

# Coupled Joint Registration and Co-segmentation for Indoor Rigid Object Sets

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## Abstract

**Keywords:** Co-segmentation, Joint Registration

**Concepts:** •Computing methodologies → Image manipulation; Computational photography;

## 1 Introduction

In many researches and applications of indoor scenes the data of segmented and even annotated 3D indoor scenes are required as either data base or training data (e.g.[Dema and Sari-Sarraf 2012][Fisher et al. 2012][Chen et al. 2014][Fisher et al. 2015]). One way to build such data base is to interactively compose scenes from 3D shape models resulting in scenes with object segmentation and annotation naturally available, or to manually segment and annotate existing scenes. This procedure can be tedious and time consuming, despite the efforts to improve the interaction experience(e.g.[Merrell et al. 2011][Xu et al. 2013]).

Another way is to automatically generate scenes from 3D shape models according to the input RGB or RGB-D images(e.g.[Liu et al. 2015][Chen et al. 2014]). In such methods, a retrieval procedure is usually needed and inevitably limit the result to a certain set of 3D models despite the actual 3D model in the input images.

We prefer a approach that helps us build such data set directly from the captured data. One of the major gap between the required data set and available scene capturing framework(e.g.[Izadi et al. 2011]) is the general object level segmentation. We want to stress that a general object level segmentation problem should not be treated as an equivalence of multilabel classification problem since it is not limited to a certain set of objects. For 3D data, [Jia et al. 2015] used some simplified physical prior knowledge (i.e. the block based stability) to help achieving the general object segmentation, while the work of [Xu et al. 2015] proposes a practical and rather complete framework to close the gap between the required data set and available scene capturing method. One of the observation in [Xu et al. 2015] is that the motion consistency of rigid object can serve as a strong evidence of general objectness. To exploit this fact, they employ a robot to do proactive push and use the movement tracking to verify and iteratively improve their object level segmentation result. Our work presented in this paper is trying to exploit the same observation from a different approach.

We intend to use the motion consistency that is naturally revealed by human activities along the time. Down to this approach, we are facing the choice of scanning scheme. One way is to record the change of the scene along with the human activities, another is to arrange a daily or even a once every half day sweep to only record the result of human activities but avoid the instant of human motion. The main challenge brought in by the second scheme is that we may not be able to solve the object correspondence by a local search due to the sparse sampling over time, but the very same

challenge exists in the first scheme due to the exclusion caused by human bodies not to mention other additional process(e.g. tracking and segment) needed for human bodies. With the second scanning scheme, our original intention of building 3D scene data set from capturing naturally leads us to the problem of coupled joint registration and co-segmentation. In this problem,

## 2 Related Work

### 2.1 Functional Mapping

The Coupled Joint Registration and Co-segmentation problem addressed here is essentially a problem of point-to-point correspondence problem. A series of work based on the functional maps representation advocated in [Ovsjanikov et al. 2012] have been done. In one of the most recent work [Maron et al. 2016], a convex relaxation technique was used to better approximate the global minimal for both rigid and non-rigid registration problem.

## 3 Method Overview

### 3.1 Problem Statement

Given a set of point clouds which record the same group of rigid indoor objects with different layout. We intend to simultaneously partition the point clouds into objects and align the points of same object to recover layouts for corresponding object. Figure ?? shows an example of input point clouds set.

### 3.2 Formulation

To formulate the relation between the unknown object set and the input point clouds. We come up with a generation model as follows:

$$P(v_{mi}) = \sum_{n=1}^N p_n \sum_{k=1}^{K_n} p_k N(\phi_{mn}(v_{mi})|x_k, \Sigma_k) \quad (1)$$

which means, The observed point clouds are generated by  $N$  object model. Each object model is represented by a gaussian mixture model with  $K_n$  centroids. Our goal is to maximize the probability of the expected complete-data log-likelihood. The object function can be written as:

$$\Theta = \operatorname{argmax}_{\Theta} \sum_Z P(Z|V, \Theta) \ln P(V, Z; \Theta) \quad (2)$$

in which:

$$\Theta = \{\{p_n\}_{n=1}^N, \{p_k, x_k, \Sigma_k\}_{k=1}^{K_n}, \{\phi_{mn}\}_{m=1, n=1}^{MN}\}$$

is the parameters of the generation model.

$p_n$  is the prior probability that the point is generated by the  $n$ -th object.

$p_k$  is the weight of the  $k$ -th Gaussian.

$x_k$  is the center of the  $k$ -th Gaussian.

$\Sigma_k$  is the standard deviation of the  $k$ -th Gaussian.

There are  $\sum K_n$  Gaussian model in total and among them,  $K_n$  Gaussian models belongs to object  $n$ .

$V$  is the  $M$  input point clouds.

$v_{mi}$  is the  $i$ -th point of the  $m$ -th point cloud.

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SIGGRAPH 2016 Posters, July 24-28, 2016, Anaheim, CA

ISBN: 978-1-4503-ABCD-E/16/07

DOI: <http://doi.acm.org/10.1145/9999997.9999999>

$Z$  is a latent variable set defined as:

$$Z = \{z_{ij} | j = 1 \dots M, i = 1 \dots N_j\}$$

among which if  $z_{ij} = k (k = 1 \dots \sum K_n)$  assign the observation of  $\phi_{mn}(v_{mi})$  to the  $k$ -th component of Gaussian mixture model. Such formulation can be seen as an extension of joint registration formulation in [?], upon which we add several gaussian mixture model together to express a group of objects. By solving this new problem we simultaneously solve the object co-segmentation of given observation.

## 4 Algorithms and Implementation

### 4.1 Expectation Conditional Maximization

Assuming the observed point clouds  $\{V_m\}$  are independent and identically distributed, we can then write the (2) as:

$$\varepsilon(\Theta | V, Z) = \sum_{m,i,k} \alpha_{mik} (\log p_n + \log p_k + \log P(\phi_{nm}(v_{mi}) | z_{ji} = k; \Theta)) \quad (3)$$

In which the  $\alpha_{mik} = P(z_{mi} = k | v_{mi}; \Theta)$ ,

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#### Algorithm 1 Joint Registration and Co-segmentation (JRCS)

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##### Input:

$\{V_m\}$ : Observed point clouds

$\{\alpha_{mik}^0\}$ : Initial posterior probabilities

##### Output:

$\Theta^q$ : Final parameter set

1.  $q \leftarrow 0$
  2. **repeat**
  3. CM-step-a: Use  $\alpha_{mik}^q, x_k^{q-1}$  to estimate  $\{R_{mn}^q\}$  and  $\{t_{mn}^q\}$
  4. CM-step-b: Use  $\alpha_{mik}^q, \{R_{mn}^q\}$  and  $\{t_{mn}^q\}$  to estimate the Gaussian centers  $x_k^q$
  5. CM-step-c: Use  $\alpha_{mik}^q, \{R_{mn}^q\}$  and  $\{t_{mn}^q\}$  to estimate the covariances  $\Sigma_k^q$
  6. CM-step-d: Use  $\alpha_{mik}^q$  to estimate the priors  $p_k^q, p_n^q$
  7. E-step: Use  $\Theta^{q-1}$  to estimate posterior probabilities.  $\alpha_{mik}^q = P(z_{mi} | v_{mi}; \Theta^{q-1})$
  8.  $q \leftarrow q + 1$
  9. **until** Convergence
  10. **return**  $\Theta^q$
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### 4.2 Initialization Techniques

A key advantage motivates our formulation is that the soft correspondence can be initialized more flexibly comparing to the typical initialization techniques such as landmark point pairs in registration.

#### Initial Segment based on Planar Fitting

#### Block Based Feature Extraction and Clustering

The result of Clustering:

$$P(B_{mj} \in C_n)$$

#### Soft Correspondence Initialization

Then the  $\alpha$  is initialized as:

$$\alpha_{ijk} = P(B_{mj} \in C_n)$$

on the condition that:

$$v_{ij} \in B_{mj} \wedge x_k \in O_n$$

## 5 Experiments and Discussion

### 5.1 Debugging The Smooth Step

### 5.2 Current Result

### 5.3 Initialization Experiments

## Acknowledgements

To Robert, for all the bagels.

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