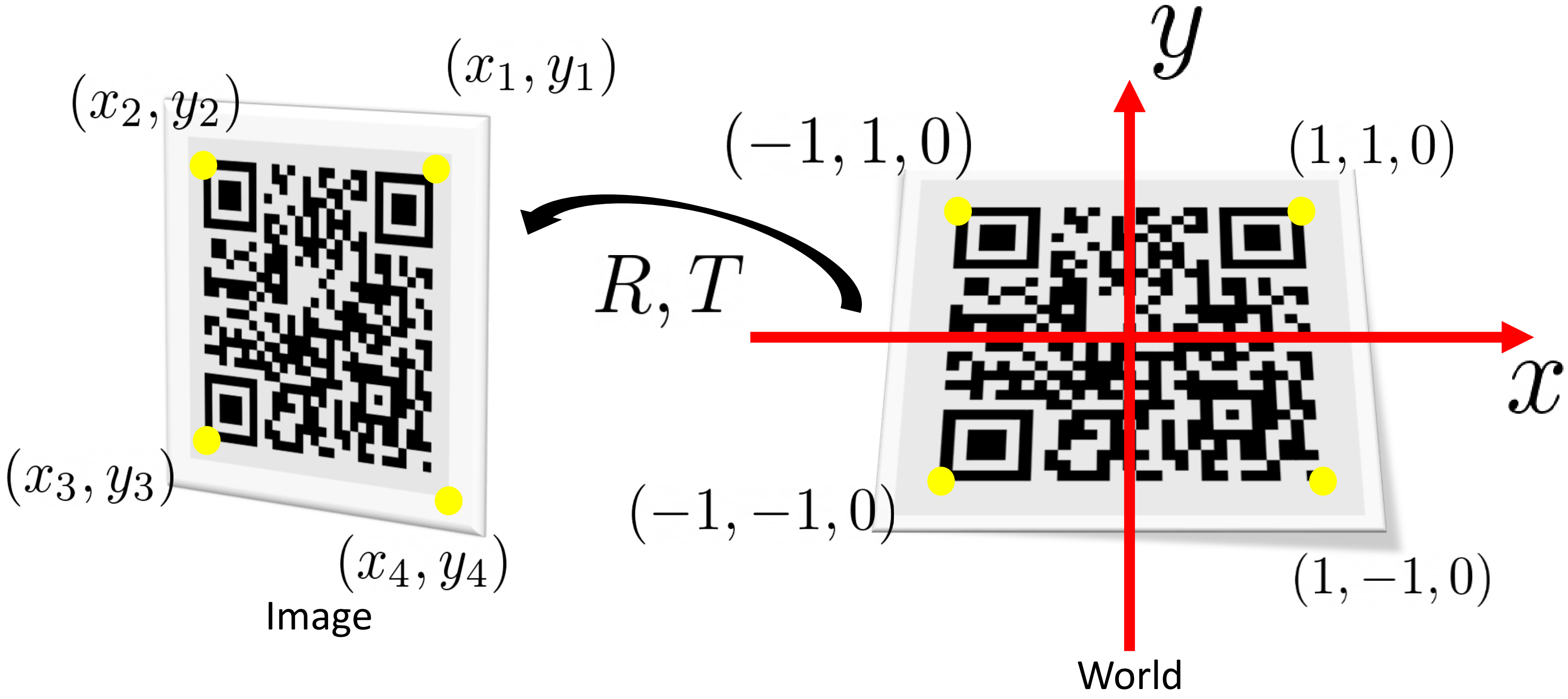
- Tracking the user's sense organs
  - E.g., Head and eye
  - Render stimulus accordingly

- Tracking user's other body parts
  - E.g., human body and hands
  - Locomotion and manipulation

- Tracking the rest of the environment
  - Augmented reality
  - Obstacle avoidance in the real world

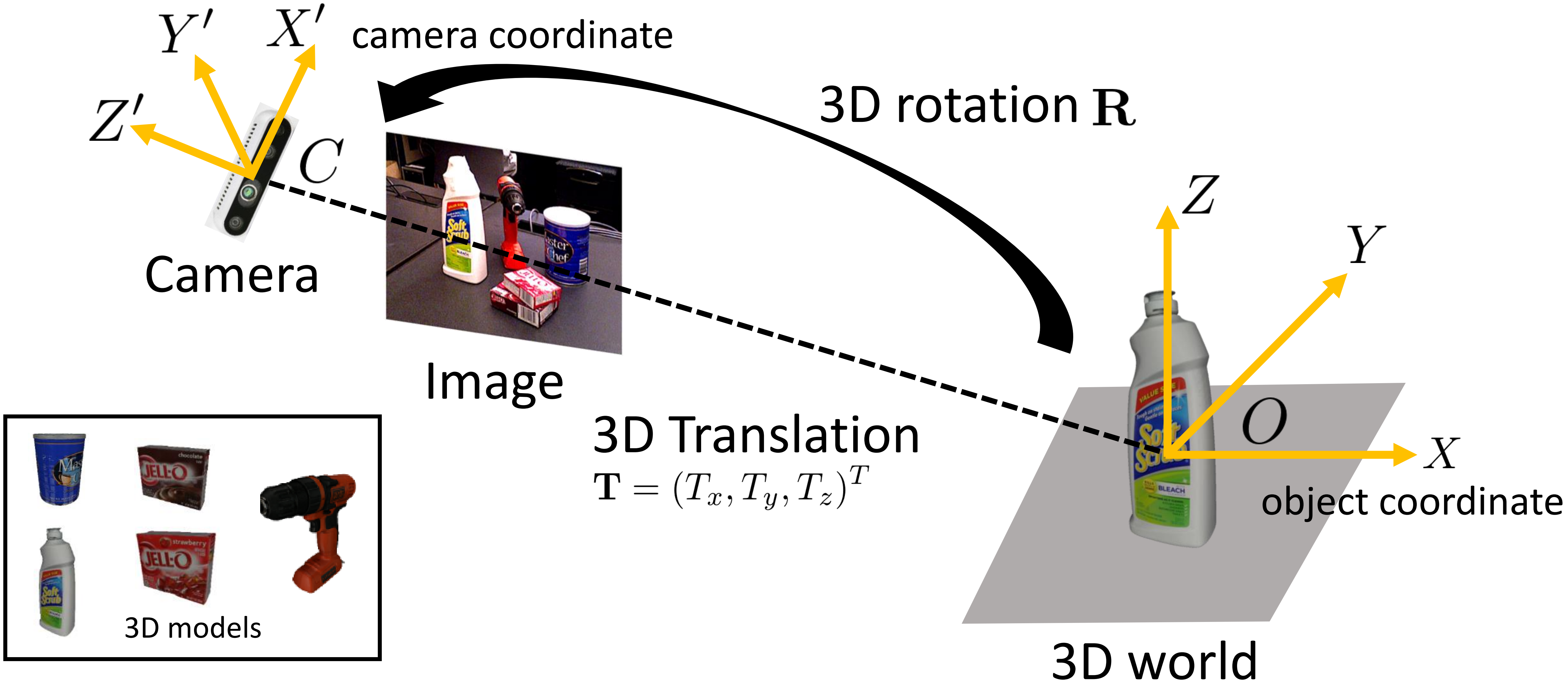
Tracking Objects in the Real World

- AR tags



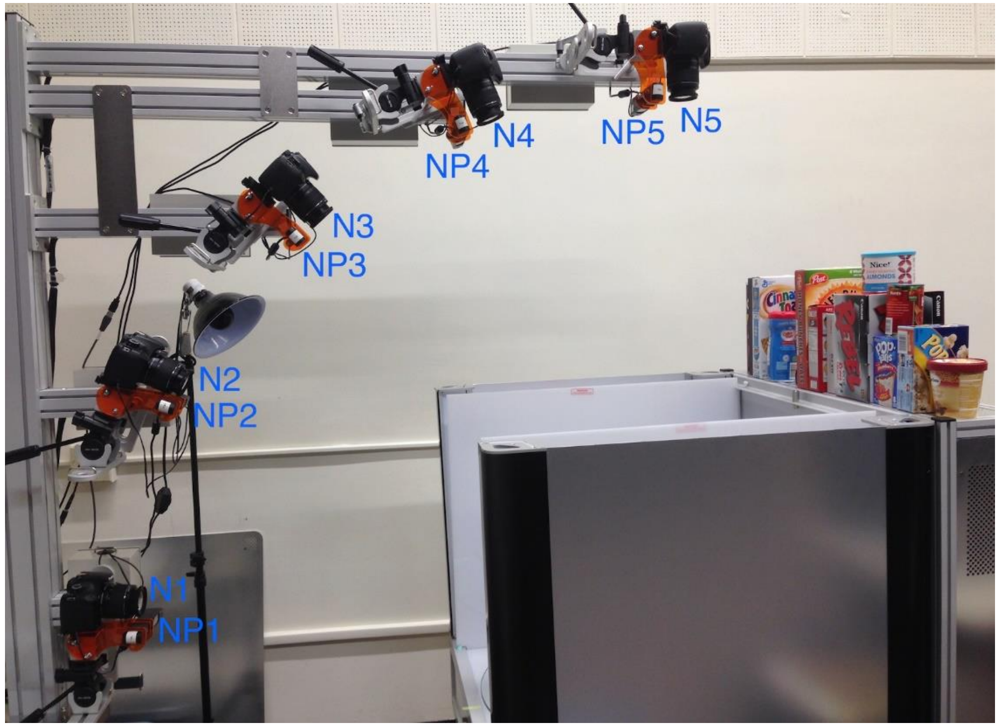
How about tracking general objects in the world?

6D Object Pose Estimation



Building 3D Object Models

- 3D reconstruction from multiple images



Berkeley Instance Recognition Dataset. Singh et al., ICRA, 2014

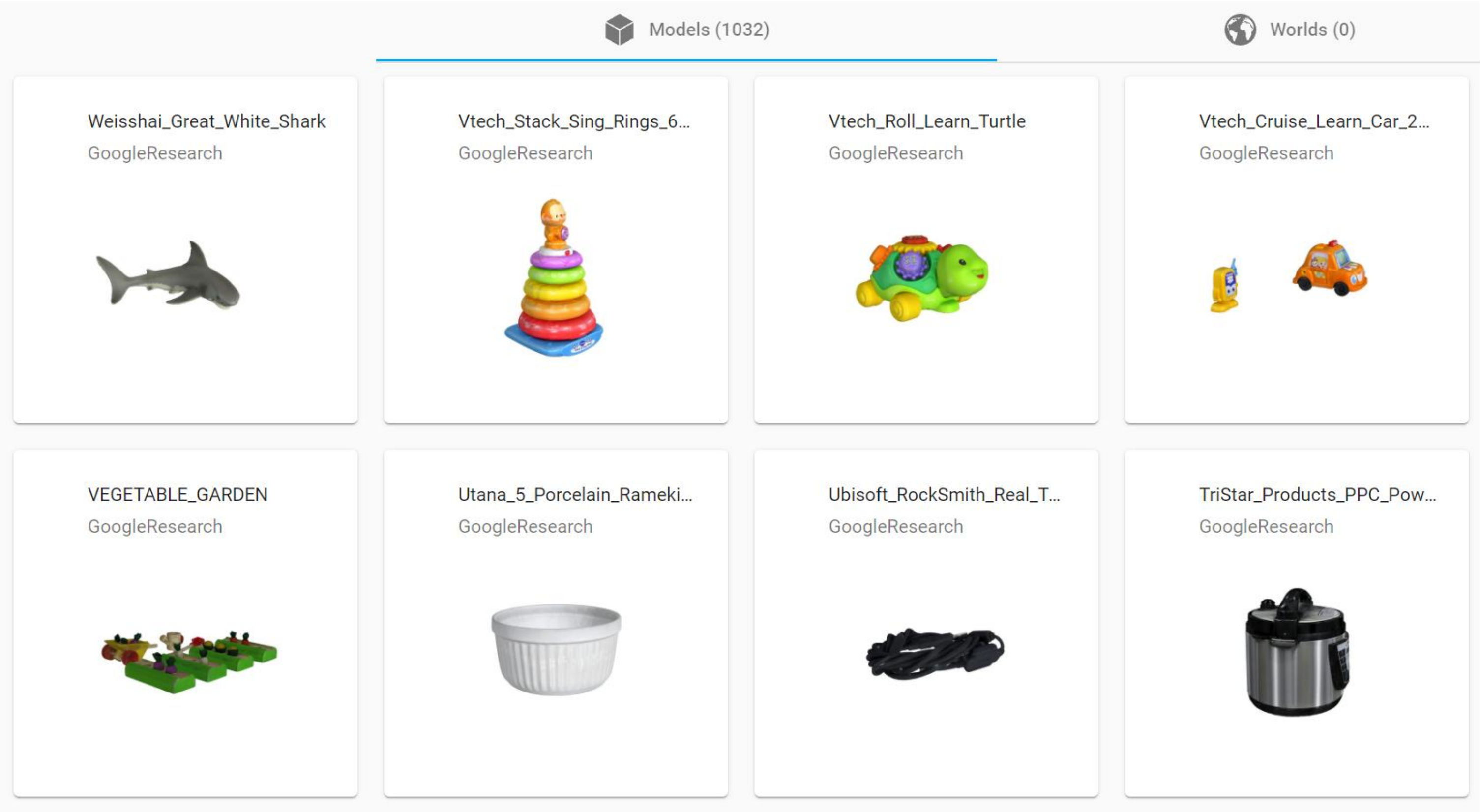
Building 3D Object Models

- A 3D reconstruction example

https://blog.kitware.com/3d-reconstruction-from-smartphone-videos/

Building 3D Object Models

- 3D Scanning



https://app.ignitionrobotics.org/GoogleResearch/fuel/collections/Google%20Scanned%20Objects

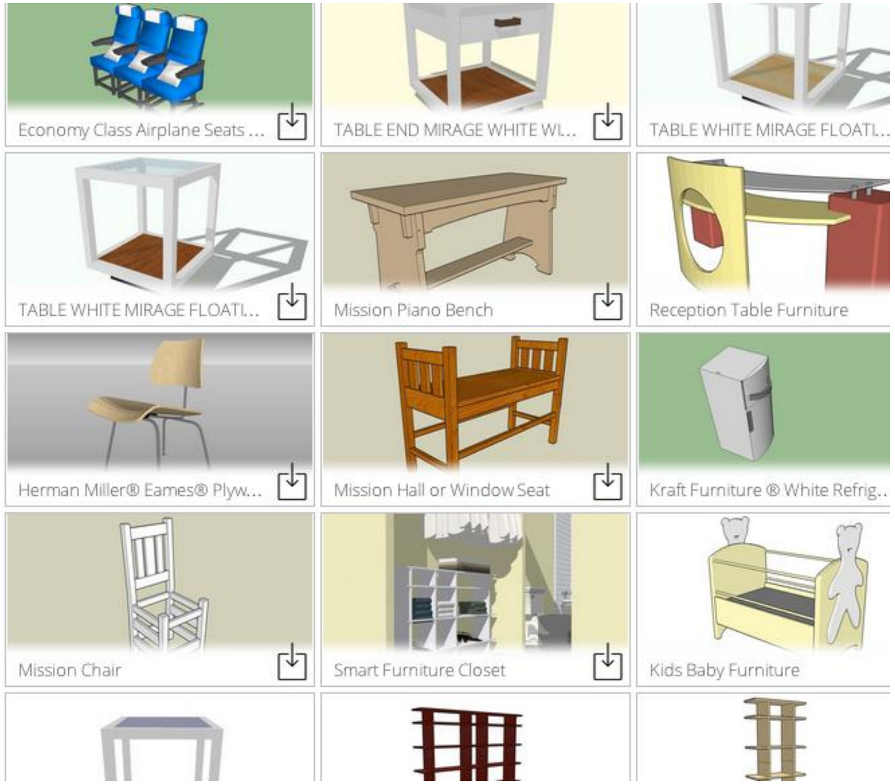
Building 3D Object Models

- 3D Scanning

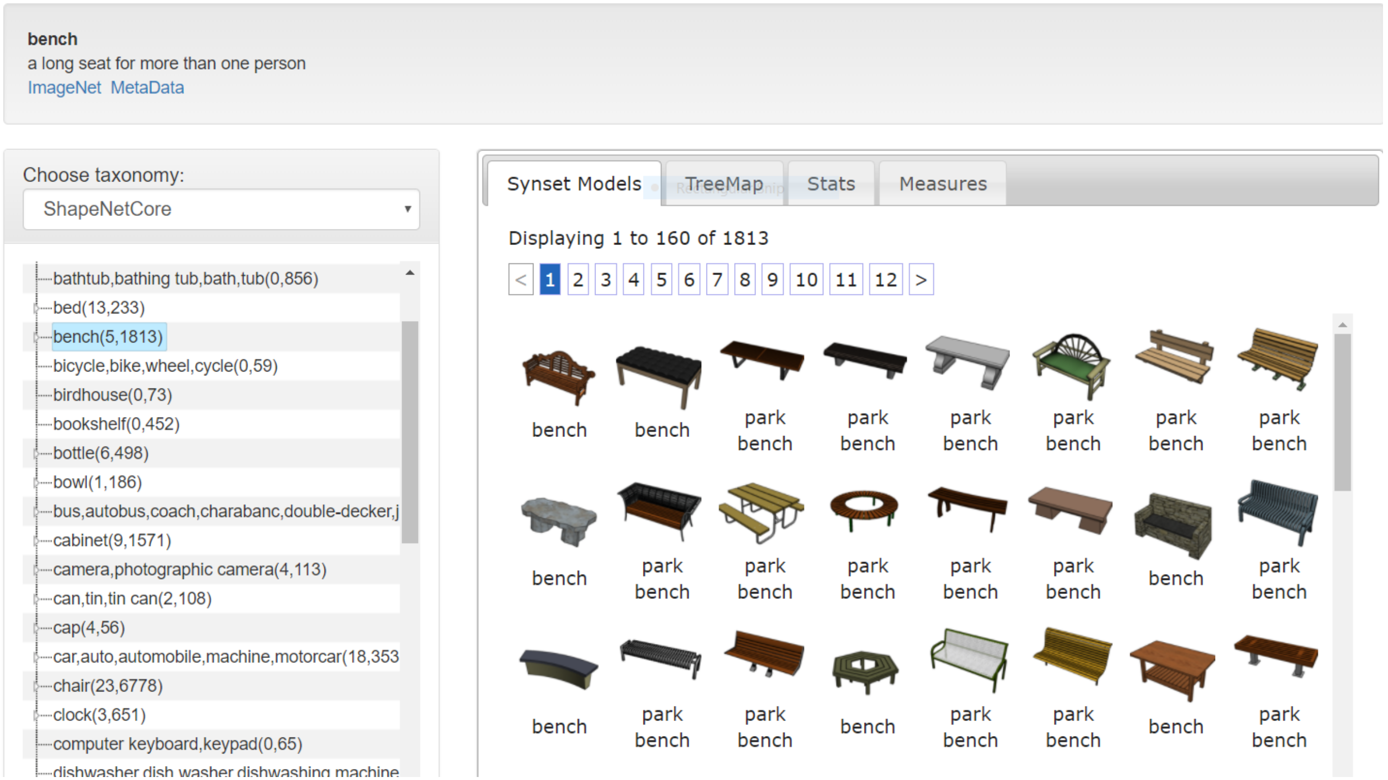
https://3dscanexpert.com/shining-3d-einscan-pro-3d-scanner-review/

Building 3D Object Models

- 3D CAD models



Trimble 3D Warehouse
https://3dwarehouse.sketchup.com

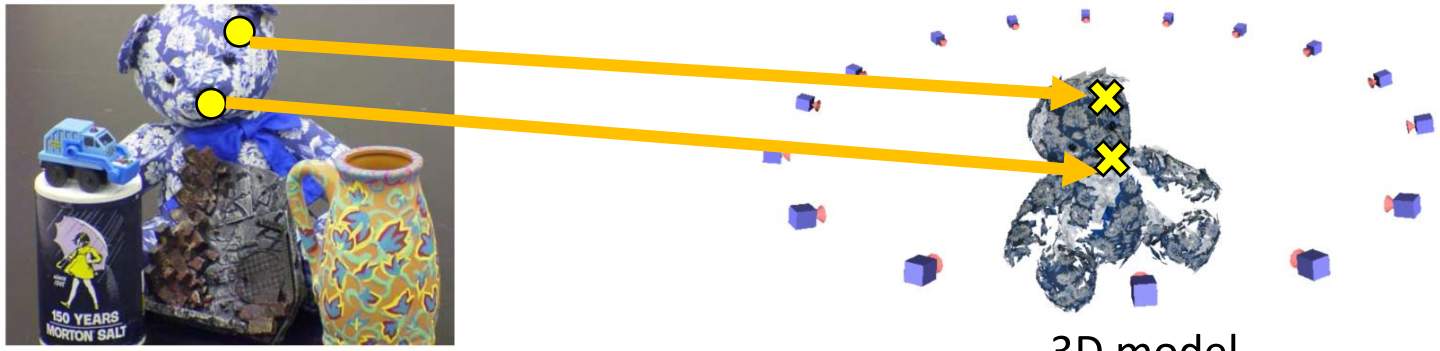


ShapeNet
https://www.shapenet.org/

6D Object Pose Estimation

- Feature matching-based methods

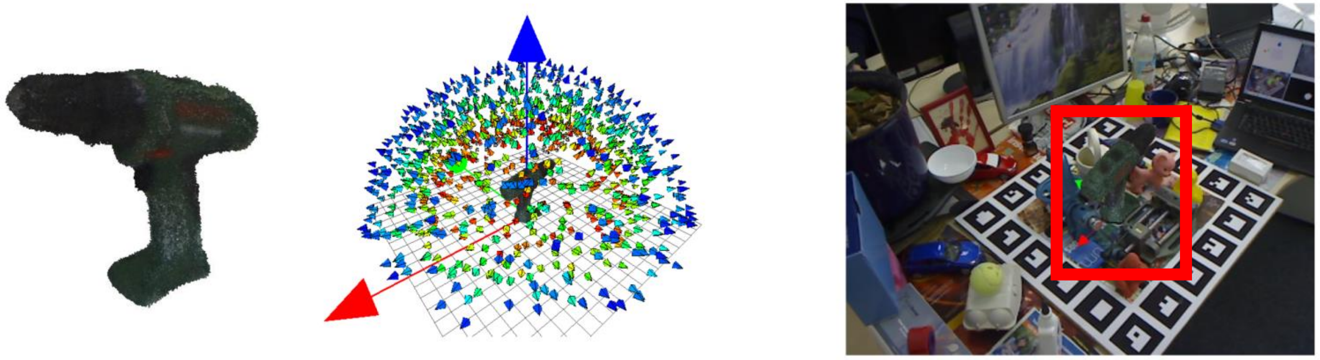
Rothganger et al., IJCV, 2006



2D image

3D model

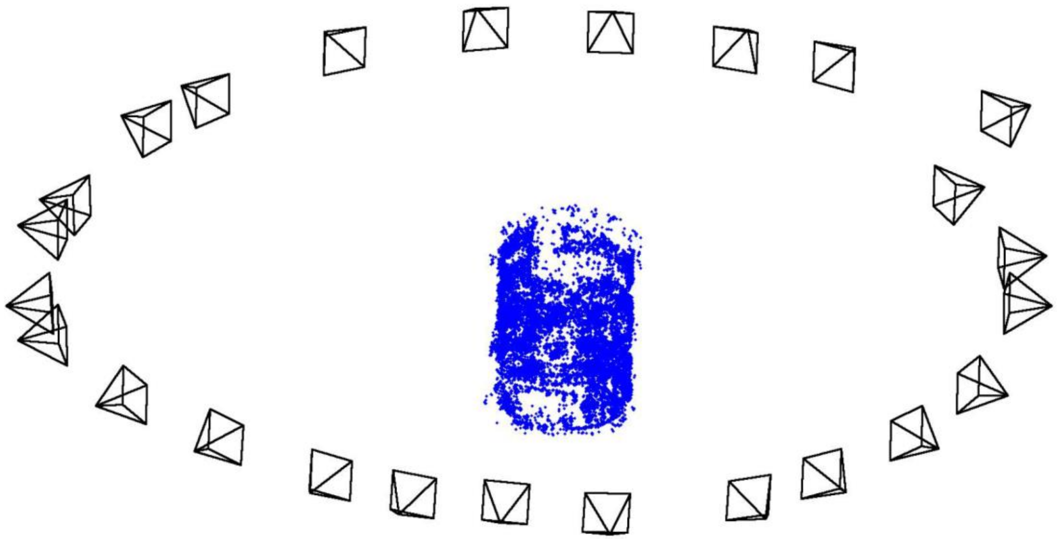
- Template matching-based methods



Hinterstoisser et al., ACCV, 2012

A Case Study for Feature Matching

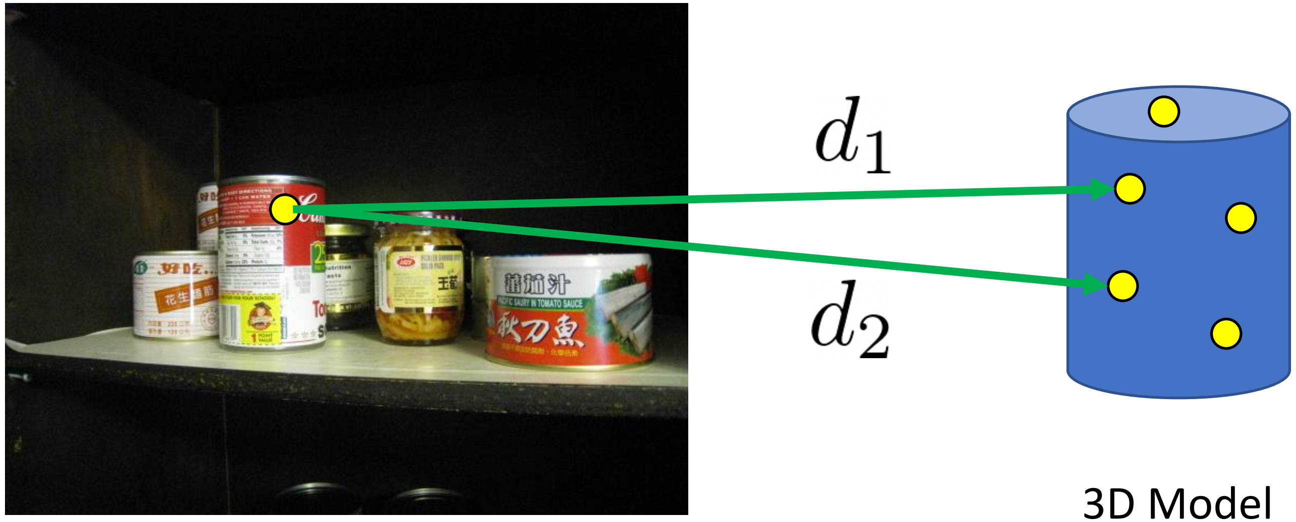
- 3D Models of Objects using Structure from Motion
  - 3D points with SIFT descriptors (each 3D point can have a list of descriptors or use the mean of the descriptors)



Making specific features less discriminative to improve point-based 3D object recognition. Hsiao, Collet and Hebert. CVPR’10.

A Case Study for Feature Matching

- Ratio test



Query Image

3D Model

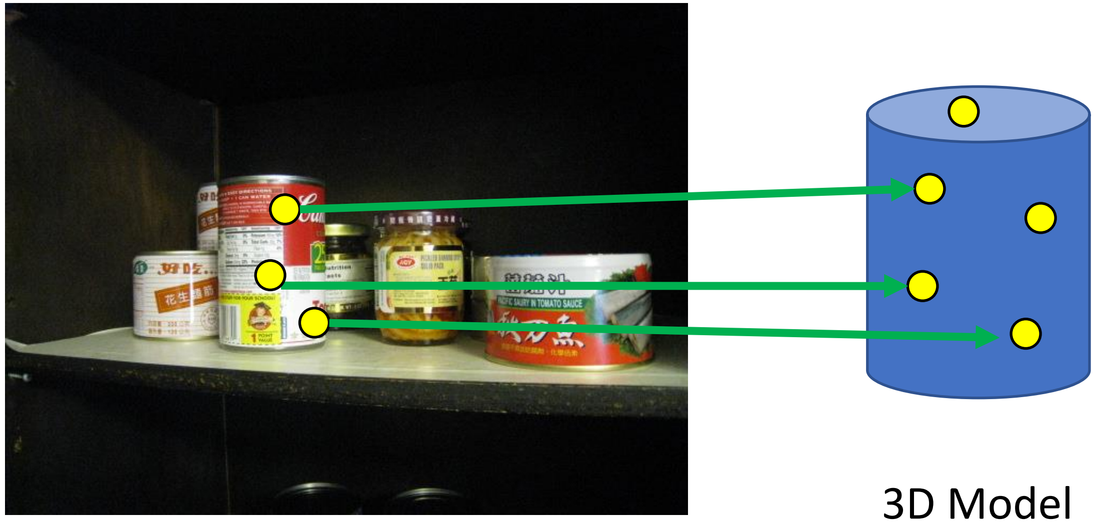
Distance to closest 3D point

$$\text{ratio} = \frac{d_1}{d_2} < 0.8$$

Distance to second closest 3D point

A Case Study for Feature Matching

- 3D-2D correspondences from feature matching $(\mathbf{X}_i, \mathbf{x}_i)_{i=1}^N$



Query Image

3D Model

Option 1: minimizing reprojection error

- Levenberg-Marquardt

$$g(\mathbf{R}, \mathbf{T}) = \sum_{i=1}^{N} \| P(\mathbf{X}_i, \mathbf{R}, \mathbf{T}) - \mathbf{x}_i \|^2$$

Option 2: solve the PnP problem

- EPnP

Random Sample Consensus (RANSAC)

- An iterative method for parameter estimation from a set of observed data that contains **outliers**

RANSAC Algorithm {

1. Selects N data items as random
2. Estimates parameter $\vec{x}$
3. Finds how many data items (of M) fit the model with parameter vector $\vec{x}$ within a user given tolerance. Call this K.
4. If K is big enough, accept fit and exit with success.
5. Repeat step 1 until 4 (as Ltimes)
6. Algorithm will be exit with fail

}

Sample N 3D-2D correspondences $(\mathbf{X}_i, \mathbf{x}_i)_{i=1}^{N}$

Estimate $(\mathbf{R}, \mathbf{T})$

Find how many $(\mathbf{X}_i, \mathbf{x}_i)$ obeys $(\mathbf{R}, \mathbf{T})$

A Case Study for Feature Matching

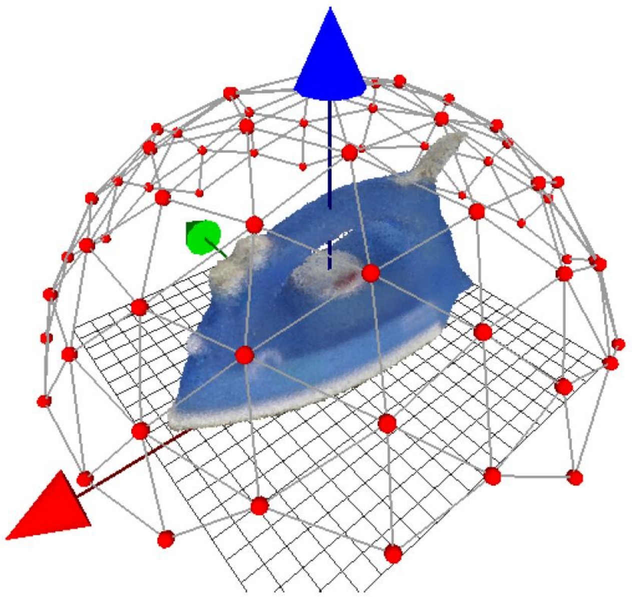
- Pose estimation examples

3D models

Making specific features less discriminative to improve point-based 3D object recognition. Hsiao, Collet and Hebert. CVPR’10.

A Case Study for Template Matching

- Render 3D models of objects to obtain template images

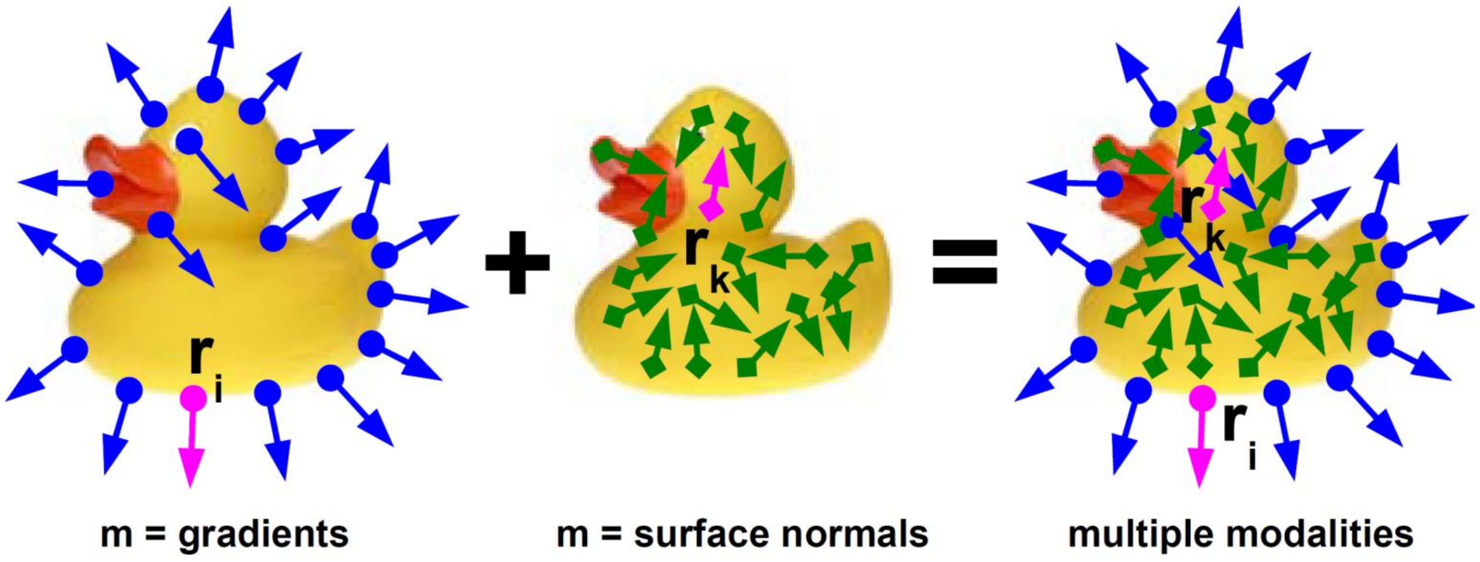


Viewpoint sampling

Model Based Training, Detection and Pose Estimation of Texture-Less 3D Objects in Heavily Cluttered Scenes. Hinterstoisser et al., ACCV'12.

A Case Study for Template Matching

- Compute color and depth features for each template image



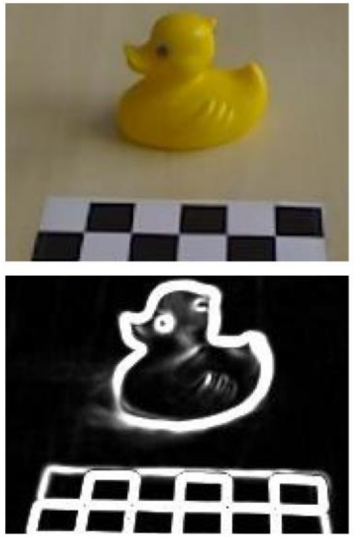
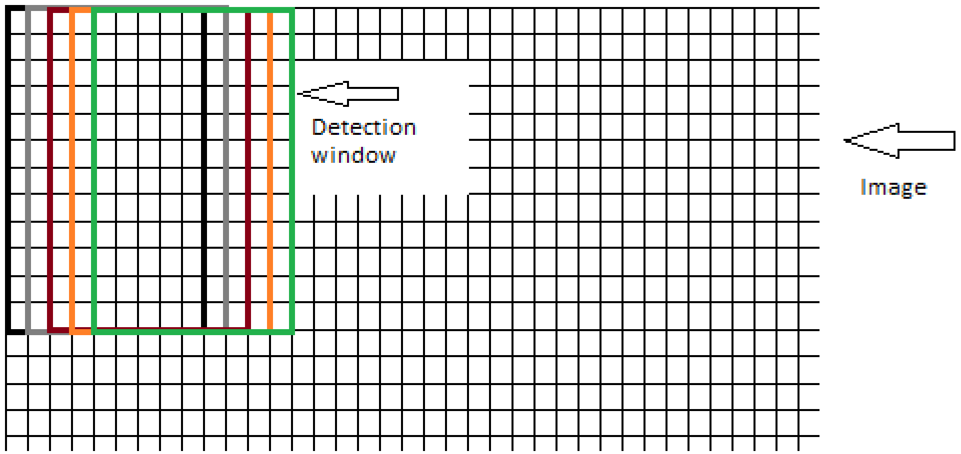


Image gradients

Model Based Training, Detection and Pose Estimation of Texture-Less 3D Objects in Heavily Cluttered Scenes. Hinterstoisser et al., ACCV'12.

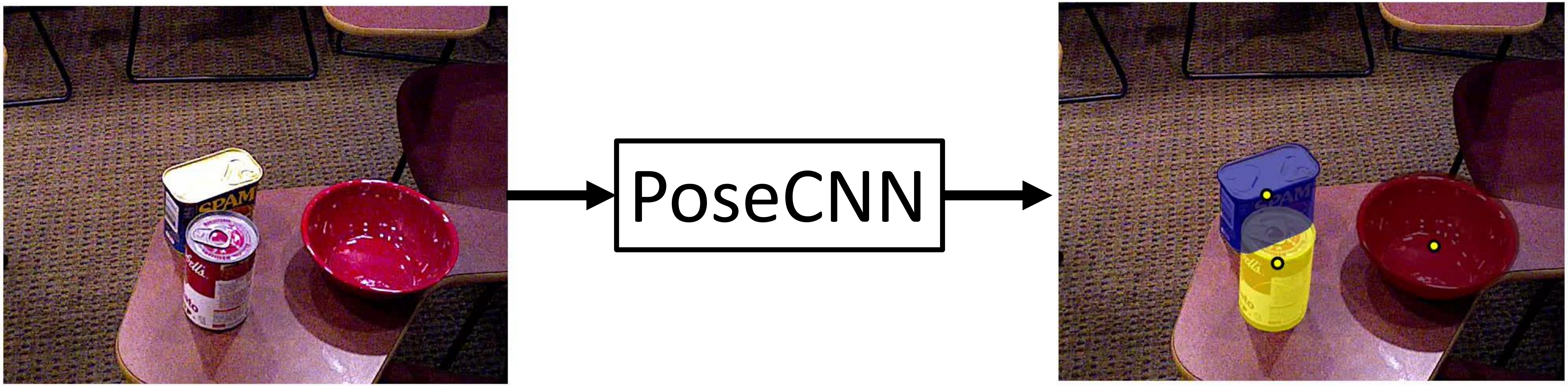
A Case Study for Template Matching

- Apply the templates to an input image for detection and pose estimation (sliding window)
  - Each template is associated with a 6D pose



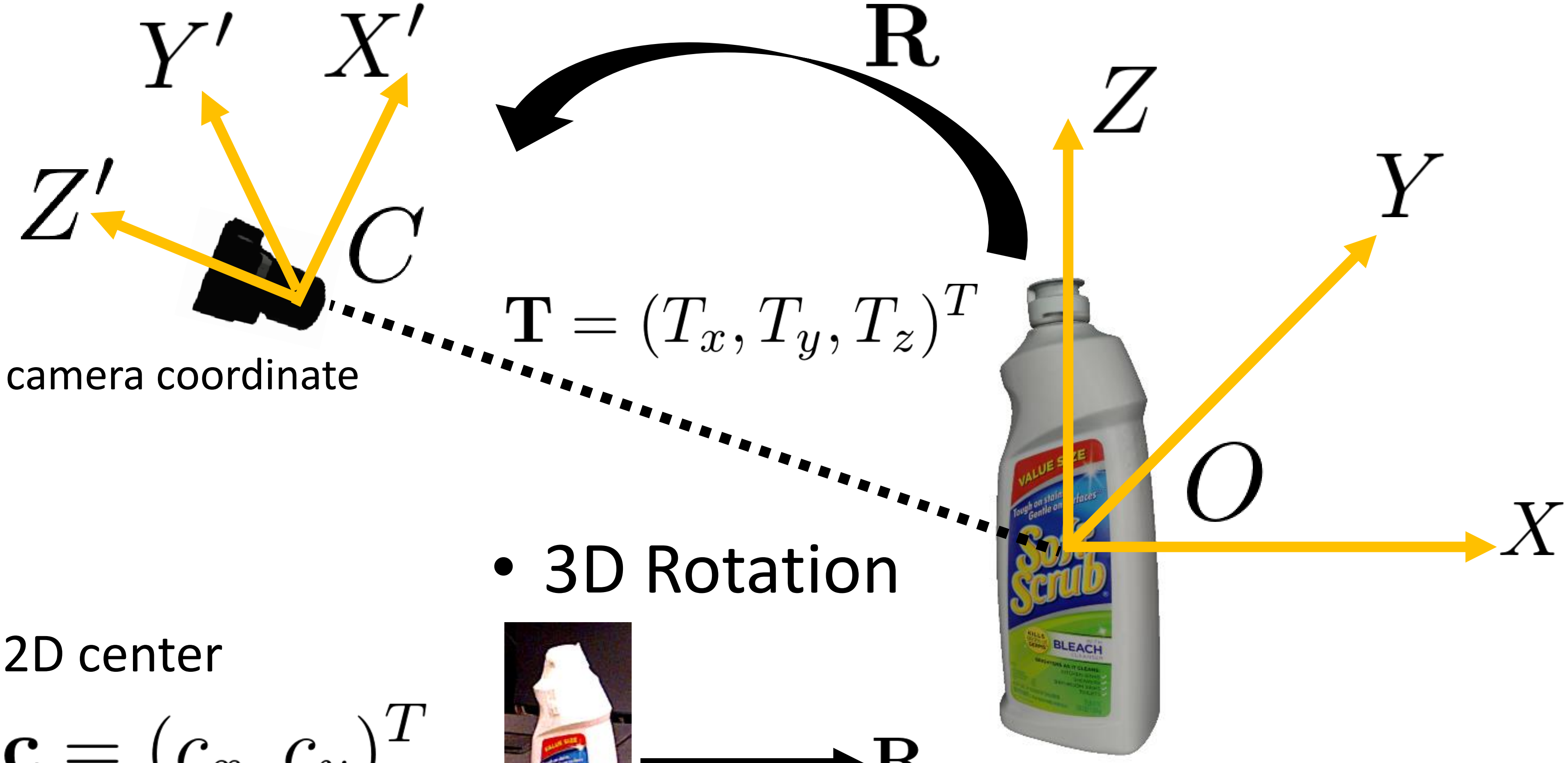
Model Based Training, Detection and Pose Estimation of Texture-Less 3D Objects in Heavily Cluttered Scenes. Hinterstoisser et al., ACCV’12.

PoseCNN



Y. Xiang, T. Schmidt, V. Narayanan and D. Fox. PoseCNN: A Convolutional Neural Network for 6D Object Pose Estimation in Cluttered Scenes. In RSS'18.

PoseCNN: Decouple 3D Translation and 3D Rotation



- 3D Translation

2D center

$\mathbf{c} = (c_x, c_y)^T$

Distance T_z

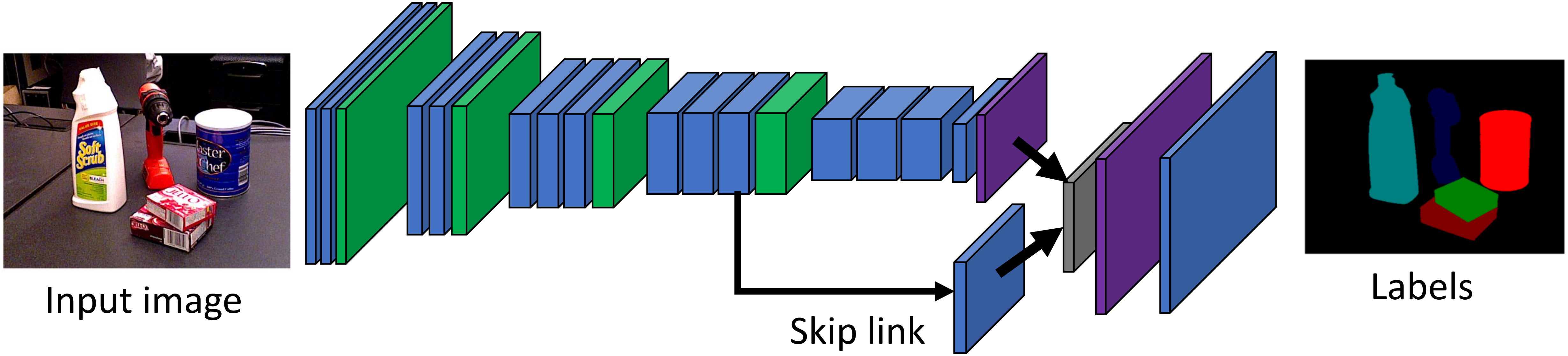
2D Center Localization

- 3D Rotation

$\longrightarrow \mathbf{R}$

3D Rotation Regression

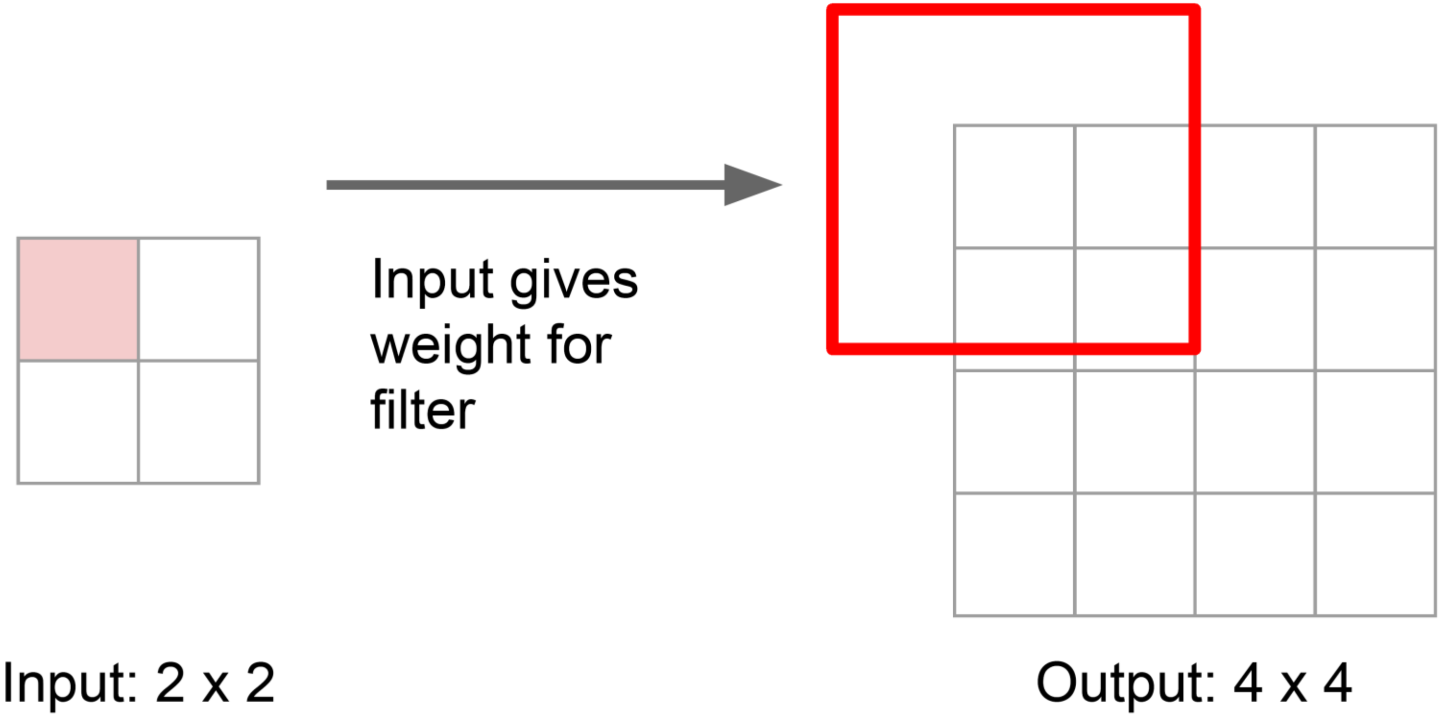
PoseCNN: Semantic Labeling



Fully convolutional network

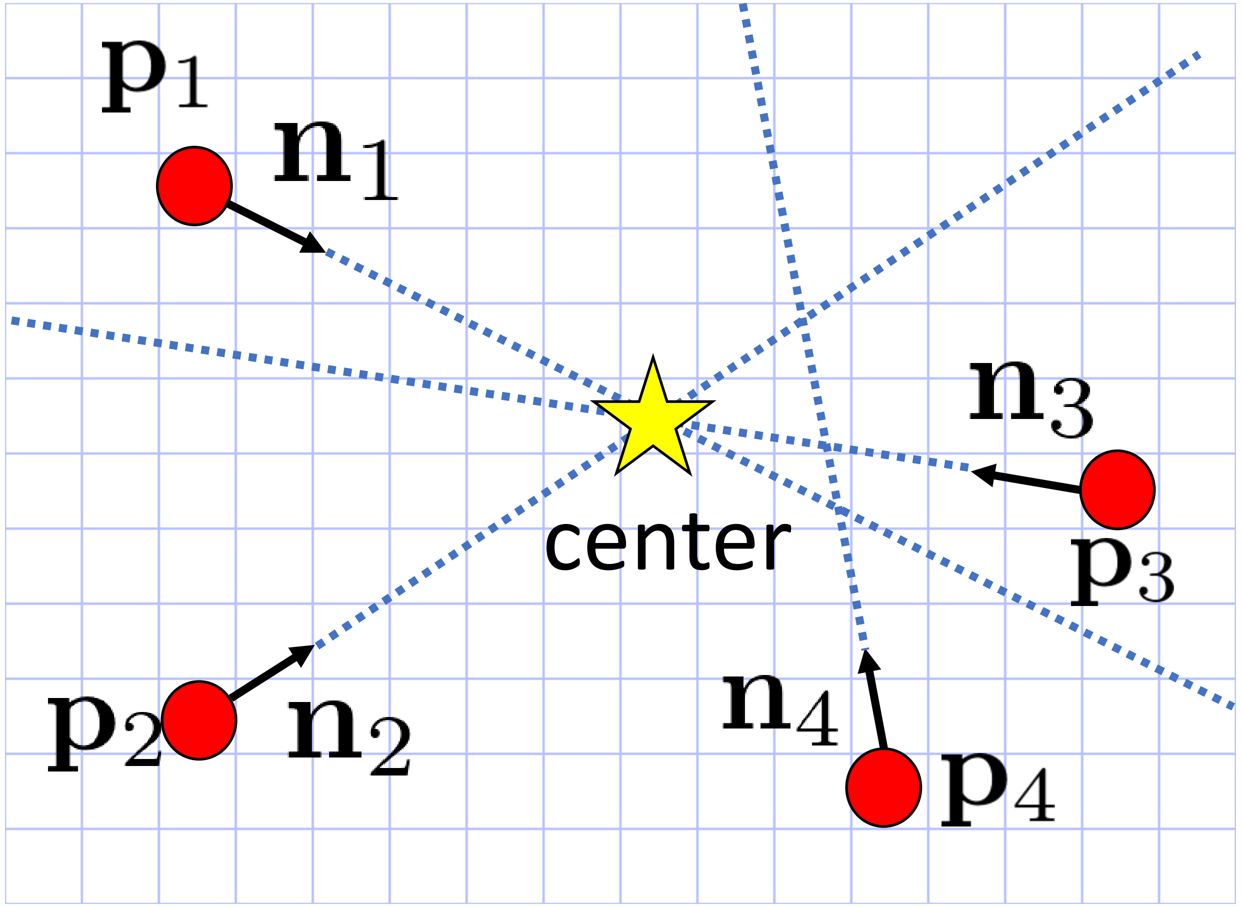
Deconvolution

3 x 3 "deconvolution", stride 2 pad 1

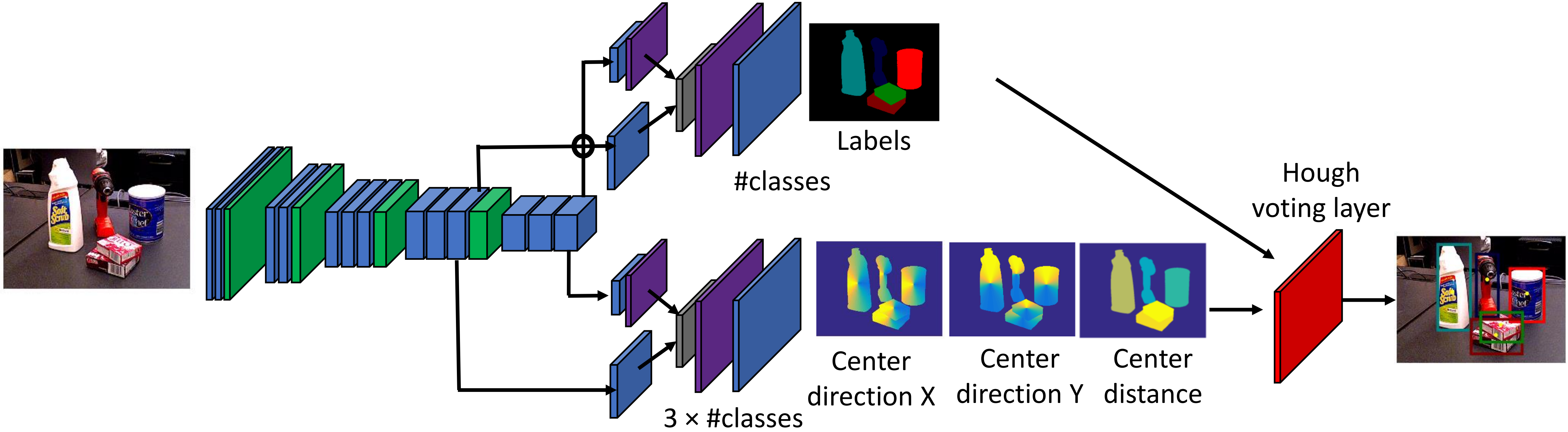


Credit: Andrej Karpathy & Justin Johnson

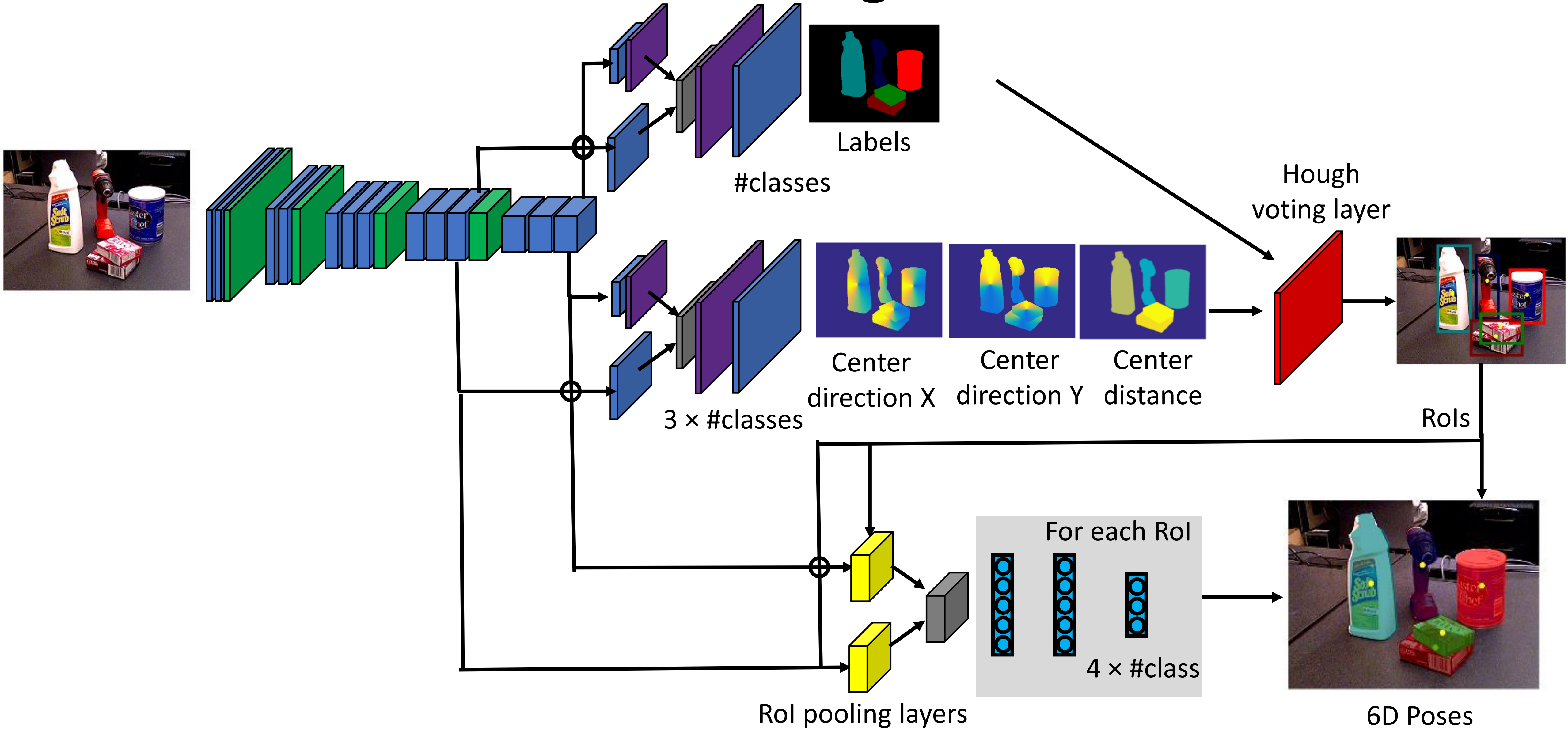
PoseCNN: 2D Center Voting for Handling Occlusions



PoseCNN: 3D Translation Estimation



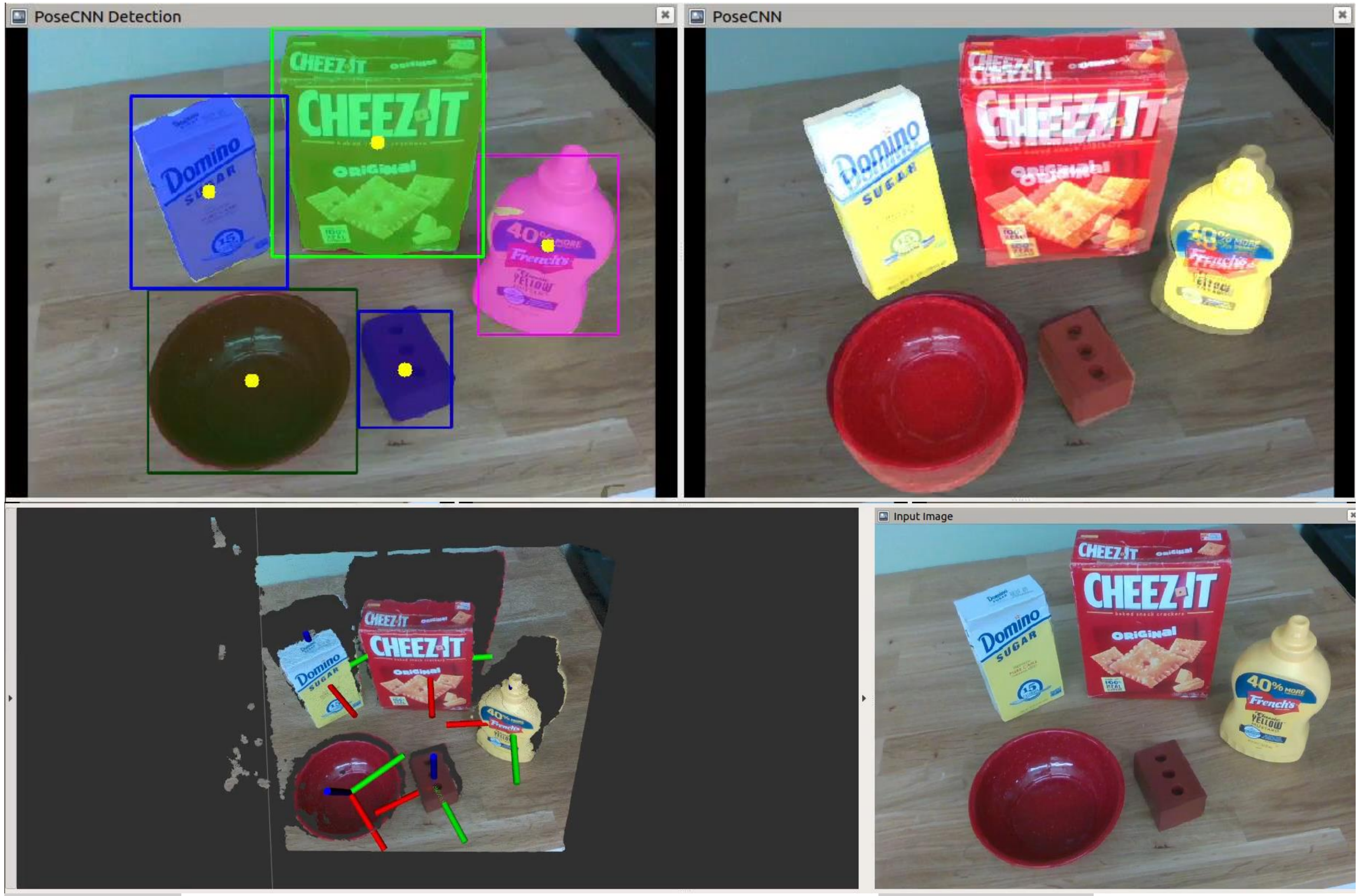
PoseCNN: 3D Rotation Regression



PoseCNN

Segmentation and Detection

Poses



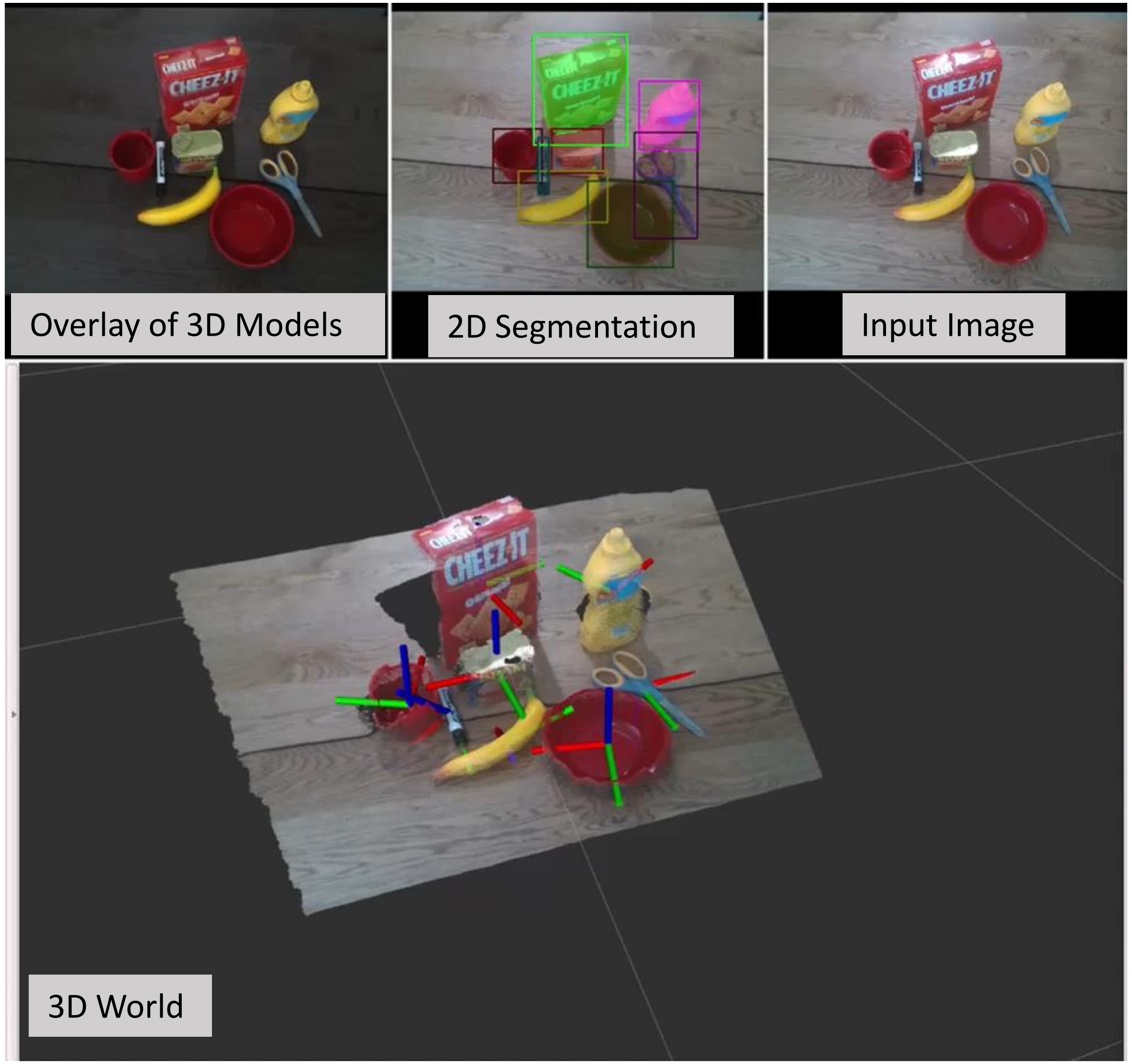
3D World

Input image

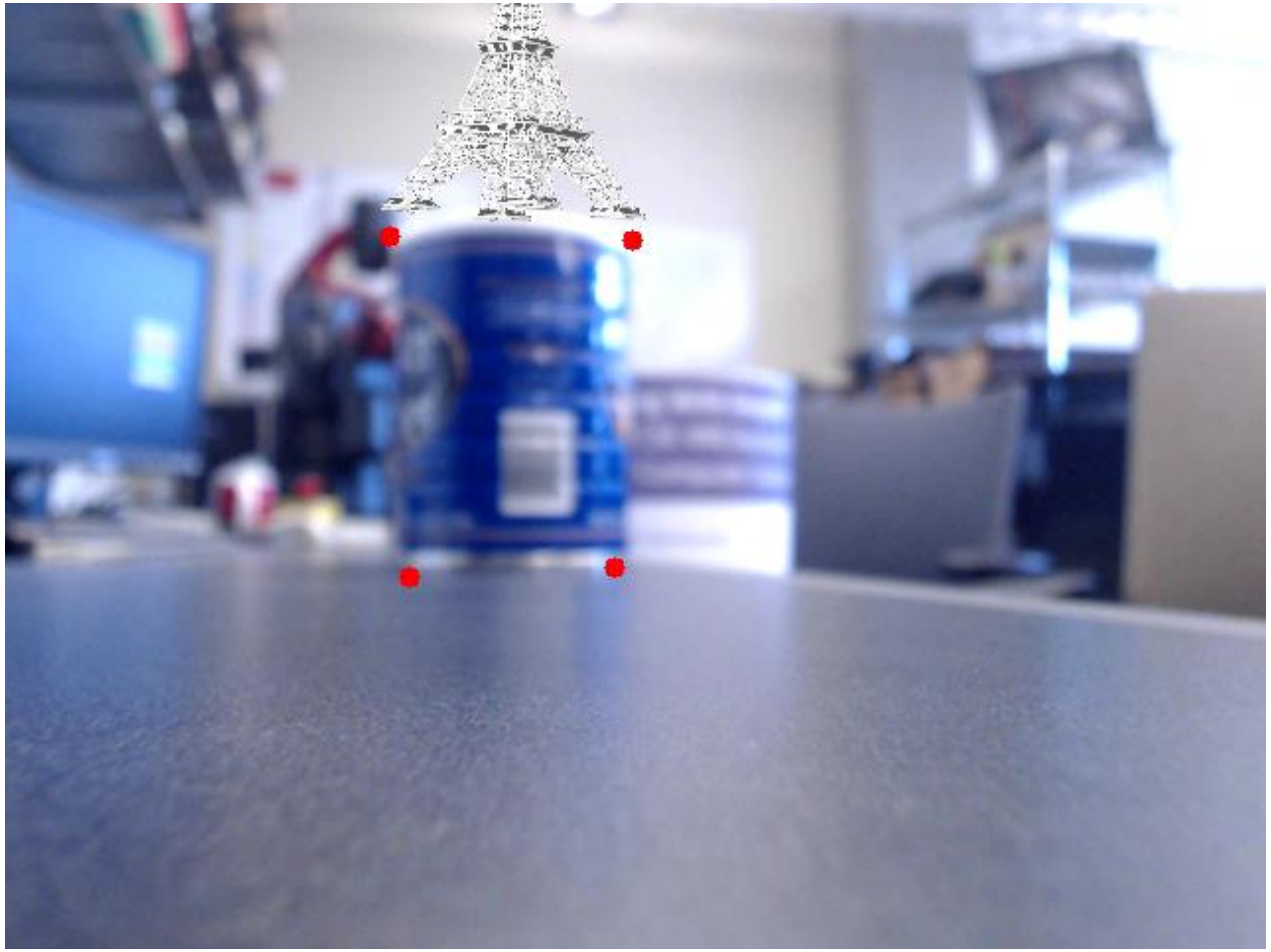
6D Object Pose Tracking

3D models

PoseRBPF: Deng et al., RSS'19



AR Demo with 6D Pose Estimation



DeepIM, Li et al., IJCV'19

Credit: Lirui Wang

Further Reading

- Making specific features less discriminative to improve point-based 3D object recognition. Hsiao, Collet and Hebert. CVPR'10.
- Model Based Training, Detection and Pose Estimation of Texture-Less 3D Objects in Heavily Cluttered Scenes. Hinterstoisser et al., ACCV'12.
- PoseCNN: A Convolutional Neural Network for 6D Object Pose Estimation in Cluttered Scenes. Xiang et al., RSS'18.