Supplementary Material for
SAUM: Symmetry-Aware Upsampling Module for Consistent Point Cloud Completion

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This document is the supplementary material of the Paper SAUM. Section 1 contains further implementation details and is followed by Section 2 with additional quantitative results as an extension of Section 4 and 5 of the main paper.

1 Experimental Setting

1.1 Point Cloud Completion

While the main paper contains quantitative results with the entire dataset, we provide the categorical results of point cloud completion. In this section, we remind you of the experimental setting in the main paper and report the detailed network architecture of the decoders. Basically, we evaluated the shape completion results based on the three metrics proposed in Section 4.2 of the main paper: Chamfer Distance, Earth Mover's Distance, and F-Score. We used farthest point sampling to sample the same number of points for the output of ours and the provided ground truth for the fair comparison. We chose d for the F-Score roughly around the mean Chamfer Distance.

PCN dataset. All decoders are designed to generate $M = 16384$ points. Followings are detailed network architectures of the decoders.

- **FCAE** contains 3 fully-connected layers with 1024, 1024, and $16384 \cdot 3$ units.
- **AtlasNet** contains 16 MLP branches. Each branch is implemented as a 3-layer shared-MLP with 256, 256, and 3 units, deforming a 2D 32×32 grid to 1024 3D points.
- **PCN** has 3 fully-connected layers with 1024, 1024, and $1024 \cdot 3$ units for generating coarse points, and the following 1 folding layer for upsampling the coarse output by 16×.
- **TopNet** has 8 tree levels and the number of children per level is 2, 2, 4, 4, 4, 4, 4, 4. Each node of the tree is a 8-dimensional feature vector.

We sampled M points from the output of the SAUM-attached models. For the F-Score, we selected $d = 10 \times 10^{-3}$ near the mean Chamfer Distance of the decoder-only models.

TopNet dataset. All decoders are designed to generate $M = 2048$ points. Followings are detailed network architectures of the decoders.

- **FCAE** contains 3 fully-connected layers with 1024, 1024, and $2048 \cdot 3$ units.
- **AtlasNet** contains 16 MLP branches. Each branch is implemented as a 3-layer shared-MLP with 256, 256, and 3 units, deforming a 2D 16×8 grid to 128 3D points.
- **PCN** has 3 fully-connected layers with 1024, 1024, and $512 \cdot 3$ units for generating coarse points, and the following 1 folding layer for upsampling the coarse output by 4×.
- **TopNet** has 8 tree levels and the number of children per level is 2, 2, 2, 2, 2, 4, 4, 4. Each node of the tree is a 8-dimensional feature vector.

We sampled M points from the output of the SAUM-attached models. For the F-Score, we selected $d = 20 \times 10^{-3}$ near the mean Chamfer Distance of the decoder-only models.

1.2   Self-Consistency Test

On the PCN dataset, we pass the ground truth shape to the completion networks and compare it with the output for evaluating the consistency of the networks. We provide the categorical results of the self-consistency test with the same metrics: CD, EMD, F-Score. We sampled 16384 points from the output of the SAUM-attached models for the fair comparison. For the F-Score, we chose $d = 10 \times 10^{-3}$ following the same setting of the completion experiments.

1.3   Ablation Study

On the PCN dataset, we evaluate the performance of the networks with different settings. First, we compare the SAUM-only models, decoder-only models, and two-branch models. Second, we test the models with the different upsampling ratio r. We provide the categorical results of the ablation study with the same metrics: CD, EMD, F-Score. We sampled 16384 points from the output of the SAUM-attached models for the fair comparison. For the F-Score, we chose $d = 10 \times 10^{-3}$ following the same setting of the previous experiments.

2   Results

The per-category results of the aforementioned setting are presented in this Section. The last column contains the mean values of the entire categories as reported in the main paper. While there might be rare exceptions, the overall result shows that the combination of SAUM and decoder is superior to the conventional approaches for shape completion. The argument can be further verified by the ability to transfer the structure for the self-consistency test. We also note that the higher upsampling ratio results in a stronger performance.

2.1   Point Cloud Completion

Methods	Chair	Table	Sofa	Cabinet	Lamp	Car	Airplane	Vessel	Avg
FCAE	10.969	9.320	11.756	11.023	11.131	8.775	5.698	9.720	9.799
FCAE+SAUM	**9.524**	**8.011**	**11.115**	**10.105**	**8.848**	**8.515**	**5.088**	**8.141**	**8.668**
AtlasNet	10.803	8.979	11.472	10.946	11.212	9.009	5.757	9.740	9.739
AtlasNet+SAUM	**9.604**	**8.273**	**11.279**	**10.310**	**8.553**	**8.752**	**4.995**	**8.032**	**8.725**
PCN	10.998	8.590	11.676	10.625	11.339	8.696	5.502	9.665	9.636
PCN+SAUM	**10.024**	**8.148**	**11.452**	**10.149**	**9.228**	**8.645**	**5.017**	**8.540**	**8.900**
TopNet	10.664	8.756	11.682	10.624	11.210	8.948	5.659	9.551	9.637
TopNet+SAUM	**9.079**	**7.677**	**11.055**	**10.038**	**7.564**	**8.570**	**4.975**	**7.568**	**8.316**

Table 1: Quantitative results on the PCN dataset. The Chamfer Distance (CD) multiplied by 10^3 is reported. The lower the CD, the better. Better results are in bold.

Methods	Chair	Table	Sofa	Cabinet	Lamp	Car	Airplane	Vessel	Avg
FCAE	18.973	16.112	19.149	21.472	24.055	15.730	7.356	14.178	17.128
FCAE+SAUM	**8.951**	**7.158**	**10.306**	**9.779**	**12.811**	**7.968**	**6.627**	**8.522**	**9.015**
AtlasNet	22.547	16.296	17.886	23.167	29.198	11.695	11.678	13.894	18.295
AtlasNet+SAUM	**8.592**	**6.776**	**9.254**	**9.442**	**13.146**	**6.315**	**5.917**	**8.043**	**8.436**
PCN	8.679	8.078	8.342	9.769	16.954	5.718	4.664	7.509	8.714
PCN+SAUM	**6.628**	**6.017**	**7.308**	**7.180**	**9.852**	**5.576**	**4.493**	**5.990**	**6.631**
TopNet	**13.738**	9.707	11.816	11.374	22.523	7.831	**8.620**	12.037	12.206
TopNet+SAUM	14.079	**7.634**	**11.377**	**8.336**	**15.297**	**7.034**	10.215	**9.796**	**10.471**

Table 2: Quantitative results on the PCN dataset. The Earth Mover's Distance (EMD) multiplied by 10^2 is reported. The lower the EMD, the better. Better results are in bold.

Methods	Chair	Table	Sofa	Cabinet	Lamp	Car	Airplane	Vessel	Avg
FCAE	0.576	0.697	0.509	0.574	0.594	0.706	0.876	0.672	0.651
FCAE+SAUM	**0.702**	**0.814**	**0.604**	**0.660**	**0.760**	**0.735**	**0.906**	**0.775**	**0.745**
AtlasNet	0.610	0.734	0.544	0.594	0.617	0.698	0.869	0.682	0.669
AtlasNet+SAUM	**0.704**	**0.807**	**0.616**	**0.659**	**0.773**	**0.725**	**0.909**	**0.780**	**0.747**
PCN	0.625	0.765	0.581	0.651	0.638	0.725	0.881	0.697	0.695
PCN+SAUM	**0.686**	**0.809**	**0.616**	**0.681**	**0.739**	**0.734**	**0.906**	**0.759**	**0.741**
TopNet	0.602	0.742	0.542	0.624	0.594	0.696	0.874	0.673	0.668
TopNet+SAUM	**0.710**	**0.821**	**0.605**	**0.674**	**0.808**	**0.731**	**0.907**	**0.794**	**0.756**

Table 3: Quantitative results on the PCN dataset. The F-Score is reported. The higher the F-Score, the better. Better results are in bold.

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Methods	Chair	Table	Sofa	Cabinet	Lamp	Car	Airplane	Vessel	Avg
FCAE	25.250	25.802	23.737	27.007	26.285	17.944	11.109	19.156	22.036
FCAE+SAUM	**23.332**	**24.932**	**22.130**	**24.980**	**22.306**	**17.794**	**10.120**	**16.767**	**20.295**
AtlasNet	24.735	25.275	23.311	27.044	25.797	18.224	11.787	19.053	21.903
AtlasNet+SAUM	**23.735**	**25.241**	**22.716**	**25.627**	**22.261**	**18.168**	**10.744**	**16.696**	**20.649**
PCN	24.734	**24.775**	**23.160**	26.040	25.870	18.006	11.318	18.890	21.600
PCN+SAUM	**22.556**	24.926	24.082	**24.982**	**22.347**	**17.917**	**10.142**	**16.243**	**20.400**
TopNet	24.918	25.518	**23.298**	26.216	25.422	**17.978**	11.640	19.175	21.770
TopNet+SAUM	**22.651**	**25.104**	24.284	**24.399**	**21.053**	18.077	**10.527**	**16.346**	**20.305**

Table 4: Quantitative results on the TopNet dataset. The Chamfer Distance (CD) multiplied by 10^3 is reported. The lower the CD, the better. Better results are in bold.

Methods	Chair	Table	Sofa	Cabinet	Lamp	Car	Airplane	Vessel	Avg
FCAE	17.329	14.659	13.651	21.749	25.157	8.075	6.967	10.264	14.731
FCAE+SAUM	**9.112**	**9.870**	**7.368**	**10.500**	**14.003**	**5.404**	**5.077**	**7.247**	**8.573**
AtlasNet	11.361	12.152	9.411	13.623	19.172	5.812	5.271	9.203	10.751
AtlasNet+SAUM	**8.871**	**9.521**	**6.904**	**9.348**	**12.195**	**5.253**	**5.227**	**6.717**	**8.004**
PCN	10.902	11.434	8.826	13.019	18.392	5.982	5.773	8.226	10.319
PCN+SAUM	**8.500**	**9.594**	**7.514**	**9.303**	**11.881**	**5.453**	**4.137**	**6.396**	**7.847**
TopNet	12.360	11.573	9.235	13.180	19.311	5.752	6.063	9.031	10.813
TopNet+SAUM	**8.899**	**9.105**	**7.429**	**8.888**	**11.812**	**5.318**	**4.603**	**6.562**	**7.827**

Table 5: Quantitative results on the TopNet dataset. The Earth Mover's Distance (EMD) multiplied by 10^2 is reported. The lower the EMD, the better. Better results are in bold.

Methods	Chair	Table	Sofa	Cabinet	Lamp	Car	Airplane	Vessel	Avg
FCAE	0.522	0.560	0.483	0.410	0.534	0.684	0.895	0.684	0.597
FCAE+SAUM	**0.582**	**0.605**	**0.546**	**0.479**	**0.654**	**0.689**	**0.920**	**0.758**	**0.654**
AtlasNet	0.545	0.571	0.508	0.444	0.558	0.677	0.893	0.696	0.612
AtlasNet+SAUM	**0.586**	**0.605**	**0.549**	**0.475**	**0.660**	0.677	**0.915**	**0.764**	**0.654**
PCN	0.542	0.588	0.512	0.469	0.567	0.685	0.900	0.701	0.620
PCN+SAUM	**0.606**	**0.626**	**0.544**	**0.491**	**0.665**	0.685	**0.928**	**0.773**	**0.665**
TopNet	0.533	0.572	0.504	0.455	0.564	**0.685**	0.894	0.686	0.612
TopNet+SAUM	**0.601**	**0.625**	**0.544**	**0.498**	**0.686**	0.677	**0.919**	**0.775**	**0.666**

Table 6: Quantitative results on the TopNet dataset. The F-Score is reported. The higher the F-Score, the better. Better results are in bold.

2.2 Self-Consistency Test

Methods	Chair	Table	Sofa	Cabinet	Lamp	Car	Airplane	Vessel	Avg
FCAE	9.850	8.795	9.660	9.542	10.678	8.356	5.258	9.347	8.936
FCAE+SAUM	**6.645**	**7.072**	**8.569**	**7.420**	**7.106**	**6.372**	**3.576**	**6.123**	**6.610**
AtlasNet	9.533	8.534	9.357	9.779	10.245	8.463	5.209	9.285	8.801
AtlasNet+SAUM	**6.530**	**7.067**	**8.191**	**7.168**	**6.632**	**6.514**	**3.586**	**6.066**	**6.469**
PCN	9.516	8.264	9.513	9.383	10.874	8.147	5.038	9.208	8.743
PCN+SAUM	**6.662**	**6.855**	**8.132**	**6.856**	**7.056**	**6.300**	**3.605**	**6.396**	**6.483**
TopNet	9.378	8.364	9.622	9.514	10.715	8.439	5.067	8.937	8.754
TopNet+SAUM	**6.114**	**6.482**	**7.830**	**7.115**	**6.090**	**6.269**	**3.468**	**5.680**	**6.131**

Table 7: Self-consistency test on the PCN dataset. The Chamfer Distance (CD) multiplied by 10^3 is reported. The lower the CD, the better. Better results are in bold.

Methods	Chair	Table	Sofa	Cabinet	Lamp	Car	Airplane	Vessel	Avg
FCAE	18.669	14.664	19.043	21.229	23.969	15.856	7.192	14.188	16.851
FCAE+SAUM	**3.494**	**3.475**	**4.165**	**3.463**	**4.920**	**2.943**	**2.572**	**3.155**	**3.523**
AtlasNet	21.001	15.387	15.953	21.945	28.960	11.419	11.315	13.675	17.457
AtlasNet+SAUM	**3.480**	**3.598**	**4.163**	**3.480**	**4.713**	**3.008**	**2.731**	**3.170**	**3.543**
PCN	8.018	7.985	6.700	9.078	16.662	5.607	4.436	7.359	8.231
PCN+SAUM	**3.767**	**3.826**	**4.294**	**3.466**	**5.355**	**3.012**	**2.704**	**3.310**	**3.717**
TopNet	12.319	9.069	9.209	10.925	22.418	8.743	8.470	12.074	11.653
TopNet+SAUM	**3.431**	**3.704**	**4.033**	**3.548**	**4.431**	**2.847**	**2.349**	**3.019**	**3.420**

Table 8: Self-consistency test on the PCN dataset. The Earth Mover's Distance (EMD) multiplied by 10^2 is reported. The lower the EMD, the better. Better results are in bold.

Methods	Chair	Table	Sofa	Cabinet	Lamp	Car	Airplane	Vessel	Avg
FCAE	0.641	0.701	0.625	0.637	0.608	0.735	0.895	0.690	0.692
FCAE+SAUM	**0.861**	**0.883**	**0.830**	**0.825**	**0.848**	**0.871**	**0.959**	**0.878**	**0.869**
AtlasNet	0.685	0.745	0.681	0.646	0.660	0.730	0.896	0.703	0.718
AtlasNet+SAUM	**0.871**	**0.887**	**0.846**	**0.839**	**0.872**	**0.863**	**0.958**	**0.879**	**0.877**
PCN	0.693	0.754	0.681	0.689	0.656	0.754	0.902	0.711	0.730
PCN+SAUM	**0.851**	**0.888**	**0.832**	**0.852**	**0.840**	**0.867**	**0.953**	**0.856**	**0.868**
TopNet	0.675	0.740	0.660	0.670	0.611	0.717	0.903	0.697	0.709
TopNet+SAUM	**0.891**	**0.904**	**0.853**	**0.842**	**0.890**	**0.881**	**0.969**	**0.902**	**0.892**

Table 9: Self-consistency test on the PCN dataset. The F-Score is reported. The higher the F-Score, the better. Better results are in bold.

2.3   Ablation Study

Methods	Chair	Table	Sofa	Cabinet	Lamp	Car	Airplane	Vessel	Avg
SAUM (×4) only	12.298	10.439	14.089	13.113	8.766	12.733	6.687	9.300	10.928
SAUM (×8) only	**10.736**	**9.105**	**13.252**	**11.884**	**8.023**	**11.602**	**5.850**	**8.200**	**9.832**
FCAE	10.969	9.320	11.756	11.023	11.131	8.775	5.698	9.720	9.799
FCAE+SAUM (×4)	9.604	8.269	**11.096**	10.153	9.335	**8.448**	5.334	8.286	8.816
FCAE+SAUM (×8)	**9.524**	**8.011**	11.115	**10.105**	**8.848**	8.515	**5.088**	**8.141**	**8.668**
AtlasNet	10.803	8.979	11.472	10.946	11.212	9.009	5.757	9.740	9.739
AtlasNet+SAUM (×4)	9.686	**8.114**	**10.986**	10.502	8.682	**8.692**	5.124	8.259	8.756
AtlasNet+SAUM (×8)	**9.604**	8.273	11.279	**10.310**	**8.553**	8.752	**4.995**	**8.032**	**8.725**
PCN	10.998	8.590	11.676	10.625	11.339	8.696	5.502	9.665	9.636
PCN+SAUM (×4)	10.227	**7.945**	**11.379**	9.968	9.498	**8.543**	5.145	**8.476**	**8.898**
PCN+SAUM (×8)	**10.024**	8.148	11.452	10.149	**9.228**	8.645	**5.017**	8.540	8.900
TopNet	10.664	8.756	11.682	10.624	11.210	8.948	5.659	9.551	9.637
TopNet+SAUM (×4)	9,897	7.709	11.466	10.310	8.998	8.624	5.200	8.078	8.785
TopNet+SAUM (×8)	**9.079**	**7.677**	**11.055**	**10.038**	**7.564**	**8.570**	**4.975**	**7.568**	**8.316**

Table 10: Ablation study on the PCN dataset. The Chamfer Distance (CD) multiplied by 10^3 is reported. The lower the CD, the better. Better results are in bold.

Methods	Chair	Table	Sofa	Cabinet	Lamp	Car	Airplane	Vessel	Avg
SAUM (×4) only	36.645	39.768	37.998	39.328	33.913	29.169	21.293	27.196	33.164
SAUM (×8) only	**26.197**	**26.546**	**27.991**	**26.043**	**22.820**	**19.521**	**16.585**	**18.946**	**23.081**
FCAE	18.973	16.112	19.149	21.472	24.055	15.730	7.356	14.178	17.128
FCAE+SAUM (×4)	17.517	12.350	16.110	17.185	20.778	11.191	8.435	11.494	14.383
FCAE+SAUM (×8)	**8.951**	**7.158**	**10.306**	**9.779**	**12.811**	**7.968**	**6.627**	**8.522**	**9.015**
AtlasNet	22.547	16.296	17.886	23.167	29.198	11.695	11.678	13.894	18.295
AtlasNet+SAUM (×4)	16.436	11.267	13.466	16.226	21.163	8.073	10.901	10.282	13.477
AtlasNet+SAUM (×8)	**8.592**	**6.776**	**9.254**	**9.442**	**13.146**	**6.315**	**5.917**	**8.043**	**8.436**
PCN	8.679	8.078	8.342	9.769	16.954	5.718	4.664	7.509	8.714
PCN+SAUM (×4)	7.413	6.529	7.837	7.886	12.038	5.796	4.693	6.738	7.366
PCN+SAUM (×8)	**6.628**	**6.017**	**7.308**	**7.180**	**9.852**	**5.576**	**4.493**	**5.990**	**6.631**
TopNet	13.738	9.707	11.816	11.374	22.523	7.831	**8.620**	12.037	12.206
TopNet+SAUM (×4)	**11.187**	8.478	11.421	9.838	21.379	7.983	8.982	11.741	11.376
TopNet+SAUM (×8)	14.079	**7.634**	**11.377**	**8.336**	**15.297**	**7.034**	10.215	**9.796**	**10.471**

Table 11: Ablation study on the PCN dataset. The Earth Mover's Distance (EMD) multiplied by 10^2 is reported. The lower the EMD, the better. Better results are in bold.

Methods	Chair	Table	Sofa	Cabinet	Lamp	Car	Airplane	Vessel	Avg
SAUM (×4) only	0.552	0.622	0.401	0.464	0.748	0.478	0.796	0.653	0.589
SAUM (×8) only	**0.616**	**0.706**	**0.466**	**0.556**	**0.781**	**0.554**	**0.857**	**0.731**	**0.658**
FCAE	0.576	0.697	0.509	0.574	0.594	0.706	0.876	0.672	0.651
FCAE+SAUM (×4)	0.675	0.788	0.570	0.632	0.721	0.730	0.894	0.761	0.721
FCAE+SAUM (×8)	**0.702**	**0.814**	**0.604**	**0.660**	**0.760**	**0.735**	**0.906**	**0.775**	**0.745**
AtlasNet	0.610	0.734	0.544	0.594	0.617	0.698	0.869	0.682	0.669
AtlasNet+SAUM (×4)	0.686	0.803	0.593	0.639	0.754	0.721	0.902	0.760	0.732
AtlasNet+SAUM (×8)	**0.704**	**0.807**	**0.616**	**0.659**	**0.773**	**0.725**	**0.909**	**0.780**	**0.747**
PCN	0.625	0.765	0.581	0.651	0.638	0.725	0.881	0.697	0.695
PCN+SAUM (×4)	0.676	**0.811**	0.609	**0.687**	0.721	**0.736**	0.899	0.755	0.737
PCN+SAUM (×8)	**0.686**	0.809	**0.616**	0.681	**0.739**	0.734	**0.906**	**0.759**	**0.741**
TopNet	0.602	0.742	0.542	0.624	0.594	0.696	0.874	0.673	0.668
TopNet+SAUM (×4)	0.676	0.817	0.593	0.655	0.728	0.719	0.897	0.766	0.731
TopNet+SAUM (×8)	**0.710**	**0.821**	**0.605**	**0.674**	**0.808**	**0.731**	**0.907**	**0.794**	**0.756**

Table 12: Ablation study on the PCN dataset. The F-Score is reported. The higher the F-Score, the better. Better results are in bold.