In [1]:

```
import pandas as pd
import numpy as np
import seaborn as sns
import os
from tabulate import tabulate
```

Segmentation Method Comparison

Metrics: IoU(Intersection over Union), F1 score, false positive rate averaged on video frames

In [2]:

```
seg_results = pd.read_csv(os.path.join(os.getcwd(), "seg_comparison.csv"))
seg_results.head()
```

Out[2]:

	seg method	data type	object name	IoU	F1	FP rate
0	BackFlow	Data	YcbMustardBottle	0.907731	0.931602	0.076235
1	BackFlow	Data	YcbGelatinBox	0.883326	0.934864	0.115640
2	BackFlow	Data	YcbPottedMeatCan	0.898410	0.945141	0.097698
3	BackFlow	Data	YcbTomatoSoupCan	0.871855	0.929788	0.124419
4	BackFlow	Data	YcbCrackerBox	0.961743	0.978536	0.032422

In [3]:

```
seg_results.tail()
```

Out[3]:

	seg method	data type	object name	IoU	F1	FP rate
27	OSVOS	Data_stuck	YcbTomatoSoupCan	0.899331	0.946114	0.071509
28	OSVOS	Data_stuck	YcbCrackerBox	0.980633	0.990175	0.015067
29	OSVOS	Data_stuck	YcbSugarBox	0.905609	0.948766	0.048143
30	OSVOS	Data_stuck	YcbBanana	0.924367	0.960452	0.074216
31	OSVOS	Data_stuck	YcbTennisBall	0.886893	0.939427	0.111143

In [4]:

```
seg_method = seg_results['seg method'].unique()
table = []
for s in seg_method:
    table.append([str(s), np.mean(seg_results.loc[seg_results['seg method'] == s]['
                  np.mean(seg_results.loc[seg_results['seg method'] == s]['F1']),
                  np.mean(seg_results.loc[seg_results['seg method'] == s]['FP rate']
print(tabulate(table, headers=['seg method', 'mIoU','F1','FP rate']))
```

```
seg method        mIoU        F1    FP rate
------------  --------  --------  ---------
BackFlow      0.896087  0.939715  0.0879889
OSVOS         0.909781  0.950612  0.0719721
```

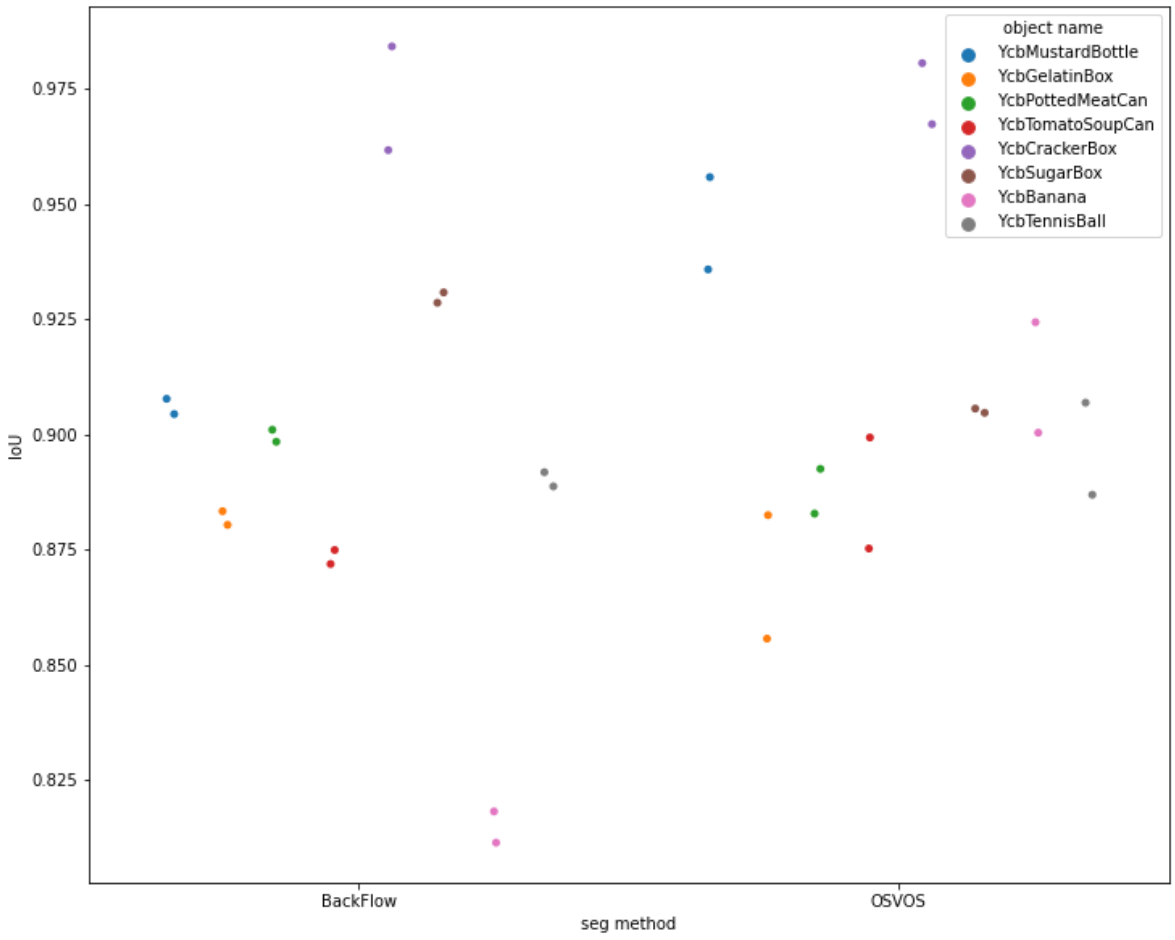
OSVOS performs better than BackFlow on three different metrics. Note that: FP rate is relatively more important for reconstruction, because it's worse if the background is involved in reconstructed model.

In [5]:

```
sns.set_context({"figure.figsize":(12,10)})
sns.stripplot(x="seg method",y="IoU",data=seg_results,jitter=True,hue="object name"
```

Out[5]:

```
<AxesSubplot:xlabel='seg method', ylabel='IoU'>
```



BackFlow works not so well on 'YcbBanana'.

Reconstruction Algorithm Comparison

Metrics: mean usdf(unsigned distance fields) averaged on points in point-cloud, mean and RMS hausdorff distance(calculated bi-directionally)

In [6]:

```
recon_results = pd.read_csv(os.path.join(os.getcwd(), "recon_comparison.csv"))
recon_results.head()
```

Out[6]:

	Data Path	Object Name	Segmentation Method	Reconstruction Method	mean usdf	mean sdf	mean squared sdf	
0	Data	YcbMustardBottle	BackFlow	point-to-plane	0.005118	0.004831	0.002085	0
1	Data	YcbMustardBottle	BackFlow	robot-joints	0.003591	-0.000722	0.000038	0
2	Data	YcbMustardBottle	OSVOS	point-to-plane	0.000976	0.000704	0.000033	0
3	Data	YcbMustardBottle	OSVOS	robot-joints	0.002858	-0.001444	0.000017	0
4	Data_stuck	YcbMustardBottle	BackFlow	point-to-plane	0.004801	0.004575	0.001804	0

In [7]:

```
recon_results.tail()
```

Out[7]:

	Data Path	Object Name	Segmentation Method	Reconstruction Method	mean usdf	mean sdf	mean squared sdf	
59	Data	YcbTennisBall	OSVOS	robot-joints	0.002057	-0.000395	0.000020	0.0
60	Data_stuck	YcbTennisBall	BackFlow	point-to-plane	0.454618	0.454606	0.272326	0.0
61	Data_stuck	YcbTennisBall	BackFlow	robot-joints	0.001534	0.001095	0.000025	0.0
62	Data_stuck	YcbTennisBall	OSVOS	point-to-plane	0.015826	0.015702	0.013439	0.0
63	Data_stuck	YcbTennisBall	OSVOS	robot-joints	0.001028	0.000571	0.000044	0.0

'Data Path'

```
'Data': generated by grasping the object.
'Data_stuck': generated by resetting the object with the gripper and protec
ting from sliding.
```

'Reconstruction Method'

```
'point-to-plane': reconstructed with point-to-plane icp.
'robot-joints': reconstructed with robot end effector positions and orienta
tions, e.g. center of two prismatic fingers for franka
```

General performance of point-to-plane icp and robot-joints

In [8]:

```
def evaluate(data, type= 'Reconstruction Method'):
    method = recon_results[type].unique()
    table = []
    for m in method:
        table.append([str(m), np.mean(data.loc[data[type] == m]['mean usdf']),
                      np.mean(data.loc[data[type] == m]['mean haus dist']),
                      np.mean(data.loc[data[type] == m]['RMS haus dist'])])
    print(tabulate(table, headers=[type, 'mean usdf','mean haus dist','RMS haus dis
```

In [9]:

```
print("general performance")
evaluate(recon_results)
```

```
general performance
Reconstruction Method      mean usdf    mean haus dist    RMS haus dis
t
----------------------  -----------  ----------------  --------------
-
point-to-plane            0.327332         0.00190181        0.0028670
9
robot-joints              0.00247028       0.000988605       0.0015155
6
```

Performance on 'Data' or 'Data_stuck'

In [10]:

```
print("Performance on 'Data'")
evaluate(recon_results.loc[recon_results['Data Path'] == 'Data'])
```

```
Performance on 'Data'
Reconstruction Method      mean usdf    mean haus dist    RMS haus dis
t
----------------------  -----------  ----------------  --------------
-
point-to-plane            0.622899          0.00269078       0.0038156
robot-joints              0.00367258        0.0014477        0.0021286
6
```

In [11]:

```
print("Performance on 'Data_stuck'")
evaluate(recon_results.loc[recon_results['Data Path'] == 'Data_stuck'])
```

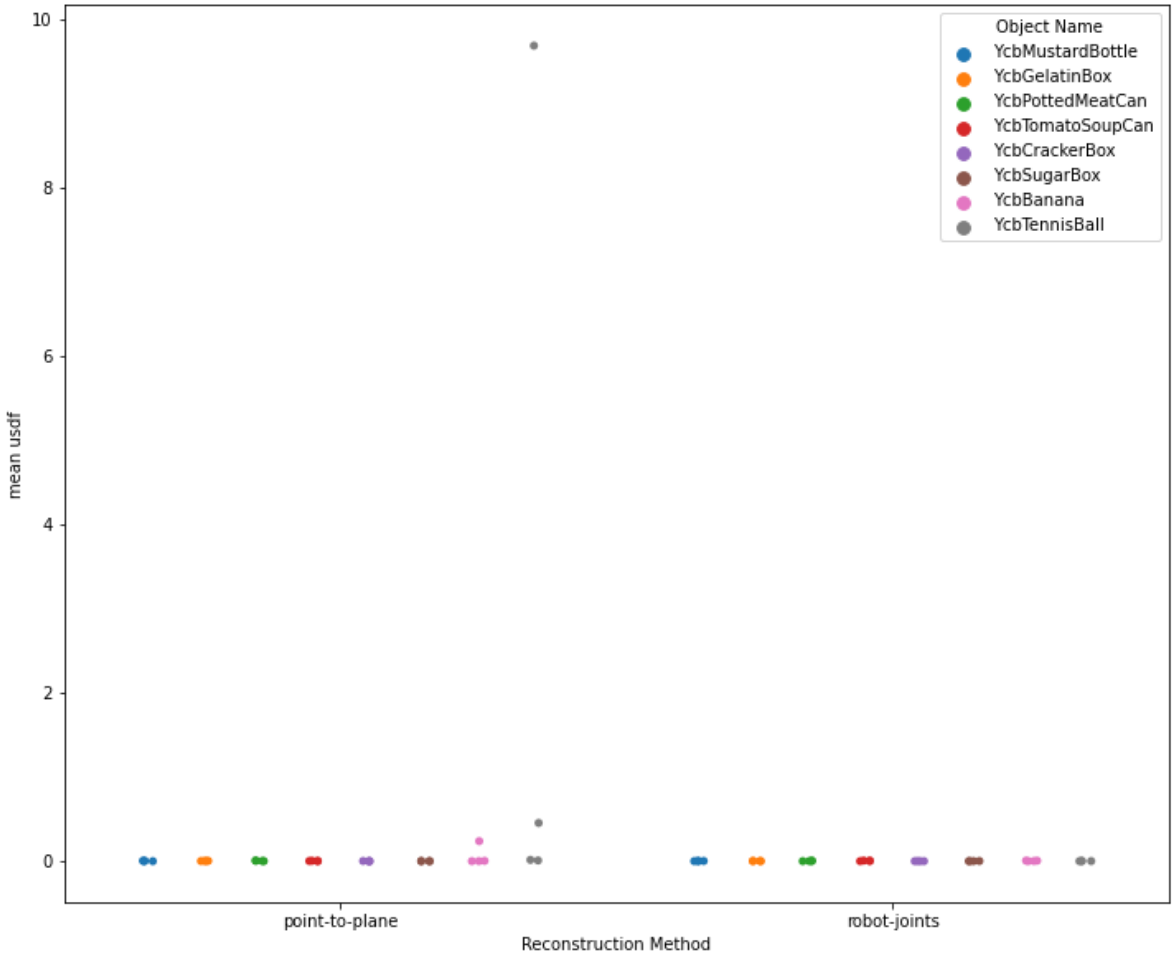
```
Performance on 'Data_stuck'
Reconstruction Method      mean usdf    mean haus dist    RMS haus dis
t
----------------------  -----------  ----------------  --------------
-
point-to-plane            0.0317661        0.00111285       0.00191859
robot-joints              0.00126798       0.000529508      0.00090245
9
```

In [12]:

```
sns.set_context({"figure.figsize":(12,10)})
sns.stripplot(x="Reconstruction Method",y="mean usdf",data=recon_results,jitter=Tru
```

Out[12]:

```
<AxesSubplot:xlabel='Reconstruction Method', ylabel='mean usdf'>
```



Point-to-plane work extremely bad on YcbTennisBall. So the general performance of point-to-plane looks much worse than robot-joints.
If YcbTennisBall is kicked out:

In [13]:

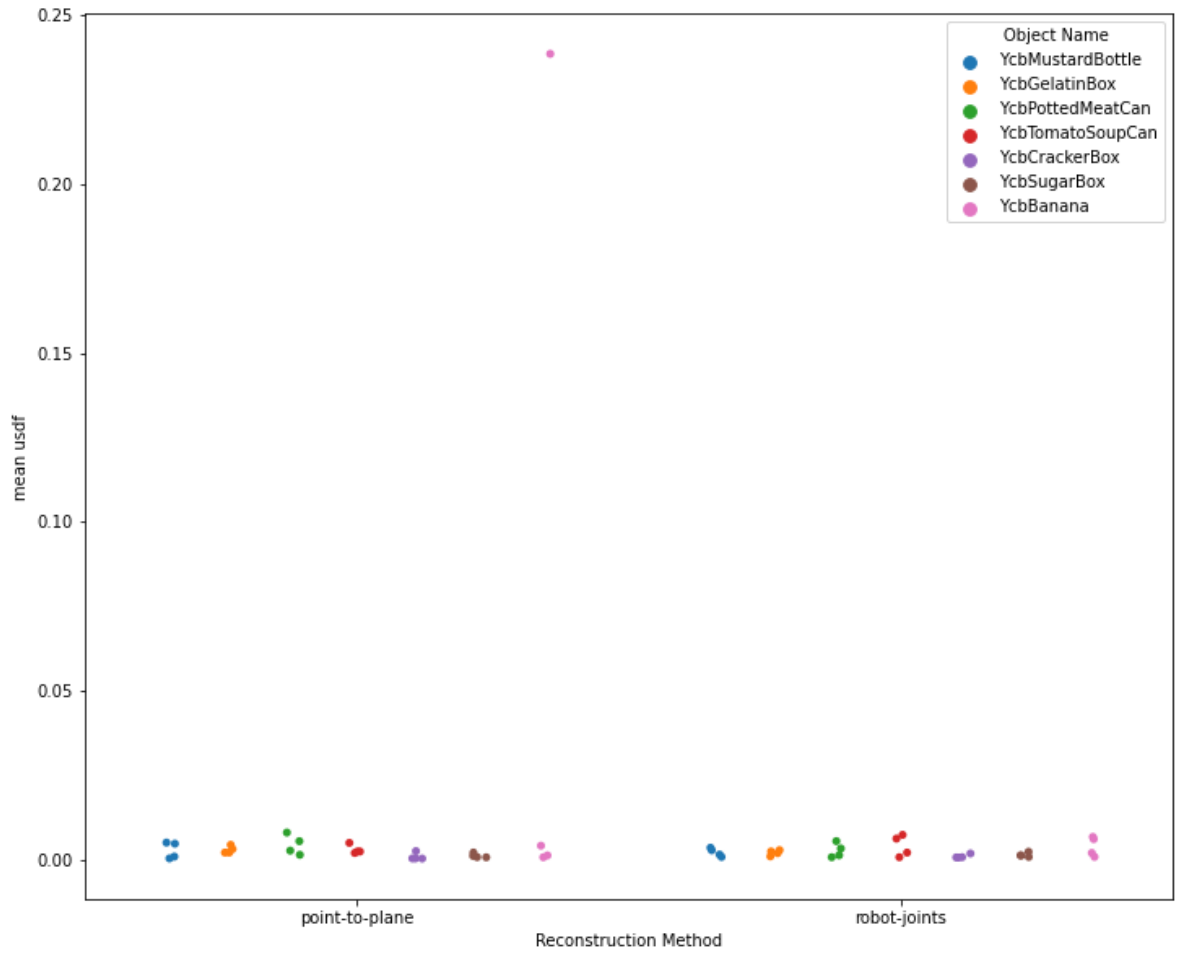
```
recon_results_drop = recon_results[recon_results['Object Name']!='YcbTennisBall']
```

In [14]:

```
sns.set_context({"figure.figsize":(12,10)})
sns.stripplot(x="Reconstruction Method",y="mean usdf",data=recon_results_drop,jitte
```

Out[14]:

```
<AxesSubplot:xlabel='Reconstruction Method', ylabel='mean usdf'>
```



In [15]:

```
print("general")
evaluate(recon_results_drop)
print("\n'Data'")
evaluate(recon_results_drop.loc[recon_results_drop['Data Path'] == 'Data'])
print("\n'Data_stuck'")
evaluate(recon_results_drop.loc[recon_results_drop['Data Path'] == 'Data_stuck'])
```

```
general
Reconstruction Method      mean usdf    mean haus dist    RMS haus dis
t
-----------------------  -----------  ----------------  --------------
-
point-to-plane            0.0109608         0.00183893       0.0026742
6
robot-joints              0.00253711        0.00103155       0.0016003
4

'Data'
Reconstruction Method      mean usdf    mean haus dist    RMS haus dis
t
-----------------------  -----------  ----------------  --------------
-
point-to-plane            0.0192207         0.00281954       0.0039368
robot-joints              0.00380814        0.0015232        0.0022679
9

'Data_stuck'
Reconstruction Method      mean usdf    mean haus dist    RMS haus dis
t
-----------------------  -----------  ----------------  --------------
-
point-to-plane            0.00270094       0.00085832        0.0014117
2
robot-joints              0.00126607       0.000539897       0.0009326
8
```

drop YcbBanana

In [16]:

```
recon_results_drop2 = recon_results[recon_results['Object Name']!='YcbTennisBall'][
```

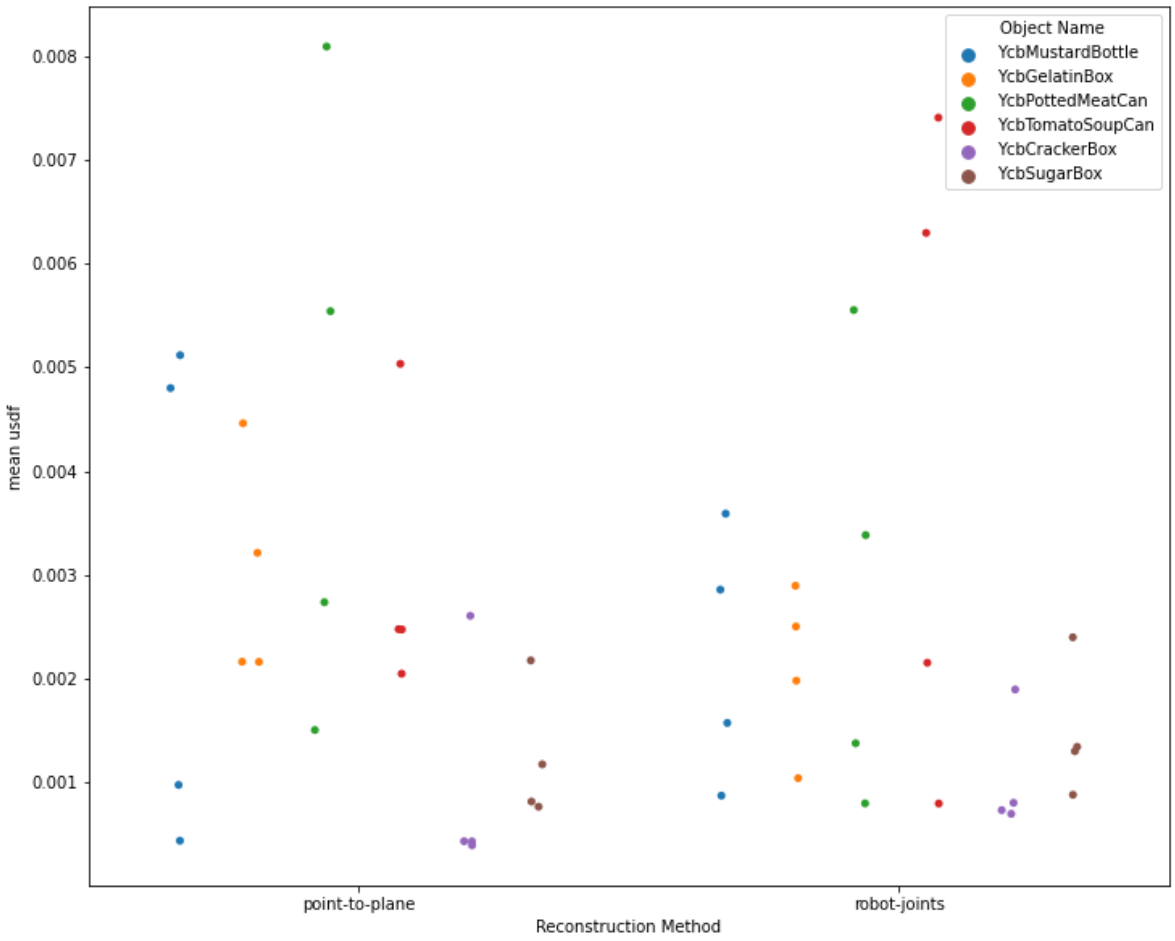
```
/tmp/ipykernel_43317/2632672501.py:1: UserWarning: Boolean Series key
will be reindexed to match DataFrame index.
  recon_results_drop2 = recon_results[recon_results['Object Name']!='Y
cbTennisBall'][recon_results['Object Name']!='YcbBanana']
```

In [17]:

```
sns.set_context({"figure.figsize":(12,10)})
sns.stripplot(x="Reconstruction Method",y="mean usdf",data=recon_results_drop2,jitt
```

Out[17]:

```
<AxesSubplot:xlabel='Reconstruction Method', ylabel='mean usdf'>
```



In [18]:

```
print("general")
evaluate(recon_results_drop2)
print("\n'Data'")
evaluate(recon_results_drop2.loc[recon_results_drop2['Data Path'] == 'Data'])
print("\n'Data_stuck'")
evaluate(recon_results_drop2.loc[recon_results_drop2['Data Path'] == 'Data_stuck'])
```

```
general
Reconstruction Method      mean usdf    mean haus dist    RMS haus dis
t
-----------------------  -----------  ----------------  --------------
-
point-to-plane            0.00258523       0.000907076       0.0014540
7
robot-joints              0.00229762       0.00100571        0.0015885
9

'Data'
Reconstruction Method      mean usdf    mean haus dist    RMS haus dis
t
-----------------------  -----------  ----------------  --------------
-
point-to-plane            0.00243453       0.000909623        0.001401
7
robot-joints              0.00336379       0.00145612         0.002199
3

'Data_stuck'
Reconstruction Method      mean usdf    mean haus dist    RMS haus dis
t
-----------------------  -----------  ----------------  --------------
-
point-to-plane            0.00273594       0.000904529      0.00150643
robot-joints              0.00123146       0.000555293      0.00097787
5
```

Brief conclusion:
If reconstruction methods are performed on the object with significant features, point-to-plane ICP and robot-ee-info have the similar reconstruction performances generally.
In detail, point-to-plane works better than robot-ee-info on the dataset generated by directly grasping('Data'), and it's opposite for the dataset generated by resetting the object within the gripper('Data_stuck').

Segmented by BackFlow or by OSVOS

In [19]:

```
print("all objects")
evaluate(recon_results, type= 'Segmentation Method')
print("\ndrop tennis ball")
evaluate(recon_results_drop, type= 'Segmentation Method')
print("\ndrop banana")
evaluate(recon_results_drop2, type= 'Segmentation Method')
```

```
all objects
Segmentation Method      mean usdf    mean haus dist    RMS haus dist
---------------------  -----------  ----------------  ---------------
BackFlow                  0.326978         0.00175713       0.00256824
OSVOS                     0.0028245        0.00113329       0.00181441

drop tennis ball
Segmentation Method      mean usdf    mean haus dist    RMS haus dist
---------------------  -----------  ----------------  ---------------
BackFlow                 0.0112672         0.00181425       0.00261059
OSVOS                    0.00223075        0.00105622       0.00166401

drop banana
Segmentation Method      mean usdf    mean haus dist    RMS haus dist
---------------------  -----------  ----------------  ---------------
BackFlow                 0.0026617        0.000823804       0.00130877
OSVOS                    0.00222116       0.00108898        0.00173389
```

Brief conclusion:
Segmentation Method influences the reconstruction performance. Generally, reconstruction following BackFlow has much worse performance than that following OSVOS.

BackFlow

In [20]:

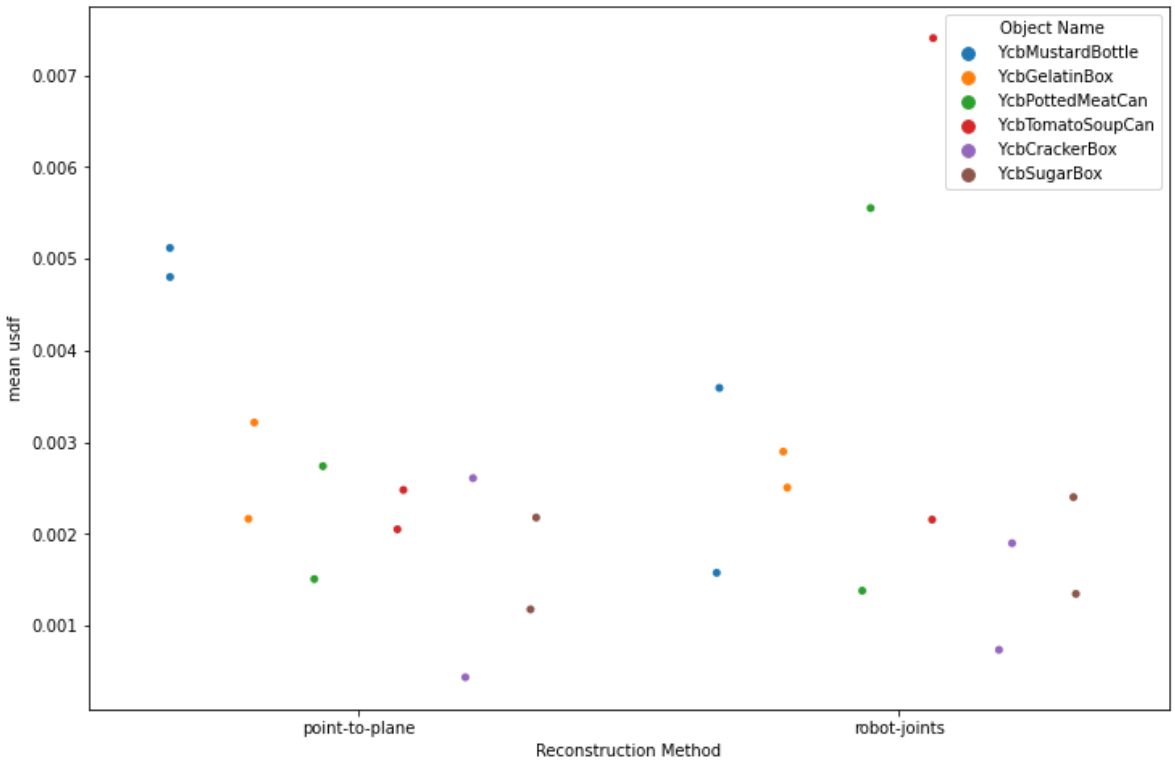
```
recon_results_backflow = recon_results_drop2[recon_results_drop2['Segmentation Meth
```

In [21]:

```
sns.set_context({"figure.figsize":(12,8)})
sns.stripplot(x="Reconstruction Method",y="mean usdf",data=recon_results_backflow,j
```

Out[21]:

```
<AxesSubplot:xlabel='Reconstruction Method', ylabel='mean usdf'>
```



In [22]:

```
print("general")
evaluate(recon_results_backflow)
print("\n'Data'")
evaluate(recon_results_backflow.loc[recon_results_backflow['Data Path'] == 'Data'])
print("\n'Data_stuck'")
evaluate(recon_results_backflow.loc[recon_results_backflow['Data Path'] == 'Data_st
```

```
general
Reconstruction Method      mean usdf    mean haus dist    RMS haus dis
t
-----------------------  -----------  ----------------  --------------
-
point-to-plane            0.00253778       0.000649172       0.0010354
1
robot-joints              0.00278561       0.000998437       0.0015821
2

'Data'
Reconstruction Method      mean usdf    mean haus dist    RMS haus dis
t
-----------------------  -----------  ----------------  --------------
-
point-to-plane             0.0028079       0.000701502       0.0010870
5
robot-joints               0.0039568       0.00144841        0.0021999

'Data_stuck'
Reconstruction Method      mean usdf    mean haus dist    RMS haus dis
t
-----------------------  -----------  ----------------  --------------
-
point-to-plane            0.00226766       0.000596841      0.00098377
9
robot-joints              0.00161442       0.000548466      0.00096434
1
```

OSVOS

In [23]:

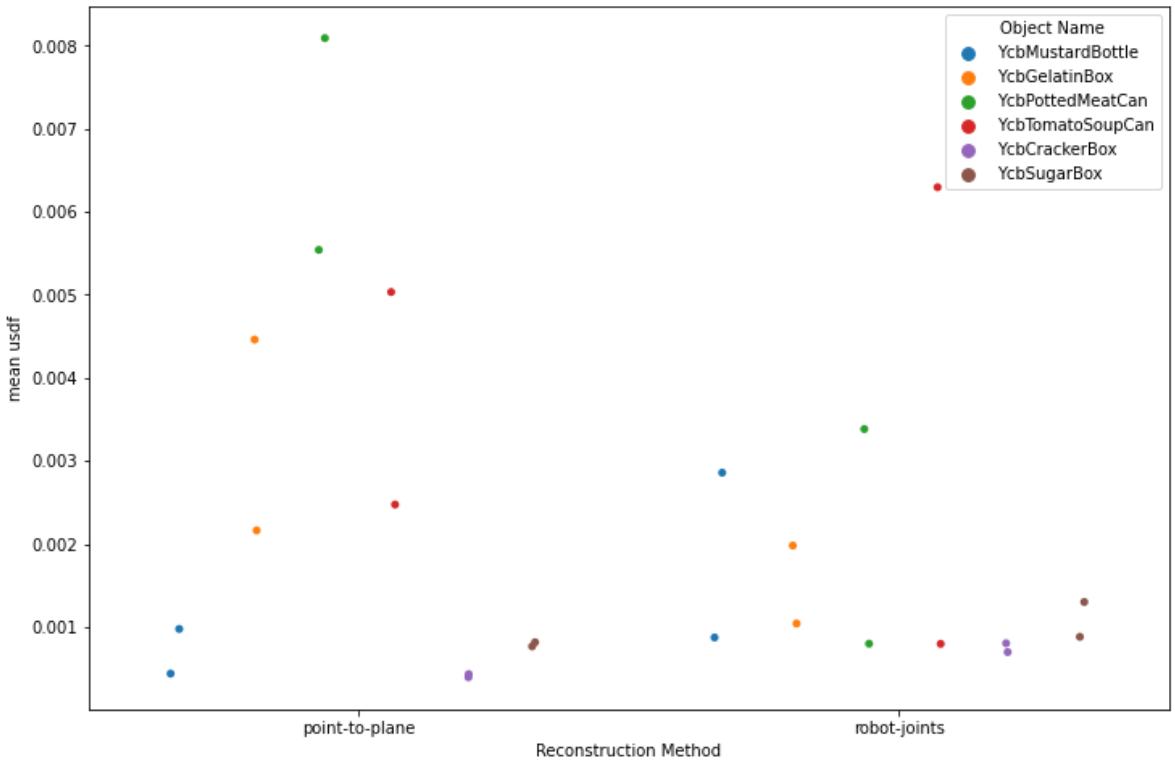
```
recon_results_osvos = recon_results_drop2[recon_results_drop2['Segmentation Method'
```

In [24]:

```
sns.set_context({"figure.figsize":(12,8)})
sns.stripplot(x="Reconstruction Method",y="mean usdf",data=recon_results_osvos,jitt
```

Out[24]:

```
<AxesSubplot:xlabel='Reconstruction Method', ylabel='mean usdf'>
```



In [25]:

```
print("general")
evaluate(recon_results_osvos)
print("\n'Data'")
evaluate(recon_results_osvos.loc[recon_results_osvos['Data Path'] == 'Data'])
print("\n'Data_stuck'")
evaluate(recon_results_osvos.loc[recon_results_osvos['Data Path'] == 'Data_stuck'])
```

```
general
Reconstruction Method      mean usdf    mean haus dist    RMS haus dis
t
-----------------------  -----------  ----------------  --------------
-
point-to-plane            0.00263268        0.00116498       0.0018727
2
robot-joints              0.00180964        0.00101298       0.0015950
6

'Data'
Reconstruction Method      mean usdf    mean haus dist    RMS haus dis
t
-----------------------  -----------  ----------------  --------------
-
point-to-plane            0.00206115        0.00111774       0.0017163
6
robot-joints              0.00277078        0.00146383       0.0021987

'Data_stuck'
Reconstruction Method      mean usdf    mean haus dist    RMS haus dis
t
-----------------------  -----------  ----------------  --------------
-
point-to-plane           0.00320421         0.00121222      0.00202908
robot-joints             0.000848496        0.00056212      0.00099140
9
```

Brief conclusion:
If reconstruction methods are performed on the object with significant features, point-to-plane ICP and robot-ee-info have the similar reconstruction performances when reconstruction is performed after BackFlow segmentation, and for OSVOS, robot-joints performs better. And the conclusions for 'Data' and 'Data_stuck' remain the same.