A. Details of the constructed ID/OOD splits

Table 4. The number of images in each constructed split.

		ID			(Fine-grained) OOD
		train	validation	test	
Aircraft	Split 1	5396	604	3000	333
	Split 2	5380	618	3002	331
	Split 3	5400	597	3003	330
Car	Split 1	5664	623	6210	1831
	Split 2	5657	625	6197	1844
	Split 3	5574	633	6131	1910
Butterfly	Split 1	7072	798	11513	3458
	Split 2	6813	735	11019	3952
	Split 3	6941	743	11219	3752
Bird	Split 1	7377	809	8547	2149
	Split 2	7278	812	8449	2247
	Split 3	7219	798	8446	2250

In Tab. 4 we list the number of train/validation/test images in each ID split and the number of holdout images in each holdout (fine-grained) OOD split. The exact classes in each split is presented below. Note, the *Aircraft* and *Car* dataset do not have explicit class identifier, so we create numerical index ourselves. Please see our code for details.

- *Aircraft*
  - Split 1
    - ID: 26, 86, 2, 55, 75, 93, 16, 73, 54, 95, 53, 92, 78, 13, 7, 30, 22, 24, 33, 8, 43, 62, 3, 71, 45, 48, 6, 99, 82, 76, 60, 80, 90, 68, 51, 27, 18, 56, 63, 74, 1, 61, 42, 41, 4, 15, 17, 40, 38, 5, 91, 59, 0, 34, 28, 50, 11, 35, 23, 52, 10, 31, 66, 57, 79, 85, 32, 84, 14, 89, 19, 29, 49, 97, 98, 69, 20, 94, 72, 77, 25, 37, 81, 46, 39, 65, 58, 12, 88, 70;
    - OOD: 9, 21, 36, 44, 47, 64, 67, 83, 87, 96;
  - Split 2
    - ID: 80, 84, 33, 81, 93, 17, 36, 82, 69, 65, 92, 39, 56, 52, 51, 32, 31, 44, 78, 10, 2, 73, 97, 62, 19, 35, 94, 27, 46, 38, 67, 99, 54, 95, 88, 40, 48, 59, 23, 34, 86, 53, 77, 15, 83, 41, 45, 91, 26, 98, 43, 55, 24, 4, 58, 49, 21, 87, 3, 74, 30, 66, 70, 42, 47, 89, 8, 60, 0, 90, 57, 22, 61, 63, 7, 96, 13, 68, 85, 14, 29, 28, 11, 18, 20, 50, 25, 6, 71, 76;
    - OOD: 1, 5, 9, 12, 16, 37, 64, 72, 75, 79;
  - Split 3
    - ID: 83, 30, 56, 24, 16, 23, 2, 27, 28, 13, 99, 92, 76, 14, 0, 21, 3, 29, 61, 79, 35, 11, 84, 44, 73, 5, 25, 77, 74, 62, 65, 1, 18, 48, 36, 78, 6, 89, 91, 10, 12, 53, 87, 54, 95, 32, 19, 26, 60, 55, 9, 96, 17, 59, 57, 41, 64, 45, 97, 8, 71, 94, 90, 98, 86, 80, 50, 52, 66, 88, 70, 46, 68, 69, 81, 58, 33, 38, 51, 42, 4, 67, 39, 37, 20, 31, 63, 47, 85, 93;
    - OOD: 7, 15, 22, 34, 40, 43, 49, 72, 75, 82;
- *Car*
  - Split 1
    - ID: 83, 12, 33, 113, 171, 134, 163, 124, 74, 18, 7, 5, 125, 161, 170, 181, 123, 60, 44, 141, 56, 173, 136, 89, 63, 55, 110, 166, 175, 45, 22, 155, 66, 37, 4, 80, 178, 106, 160, 26, 139, 143, 71, 8, 61, 130, 122, 101, 118, 92, 185, 24, 30, 109, 40, 137, 150, 90, 19, 149, 180, 54, 159, 16, 51, 177, 135, 108, 86, 96, 183, 146, 193, 14,

27, 97, 156, 46, 191, 190, 62, 2, 59, 111, 112, 43, 10, 98, 73, 188, 179, 144, 129, 93, 107, 154, 187, 50, 0, 94, 145, 95, 64, 138, 41, 69, 49, 48, 85, 13, 164, 23, 182, 131, 20, 15, 78, 104, 52, 100, 76, 3, 116, 194, 126, 6, 68, 75, 84, 121, 157, 167, 152, 91, 168, 11, 119, 102, 35, 57, 65, 1, 120, 158, 42, 105, 132, 169, 17, 38;

  * OOD: 9, 21, 25, 28, 29, 31, 32, 34, 36, 39, 47, 53, 58, 67, 70, 72, 77, 79, 81, 82, 87, 88, 99, 103, 114, 115, 117, 127, 128, 133, 140, 142, 147, 148, 151, 153, 162, 165, 172, 174, 176, 184, 186, 189, 192, 195;

- Split 2
  * ID: 127, 11, 110, 124, 18, 165, 44, 28, 171, 136, 51, 29, 105, 56, 53, 174, 16, 164, 143, 99, 27, 130, 78, 168, 108, 191, 31, 35, 173, 4, 113, 112, 116, 82, 186, 69, 169, 40, 102, 182, 58, 14, 47, 19, 81, 39, 95, 118, 73, 67, 59, 33, 176, 154, 181, 195, 138, 117, 161, 90, 42, 17, 5, 159, 66, 48, 54, 190, 98, 89, 163, 107, 12, 120, 119, 114, 151, 84, 145, 123, 13, 188, 175, 45, 93, 36, 158, 183, 150, 97, 94, 193, 103, 170, 75, 21, 91, 155, 2, 70, 85, 147, 6, 106, 0, 152, 77, 65, 55, 122, 88, 179, 46, 62, 74, 92, 189, 184, 194, 87, 180, 177, 132, 10, 34, 32, 162, 38, 83, 153, 100, 125, 23, 126, 9, 167, 104, 148, 135, 111, 185, 64, 15, 41, 160, 109, 80, 52, 26, 76;
  * OOD: 1, 3, 7, 8, 20, 22, 24, 25, 30, 37, 43, 49, 50, 57, 60, 61, 63, 68, 71, 72, 79, 86, 96, 101, 115, 121, 128, 129, 131, 133, 134, 137, 139, 140, 141, 142, 144, 146, 149, 156, 157, 166, 172, 178, 187, 192;
- Split 3
  * ID: 10, 79, 165, 143, 163, 134, 35, 137, 25, 2, 12, 128, 180, 3, 48, 29, 14, 119, 6, 23, 108, 144, 130, 175, 45, 120, 174, 125, 9, 164, 54, 13, 109, 169, 78, 114, 44, 82, 159, 123, 161, 94, 57, 41, 66, 98, 5, 53, 111, 11, 183, 24, 147, 64, 8, 195, 171, 28, 131, 71, 42, 65, 135, 113, 173, 189, 106, 140, 155, 187, 126, 92, 1, 85, 188, 146, 156, 184, 89, 36, 176, 100, 62, 0, 27, 153, 172, 178, 20, 154, 152, 139, 77, 30, 150, 17, 59, 186, 112, 166, 127, 158, 93, 115, 21, 55, 16, 142, 91, 99, 118, 193, 74, 122, 157, 141, 192, 87, 90, 84, 18, 97, 101, 160, 133, 61, 81, 138, 68, 129, 56, 19, 86, 70, 60, 34, 40, 76, 149, 26, 32, 191, 96, 83, 110, 105, 73, 117, 145, 151;
  * OOD: 4, 7, 15, 22, 31, 33, 37, 38, 39, 43, 46, 47, 49, 50, 51, 52, 58, 63, 67, 69, 72, 75, 80, 88, 95, 102, 103, 104, 107, 116, 121, 124, 132, 136, 148, 162, 167, 168, 170, 177, 179, 181, 182, 185, 190, 194;

- *Butterfly*
  - Split 1
    * ID: 018, 170, 107, 098, 177, 182, 005, 146, 012, 152, 061, 125, 180, 154, 080, 007, 033, 130, 037, 074, 183, 145, 045, 159, 060, 123, 179, 185, 122, 044, 016, 055, 150, 111, 022, 189, 129, 004, 083, 106, 134, 066, 026, 113, 168, 063, 008, 075, 118, 143, 071, 124, 184, 097, 149, 024, 030, 160, 040, 056, 131, 096, 181, 019, 153, 092, 054, 163, 051, 086, 139, 090, 137, 101, 144, 089, 109, 014, 027, 141, 187, 046, 138, 195, 108, 062, 002, 059, 136, 197, 043, 010, 194, 073, 196, 178, 175, 126, 093, 112, 158, 191, 050, 094, 110, 095, 064, 167, 041, 069, 049, 048, 085, 013, 161, 023, 186, 135, 020, 015, 078, 104, 052, 100, 076, 003, 116, 164, 198, 006, 068, 084, 121, 155, 171, 156, 091, 199, 011, 119, 102, 035, 057, 065, 001, 120, 162, 042, 105;
    * OOD: 009, 017, 021, 025, 028, 029, 031, 032, 034, 036, 038, 039, 047, 053, 058, 067, 070, 072, 077, 079, 081, 082, 087, 088, 099, 103, 114, 115, 117, 127, 128, 132, 133, 140, 142, 147, 148, 151, 157, 165, 166, 169, 172, 173, 174, 176, 188, 190, 192, 193;
  - Split 2
    * ID: 058, 040, 034, 102, 184, 198, 095, 004, 029, 168, 171, 018, 011, 089, 110, 118, 159, 035, 136, 059, 051, 016, 044, 094, 031, 162, 038, 028, 193, 027, 047, 165, 194, 177, 176, 097, 174, 073, 069, 172, 108, 107, 189, 014, 056, 019, 114, 039, 185, 124, 098, 123, 119, 053, 033, 179, 181, 106, 199, 138, 116, 067, 078, 042, 017, 005, 127, 105, 048, 066, 054, 084, 183, 158, 166, 113, 012, 117, 093, 120, 154, 090, 081, 122, 191, 013, 082, 132, 187, 045, 099, 036, 161, 186, 153, 103, 195, 197, 148, 173, 075, 021, 091, 152, 002, 070, 085, 150, 006, 112, 155, 077, 065, 055, 167, 088, 130, 046, 062, 074, 092, 147, 160, 143, 087, 180, 145, 164, 010, 032, 083, 182, 100, 125, 023, 126, 009, 170, 104, 151, 135, 111, 188, 064, 015, 041, 163, 109, 080;
    * OOD: 001, 003, 007, 008, 020, 022, 024, 025, 026, 030, 037, 043, 049, 050, 052, 057, 060, 061, 063, 068, 071, 072, 076, 079, 086, 096, 101, 115, 121, 128, 129, 131, 133, 134, 137, 139, 140, 141, 142, 144, 146, 149, 156, 157, 169, 175, 178, 190, 192, 196;
  - Split 3

* ID: 112, 029, 182, 199, 193, 085, 010, 054, 115, 035, 012, 092, 013, 126, 174, 002, 044, 003, 113, 014, 023, 025, 006, 134, 165, 173, 045, 065, 048, 122, 178, 064, 009, 057, 078, 071, 128, 176, 131, 053, 137, 163, 111, 123, 109, 141, 041, 130, 140, 005, 159, 100, 011, 187, 024, 089, 066, 008, 172, 175, 028, 133, 094, 042, 169, 082, 184, 106, 108, 143, 180, 166, 146, 079, 001, 119, 192, 149, 160, 188, 147, 036, 171, 179, 062, 027, 157, 098, 118, 020, 158, 156, 142, 077, 030, 154, 017, 059, 181, 114, 127, 139, 191, 093, 151, 021, 055, 016, 152, 091, 099, 120, 197, 074, 190, 161, 144, 196, 087, 090, 084, 018, 097, 101, 125, 164, 135, 061, 081, 068, 129, 056, 019, 086, 070, 060, 034, 040, 138, 076, 153, 026, 032, 195, 096, 083, 110, 105, 073;
* OOD: 004, 007, 015, 022, 031, 033, 037, 038, 039, 043, 046, 047, 049, 050, 051, 052, 058, 063, 067, 069, 072, 075, 080, 088, 095, 102, 103, 104, 107, 116, 117, 121, 124, 132, 136, 145, 148, 150, 155, 162, 167, 168, 170, 177, 183, 185, 186, 189, 194, 198;

- *Bird*
  - Split 1
    * ID: 0518, 0400, 0530, 0461, 0510, 0560, 0478, 0626, 0371, 0495, 0509, 0631, 0469, 0549, 0513, 0381, 0604, 0531, 0517, 0457, 0548, 0353, 0638, 0498, 0470, 0651, 0316, 0363, 0618, 0345, 0556, 0486, 0471, 0558, 0528, 0505, 0547, 0313, 0330, 0551, 0485, 0320, 0546, 0539, 0450, 0489, 0619, 0352, 0372, 0542, 0379, 0522, 0519, 0393, 0367, 0612, 0628, 0326, 0620, 0323, 0512, 0382, 0315, 0449, 0544, 0645, 0341, 0468, 0516, 0625, 0642, 0611, 0452, 0324, 0456, 0392, 0467, 0536, 0299, 0476, 0369, 0484, 0360, 0374, 0334, 0630, 0514, 0623, 0348, 0321, 0298, 0466, 0332, 0338, 0624, 0368, 0364, 0499, 0482, 0327, 0550, 0496, 0362, 0601, 0397, 0359, 0297, 0616, 0464, 0494, 0446, 0318, 0504, 0541, 0634, 0349, 0322, 0335, 0358, 0632, 0328, 0540, 0354, 0533, 0647, 0483, 0609, 0538, 0370, 0607, 0526, 0490, 0515, 0497, 0351, 0559, 0506, 0521, 0472, 0603, 0458, 0520, 0453, 0561, 0640, 0473, 0295, 0454, 0455, 0377, 0357, 0356, 0402, 0649, 0501, 0331, 0621, 0503, 0395, 0460, 0491, 0602, 0650, 0314, 0376, 0401, 0481, 0635, 0615, 0637, 0643, 0554, 0451, 0614, 0629, 0319, 0479, 0462, 0343, 0365, 0529, 0373, 0296, 0480, 0600, 0350, 0465, 0492, 0617, 0325, 0346, 0493, 0361, 0524, 0646, 0488, 0342, 0336, 0543, 0474;
    * OOD: 0317, 0329, 0333, 0337, 0339, 0340, 0344, 0347, 0355, 0366, 0375, 0378, 0380, 0394, 0396, 0398, 0399, 0447, 0448, 0459, 0463, 0475, 0477, 0487, 0500, 0502, 0507, 0508, 0511, 0523, 0525, 0527, 0532, 0534, 0535, 0537, 0545, 0552, 0553, 0555, 0557, 0599, 0605, 0606, 0608, 0610, 0613, 0622, 0627, 0633, 0636, 0639, 0641, 0644, 0648;
  - Split 2
    * ID: 0542, 0342, 0470, 0472, 0623, 0467, 0519, 0335, 0642, 0546, 0651, 0370, 0299, 0625, 0352, 0529, 0492, 0359, 0487, 0498, 0381, 0477, 0548, 0528, 0626, 0448, 0346, 0505, 0462, 0490, 0375, 0320, 0453, 0395, 0402, 0459, 0347, 0551, 0644, 0608, 0512, 0607, 0479, 0339, 0326, 0616, 0527, 0327, 0534, 0366, 0341, 0533, 0343, 0319, 0337, 0295, 0518, 0544, 0641, 0510, 0541, 0629, 0633, 0336, 0324, 0618, 0648, 0355, 0603, 0348, 0450, 0649, 0377, 0474, 0480, 0550, 0635, 0605, 0540, 0367, 0451, 0650, 0628, 0523, 0455, 0482, 0322, 0521, 0530, 0329, 0449, 0364, 0615, 0363, 0476, 0401, 0361, 0637, 0539, 0466, 0627, 0350, 0325, 0313, 0547, 0483, 0356, 0478, 0640, 0374, 0378, 0620, 0646, 0537, 0543, 0362, 0645, 0458, 0630, 0520, 0468, 0561, 0457, 0549, 0399, 0557, 0465, 0610, 0454, 0604, 0398, 0484, 0524, 0532, 0321, 0621, 0531, 0353, 0507, 0463, 0344, 0602, 0638, 0555, 0508, 0392, 0514, 0617, 0554, 0297, 0643, 0314, 0611, 0599, 0394, 0473, 0373, 0511, 0354, 0382, 0452, 0545, 0447, 0503, 0536, 0318, 0522, 0340, 0496, 0526, 0400, 0559, 0525, 0515, 0460, 0485, 0331, 0486, 0317, 0614, 0464, 0513, 0553, 0495, 0471, 0636, 0372, 0323, 0349, 0631, 0469, 0397, 0360, 0334, 0393, 0351, 0332, 0556, 0298, 0613;
    * OOD: 0296, 0315, 0316, 0328, 0330, 0333, 0338, 0345, 0357, 0358, 0365, 0368, 0369, 0371, 0376, 0379, 0380, 0396, 0446, 0456, 0461, 0475, 0481, 0488, 0489, 0491, 0493, 0494, 0497, 0499, 0500, 0501, 0502, 0504, 0506, 0509, 0516, 0517, 0535, 0538, 0552, 0558, 0560, 0600, 0601, 0606, 0609, 0612, 0619, 0622, 0624, 0632, 0634, 0639, 0647;
  - Split 3
    * ID: 0361, 0321, 0504, 0454, 0519, 0379, 0402, 0343, 0298, 0478, 0550, 0362, 0451, 0394, 0373, 0318, 0643, 0349, 0382, 0636, 0625, 0543, 0453, 0469, 0626, 0609, 0488, 0401, 0332, 0338, 0372, 0611, 0487, 0328, 0336, 0541, 0491, 0450, 0486, 0461, 0620, 0619, 0331, 0621, 0627, 0322, 0337, 0531, 0326, 0529, 0557, 0640, 0333, 0475, 0480, 0542, 0511, 0500, 0521, 0624, 0617, 0374, 0352, 0490, 0314, 0320, 0515, 0313,

0603, 0297, 0616, 0525, 0473, 0553, 0471, 0533, 0524, 0493, 0459, 0523, 0449, 0628, 0317, 0547, 0648, 0353, 0472, 0560, 0647, 0502, 0356, 0350, 0507, 0539, 0645, 0365, 0629, 0513, 0396, 0474, 0605, 0642, 0630, 0514, 0633, 0482, 0296, 0319, 0614, 0535, 0623, 0316, 0526, 0622, 0512, 0548, 0501, 0494, 0466, 0518, 0458, 0618, 0516, 0329, 0520, 0479, 0551, 0637, 0499, 0395, 0552, 0612, 0468, 0540, 0599, 0532, 0399, 0495, 0602, 0549, 0638, 0517, 0344, 0452, 0370, 0295, 0335, 0460, 0632, 0600, 0561, 0544, 0503, 0325, 0367, 0536, 0641, 0509, 0483, 0363, 0324, 0604, 0546, 0606, 0447, 0506, 0457, 0485, 0369, 0398, 0651, 0376, 0489, 0364, 0327, 0446, 0378, 0497, 0368, 0342, 0348, 0498, 0393, 0613, 0334, 0340, 0646, 0456, 0400, 0470, 0465, 0545, 0381, 0477, 0510, 0505, 0559, 0650, 0538, 0496;

* OOD: 0299, 0315, 0323, 0330, 0339, 0341, 0345, 0346, 0347, 0351, 0354, 0355, 0357, 0358, 0359, 0360, 0366, 0371, 0375, 0377, 0380, 0392, 0397, 0448, 0455, 0462, 0463, 0464, 0467, 0476, 0481, 0484, 0492, 0508, 0522, 0527, 0528, 0530, 0534, 0537, 0554, 0555, 0556, 0558, 0601, 0607, 0608, 0610, 0615, 0631, 0634, 0635, 0639, 0644, 0649;

B. Hyperparameters of the methods

In Tab. 5 we list the candidate values and final determined values for each method's hyperparameters. We make a few notes on the meaning of each symbol. For ODIN and Energy, τ is the temperature factor used to scale the model logits. Note, we do not use input pre-processing for ODIN as it is known that the perturbation hyperparameter may need exact test OOD distribution to tune [12, 14], and ODIN's performance is largely attributed to the temperature scaling rather than the pre-processing [34]. For Rotation, OE, and OE-M, β is the weighting term that controls the contribution of their regularization objective. For EnergyOE, m_{in} and m_{out} is the energy threshold for ID and training outlier data, respectively. We use $\beta = 0.1$ for EnergyOE, as we find that a larger β can hurt ID accuracy. For Mix and MixOE training, β again weights the regularization strength (see Eqn. 3). α is used to parameterize the Beta distribution for the mixing operations.

Table 5. The candidate values and final determined values for the hyperparameters of each method.

	Aircraft		Car		Butterfly		Bird	
	Candidates	Determined	Candidates	Determined	Candidates	Determined	Candidates	Determined
ODIN [25]	$\tau = \{10, 100, 1000\}$	$\tau = 1000$	$\tau = \{10, 100, 1000\}$	$\tau = 1000$	$\tau = \{10, 100, 1000\}$	$\tau = 1000$	$\tau = \{10, 100, 1000\}$	$\tau = 1000$
Energy [26]	$\tau = \{1, 10, 100\}$	$\tau = 1$	$\tau = \{1, 10, 100\}$	$\tau = 1$	$\tau = \{1, 10, 100\}$	$\tau = 1$	$\tau = \{1, 10, 100\}$	$\tau = 1$
Rotation [1]	$\beta = \{0.5, 1.0\}$	$\beta = 1.0$	$\beta = \{0.5, 1.0\}$	$\beta = 1.0$	$\beta = \{0.5, 1.0\}$	$\beta = 1.0$	$\beta = \{0.5, 1.0\}$	$\beta = 1.0$
OE [12]	$\beta = \{0.5, 1.0, 5.0\}$	$\beta = 1.0$	$\beta = \{0.5, 1.0, 5.0\}$	$\beta = 1.0$	$\beta = \{0.5, 1.0, 5.0\}$	$\beta = 1.0$	$\beta = \{0.5, 1.0, 5.0\}$	$\beta = 1.0$
OE-M [2]	$\beta = \{0.5, 1.0, 5.0\}$	$\beta = 1.0$	$\beta = \{0.5, 1.0, 5.0\}$	$\beta = 1.0$	$\beta = \{0.5, 1.0, 5.0\}$	$\beta = 1.0$	$\beta = \{0.5, 1.0, 5.0\}$	$\beta = 1.0$
EnergyOE [26]	$m_{\text{in}} = \{-9, -13, -17\}$ $m_{\text{out}} = \{-5, -7, -9\}$	$m_{\text{in}} = -17$ $m_{\text{out}} = -9$	$m_{\text{in}} = \{-9, -13, -17\}$ $m_{\text{out}} = \{-4, -6, -8\}$	$m_{\text{in}} = -13$ $m_{\text{out}} = -6$	$m_{\text{in}} = \{-10, -14, -18\}$ $m_{\text{out}} = \{-5, -7, -9\}$	$m_{\text{in}} = -14$ $m_{\text{out}} = -5$	$m_{\text{in}} = \{-9, -13, -17\}$ $m_{\text{out}} = \{-5, -7, -9\}$	$m_{\text{in}} = -13$ $m_{\text{out}} = -5$
Mix-*linear* [48]	$\alpha = \{0.4, 1.0, 2.0\}$ $\beta = \{0.5, 1.0, 5.0\}$	$\alpha = 1.0$ $\beta = 1.0$	$\alpha = \{0.4, 1.0, 2.0\}$ $\beta = \{0.5, 1.0, 5.0\}$	$\alpha = 2.0$ $\beta = 5.0$	$\alpha = \{0.4, 1.0, 2.0\}$ $\beta = \{0.5, 1.0, 5.0\}$	$\alpha = 1.0$ $\beta = 0.5$	$\alpha = \{0.4, 1.0, 2.0\}$ $\beta = \{0.5, 1.0, 5.0\}$	$\alpha = 1.0$ $\beta = 0.5$
Mix-*cut* [47]	$\alpha = \{0.4, 1.0, 2.0\}$ $\beta = \{0.5, 1.0, 5.0\}$	$\alpha = 2.0$ $\beta = 5.0$	$\alpha = \{0.4, 1.0, 2.0\}$ $\beta = \{0.5, 1.0, 5.0\}$	$\alpha = 2.0$ $\beta = 5.0$	$\alpha = \{0.4, 1.0, 2.0\}$ $\beta = \{0.5, 1.0, 5.0\}$	$\alpha = 0.4$ $\beta = 0.5$	$\alpha = \{0.4, 1.0, 2.0\}$ $\beta = \{0.5, 1.0, 5.0\}$	$\alpha = 0.4$ $\beta = 0.5$
MixOE-*linear*	$\alpha = \{0.4, 1.0, 2.0\}$ $\beta = \{0.5, 1.0, 5.0\}$	$\alpha = 1.0$ $\beta = 5.0$	$\alpha = \{0.4, 1.0, 2.0\}$ $\beta = \{0.5, 1.0, 5.0\}$	$\alpha = 1.0$ $\beta = 5.0$	$\alpha = \{0.4, 1.0, 2.0\}$ $\beta = \{0.5, 1.0, 5.0\}$	$\alpha = 1.0$ $\beta = 5.0$	$\alpha = \{0.4, 1.0, 2.0\}$ $\beta = \{0.5, 1.0, 5.0\}$	$\alpha = 1.0$ $\beta = 5.0$
MixOE-*cut*	$\alpha = \{0.4, 1.0, 2.0\}$ $\beta = \{0.5, 1.0, 5.0\}$	$\alpha = 2.0$ $\beta = 5.0$	$\alpha = \{0.4, 1.0, 2.0\}$ $\beta = \{0.5, 1.0, 5.0\}$	$\alpha = 2.0$ $\beta = 5.0$	$\alpha = \{0.4, 1.0, 2.0\}$ $\beta = \{0.5, 1.0, 5.0\}$	$\alpha = 1.0$ $\beta = 5.0$	$\alpha = \{0.4, 1.0, 2.0\}$ $\beta = \{0.5, 1.0, 5.0\}$	$\alpha = 1.0$ $\beta = 5.0$

C. Visualization procedure

Following [30], the visualization is enabled by training a "visualization" layer (denoted as vis layer for brevity). Specifically, the vis layer is a fully-connected layer that maps the output of DNN's penultimate layer (in our case with ResNet-50 the output is a 2048-dimensional vector) to a 2D space. When training such vis layer, we concatenate it to the penultimate layer of the ResNet and add another consequent linear layer that maps the 2D output of the vis layer to the class logits. Critically, the vis layer is trained by minimizing the cross-entropy loss on ID training data only; no OOD data are ever involved. This ensures that the process remains agnostic to any OOD samples. Also, during the training the preceding layers of the DNN model are freezed, so the visualization is faithful to the model. After the training, the visualization is performed by simply passing inputs into the model and taking the 2D outputs of the vis layer.

D. Analysis on ablation study

In this section, we conduct further analysis to explain the ablation study results presented in Fig. 5.

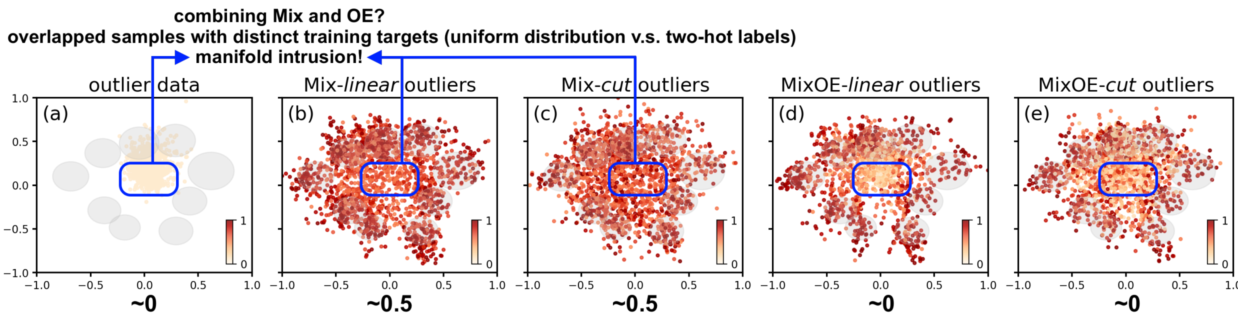

Figure 6. 2D Visualization of the data representations in the DNN's feature space. The color lightness indicates the confidence encoded in the soft target of the corresponding outlier sample. The numbers below the figures are the prediction confidence each method assigns to the outliers within the blue region during training. Compared with Mix training, our MixOE will enforce a more desirable confidence decay (from the highest level to the lowest level) as the inputs transitions from ID to OOD. This explains why MixOE outperforms Mix. Also, blindly combining Mix and OE will *not* work because of manifold intrusion [8]. See the text for detailed analysis.

Why MixOE is better than Mix training. To explain these results, using the same idea as Fig. 3, in Fig. 6 we visualize the training outliers used by Mix and MixOE in the feature space of a standardly trained model (see Fig. 12-15 for more).

Similar to MixOE, Mix training's data can also cover a broader space of the OOD region, which accounts for their improved performance against fine-grained OOD data. However, one problem we notice is that the confidence encoded in the soft targets of Mix training is still relatively high (above 50%) even when the corresponding inputs are already far away from the ID clusters. This is because when interpolating between two one-hot labels (as Mix does), the minimum confidence that can be achieved is 50%. Consequently, during Mix training the prediction confidence of the OOD samples that are relatively far away from the ID clusters may not be pushed towards the lowest level (*i.e.*, resembling uniform distribution as in MixOE; see Fig. 6). Such consequence can be confirmed by the distribution plots of Mix training's prediction confidence in Fig. 8-11. This reasoning explains why Mix training underperforms MixOE (especially its little effect on coarse OOD data) and further validates MixOE's idea of using ID and outlier data together to regularize the prediction confidence over the OOD region.

MixOE v.s. Mix + OE. Upon the previous discussion, one may wonder if naively combining the Mix and OE objective together can achieve similar effect to MixOE. Yet, a crucial problem with such combined objective is that it will assign distinct training targets to two overlapped groups of samples. Specifically, from the blue regions in Fig. 6 (a)/(b)/(c), one can see that the auxiliary outlier data can overlap with the mixed samples generated by the Mix training. However, their corresponding soft targets are very different: mixed samples are coupled with "two-hot" targets that result from the interpolation between two one-hot labels, yet the auxiliary outlier data are trained to match uniform distribution. This inconsistency is similar to the problem of manifold intrusion [8] and may cause learning difficulty for the model. Indeed, like we stated in the main text, when combining Mix and OE together, the model's accuracy can decrease by up to 10%, and the TNR95 can be worse than MSP by 10% and 20% against coarse- and fine-grained OOD samples, respectively.

E. Additional plots and results

Here we provide additional plots and results that are not shown in the main document due to space limit. Tab. 6 presents the full detection results in terms of both TNR95 and AUROC for all methods on all splits/datasets. Fig. 7 includes the bar plots that visualize the TNR95 statistics of existing methods on all splits/datasets. The corresponding numerical results can be found in Tab. 6. Fig. 8-11 show the confidence distributions of the Standard, OE, Corruption, Mix, and MixOE models on all splits/datasets. Fig. 12-15 show the 2D visualization of ID/OOD/training outlier data on all datasets. Tab. 7 presents the accuracy results of all methods on all splits/datasets.

Table 6. Full detection results. The number before and after the slash is for coarse-grained and fine-grained OOD samples, respectively. Avg. diff. is the average difference (across three splits) relative to MSP.

$\mathcal{D}_{\text{in}}$	Method	Split 1		Split 2		Split 3		Avg. diff.	
		TNR95	AUROC	TNR95	AUROC	TNR95	AUROC	TNR95	AUROC
Aircraft	MSP [11]	75.0 / 29.9	95.6 / 85.9	61.6 / 15.9	93.6 / 78.7	77.1 / 18.5	95.8 / 77.6	- / -	- / -
	ODIN [25]	87.5 / 30.2	97.4 / 85.5	73.2 / 15.3	95.6 / 75.5	86.5 / 15.8	97.2 / 78.6	+11.2 / –1.0	+1.7 / –0.9
	Energy [26]	88.5 / 30.1	97.5 / 85.2	74.4 / 14.6	95.6 / 74.9	86.2 / 16.3	97.2 / 78.3	+11.8 / –1.1	+1.8 / –1.3
	Rotation [1]	65.5 / 31.4	94.0 / 86.0	55.0 / 15.9	92.2 / 79.1	65.5 / 17.6	93.4 / 77.6	–9.2 / +0.2	–1.8 / +0.2
	Mix-*linear* [48]	80.6 / 34.2	96.2 / 86.6	80.5 / 19.8	96.6 / 77.6	76.8 / 20.9	95.6 / 78.4	+8.1 / +3.5	+1.1 / +0.1
	Mix-*cut* [47]	68.1 / 33.6	94.3 / 86.6	63.1 / 24.3	92.9 / 78.0	70.1 / 16.9	94.9 / 77.4	–4.1 / +3.5	–1.0 / –0.1
	OE [12]	99.3 / 27.8	99.8 / 84.6	98.5 / 16.0	99.6 / 78.4	98.7 / 16.5	99.7 / 78.7	+27.6 / –1.3	+4.7 / –0.2
	OE-M [2]	99.6 / 25.0	99.9 / 85.1	98.5 / 16.0	99.7 / 79.2	98.9 / 14.0	99.7 / 78.1	+27.8 / –3.1	+4.8 / +0.1
	EnergyOE [26]	99.8 / 30.3	99.9 / 86.9	99.7 / 17.0	99.8 / 76.7	99.7 / 19.9	99.8 / 79.1	+28.5 / +1.0	+4.8 / +0.2
	MixOE-*linear*	93.2 / 41.4	98.3 / 89.5	88.4 / 24.6	97.9 / 81.8	92.1 / 16.5	98.3 / 80.9	+20.0 / +6.1	+3.2 / +3.3
	MixOE-*cut*	99.0 / 39.8	99.7 / 89.4	99.4 / 23.7	99.7 / 80.1	99.4 / 24.9	99.8 / 78.6	+28.0 / +8.0	+4.7 / +2.0
Car	MSP [11]	95.5 / 58.5	98.8 / 90.2	88.0 / 56.3	97.8 / 90.6	78.8 / 53.5	96.4 / 90.2	- / -	- / -
	ODIN [25]	99.6 / 55.6	99.7 / 89.0	99.1 / 47.0	99.5 / 88.2	97.8 / 49.0	99.2 / 88.7	+11.4 / –5.6	+1.8 / –1.7
	Energy [26]	99.7 / 49.1	99.8 / 88.1	99.4 / 39.7	99.7 / 86.8	99.1 / 42.6	99.6 / 87.7	+12.0 / –12.3	+2.0 / –2.8
	Rotation [1]	97.7 / 58.9	99.3 / 90.5	88.1 / 52.4	97.6 / 90.1	81.3 / 50.4	96.9 / 90.0	+1.6 / –2.2	+0.3 / –0.1
	Mix-*linear* [48]	95.9 / 66.3	98.8 / 91.9	82.6 / 52.3	96.7 / 89.0	77.8 / 58.6	95.5 / 91.2	–2.0 / +3.0	–0.7 / +0.4
	Mix-*cut* [47]	84.6 / 68.8	97.0 / 92.0	70.6 / 65.3	93.8 / 92.2	70.6 / 61.6	93.1 / 91.6	–12.2 / +9.1	–3.0 / +1.6
	OE [12]	99.9 / 53.2	100.0 / 89.9	100.0 / 53.0	100.0 / 89.7	99.9 / 51.2	100.0 / 90.2	+12.5 / –3.6	+2.3 / –0.4
	OE-M [2]	99.9 / 53.6	100.0 / 88.9	100.0 / 49.4	100.0 / 89.5	100.0 / 50.6	100.0 / 90.1	+12.5 / –4.9	+2.3 / –0.8
	EnergyOE [26]	100.0 / 52.6	100.0 / 89.0	100.0 / 41.0	100.0 / 87.2	100.0 / 44.9	100.0 / 88.3	+12.6 / –9.9	+2.3 / –2.2
	MixOE-*linear*	99.6 / 65.9	99.8 / 92.2	99.7 / 62.9	99.8 / 92.3	99.5 / 60.1	99.8 / 92.0	+12.2 / +6.9	+2.1 / +1.8
	MixOE-*cut*	99.9 / 70.3	99.9 / 92.6	100.0 / 69.8	99.9 / 93.0	99.9 / 66.5	99.9 / 93.1	+12.5 / +12.8	+2.2 / +2.6
Butterfly	MSP [11]	87.1 / 29.9	97.8 / 79.3	89.9 / 31.8	97.9 / 78.2	88.4 / 36.6	97.9 / 83.8	- / -	- / -
	ODIN [25]	95.2 / 28.2	98.7 / 74.5	95.5 / 32.5	98.8 / 77.3	95.6 / 38.7	98.8 / 82.5	+7.0 / +0.4	+0.9 / –2.3
	Energy [26]	95.3 / 25.5	98.7 / 73.9	95.2 / 30.2	98.7 / 76.7	95.6 / 36.1	98.7 / 82.0	+6.9 / –2.2	+0.8 / –2.9
	Rotation [1]	87.9 / 27.6	97.8 / 78.0	88.5 / 31.2	97.9 / 79.7	86.2 / 37.0	97.5 / 83.9	–0.9 / –0.8	–0.1 / +0.1
	Mix-*linear* [48]	90.7 / 31.3	98.1 / 78.5	88.7 / 34.9	97.8 / 80.6	84.7 / 37.9	97.2 / 83.6	–0.4 / +1.9	–0.2 / +0.5
	Mix-*cut* [47]	85.7 / 30.4	97.3 / 78.6	86.3 / 34.6	97.2 / 79.7	84.7 / 40.5	97.1 / 84.3	–2.9 / +2.4	–0.7 / +0.4
	OE [12]	92.2 / 26.5	98.4 / 77.8	93.7 / 32.1	98.4 / 79.3	94.3 / 34.3	98.6 / 82.6	+4.9 / –1.8	+0.6 / –0.5
	OE-M [2]	88.5 / 26.9	97.7 / 78.0	94.0 / 30.5	98.4 / 79.0	93.9 / 37.8	98.4 / 83.6	+3.7 / –1.0	+0.3 / –0.2
	EnergyOE [26]	97.8 / 25.1	99.1 / 73.5	96.9 / 30.5	98.9 / 75.9	98.2 / 37.2	99.1 / 82.6	+9.2 / –1.8	+1.2 / –3.1
	MixOE-*linear*	95.3 / 32.6	98.7 / 78.3	93.9 / 37.9	98.6 / 80.9	95.5 / 45.0	98.8 / 84.9	+6.4 / +5.7	+0.8 / +0.9
	MixOE-*cut*	94.9 / 35.8	98.8 / 79.8	94.1 / 38.8	98.7 / 81.7	92.7 / 46.0	98.6 / 86.8	+5.4 / +7.4	+0.8 / +2.3
Bird	MSP [11]	72.3 / 22.6	93.7 / 76.4	67.4 / 22.3	93.5 / 78.0	66.4 / 22.3	92.9 / 76.9	- / -	- / -
	ODIN [25]	80.9 / 22.7	95.3 / 75.5	77.2 / 21.5	95.5 / 76.6	74.3 / 21.9	94.5 / 75.8	+8.8 / –0.4	+1.7 / –1.1
	Energy [26]	80.8 / 20.3	95.3 / 74.8	76.5 / 18.4	95.4 / 75.5	73.9 / 18.8	94.4 / 74.8	+8.4 / –3.2	+1.7 / –2.1
	Rotation [1]	71.3 / 23.6	93.9 / 76.0	64.0 / 24.0	92.7 / 78.7	65.4 / 21.5	92.8 / 76.8	–1.8 / +0.6	–0.2 / +0.1
	Mix-*linear* [48]	72.1 / 24.4	94.0 / 77.6	70.0 / 25.3	94.0 / 79.9	71.0 / 25.0	94.3 / 79.5	+2.3 / +2.5	+0.7 / +1.9
	Mix-*cut* [47]	69.0 / 25.6	93.5 / 77.1	58.7 / 23.6	92.1 / 79.2	65.3 / 25.0	92.9 / 77.9	–4.4 / +2.3	–0.5 / +1.0
	OE [12]	98.2 / 20.6	99.5 / 75.9	97.9 / 22.9	99.5 / 78.2	97.9 / 20.7	99.5 / 77.0	+29.3 / –1.0	+6.1 / –0.1
	OE-M [2]	98.7 / 19.8	99.6 / 76.1	98.7 / 21.4	99.6 / 78.2	97.7 / 19.2	99.4 / 76.5	+29.7 / –2.3	+6.2 / –0.2
	EnergyOE [26]	98.6 / 19.4	99.6 / 74.4	99.0 / 18.4	99.7 / 76.2	99.3 / 19.5	99.7 / 77.7	+30.3 / –3.3	+6.3 / –1.0
	MixOE-*linear*	88.6 / 24.9	97.6 / 77.8	83.9 / 26.7	96.6 / 80.6	86.3 / 28.6	97.1 / 80.7	+17.6 / +4.3	+3.7 / +2.6
	MixOE-*cut*	91.0 / 27.7	98.0 / 78.6	91.8 / 24.6	98.4 / 80.2	92.9 / 27.7	98.7 / 80.0	+23.2 / +4.3	+5.0 / +2.5

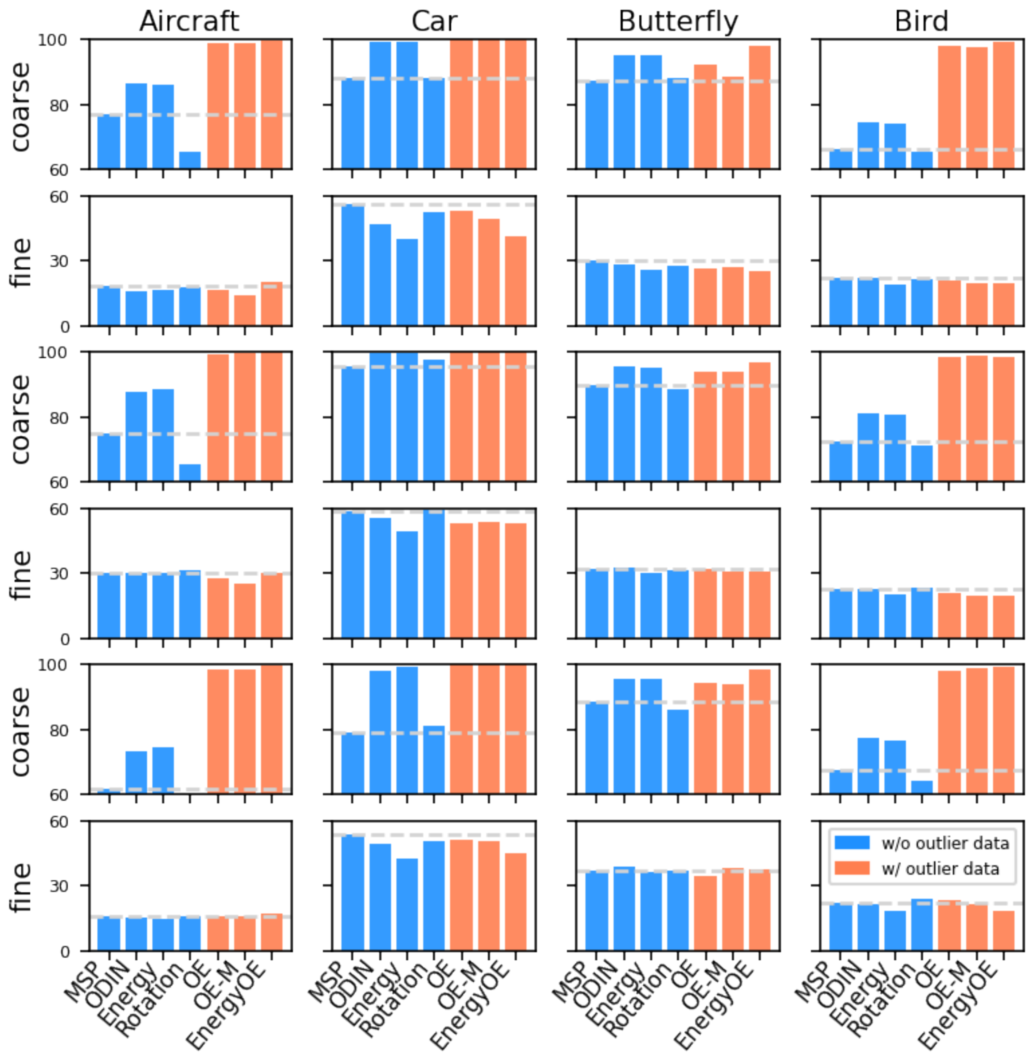

Figure 7. TNR95 statistics of existing methods on all of the three splits in each dataset. Each two rows correspond to one split.

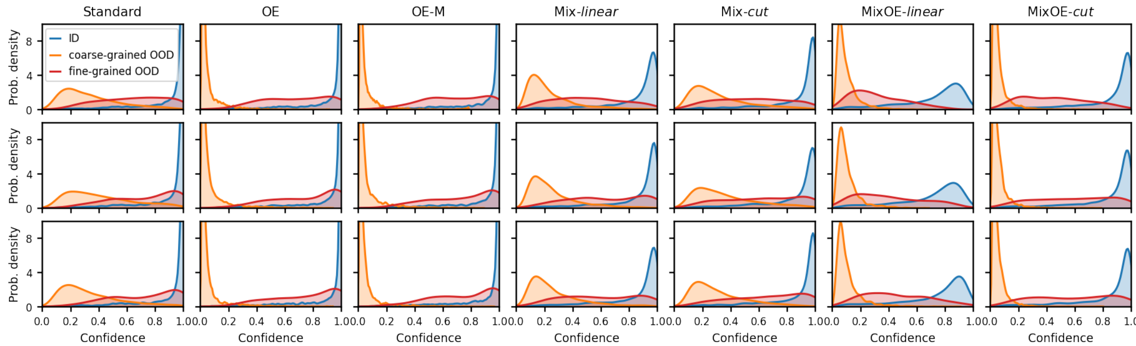

Figure 8. Confidence density plots on the three splits in the *Aircraft* dataset.

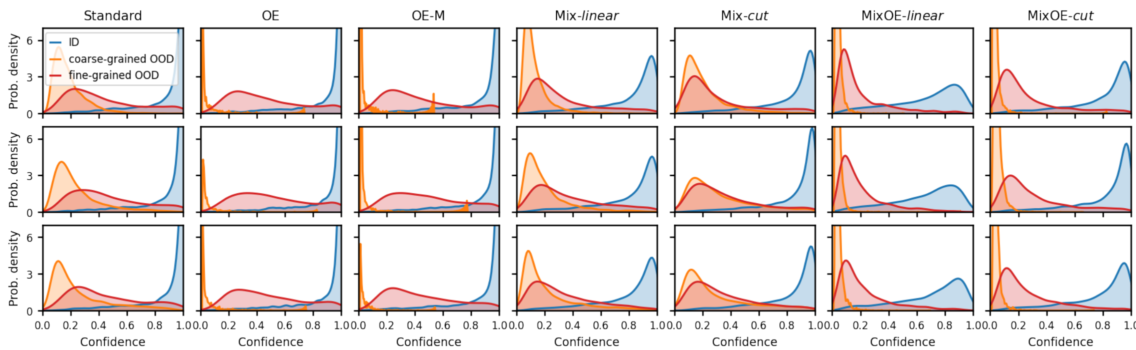

Figure 9. Confidence density plots on the three splits in the *Car* dataset.

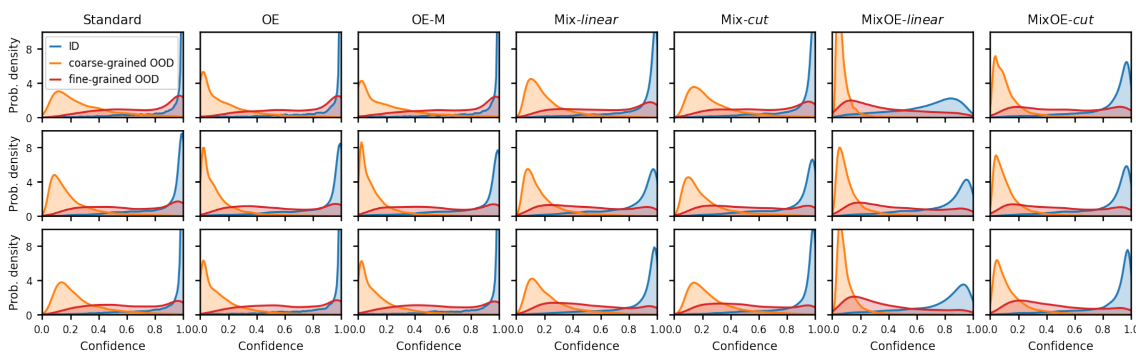

Figure 10. Confidence density plots on the three splits in the *Butterfly* dataset.

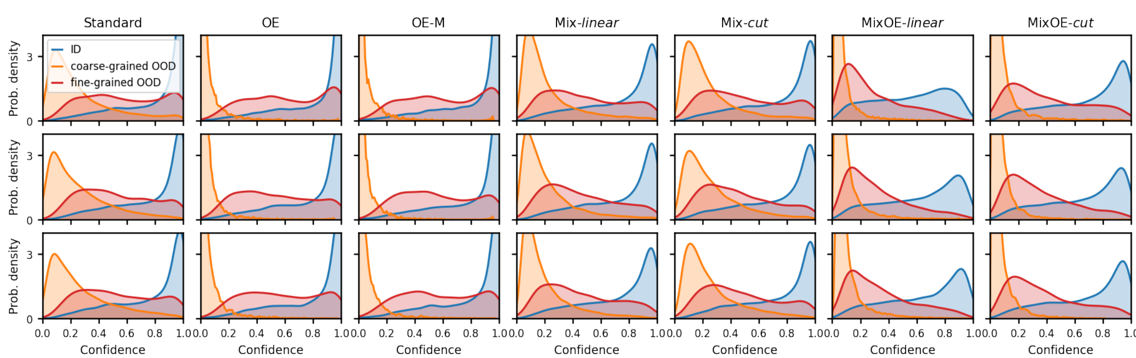

Figure 11. Confidence density plots on the three splits in the *Bird* dataset.

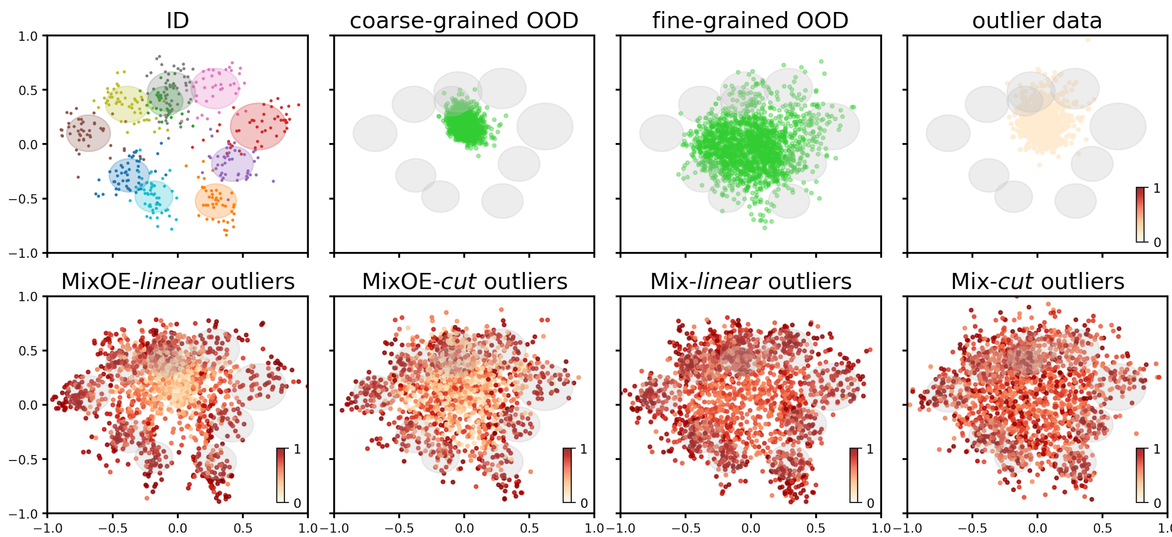

Figure 12. 2D visualization of ID/OOD/training outlier data in the feature space for the *Aircraft* dataset.

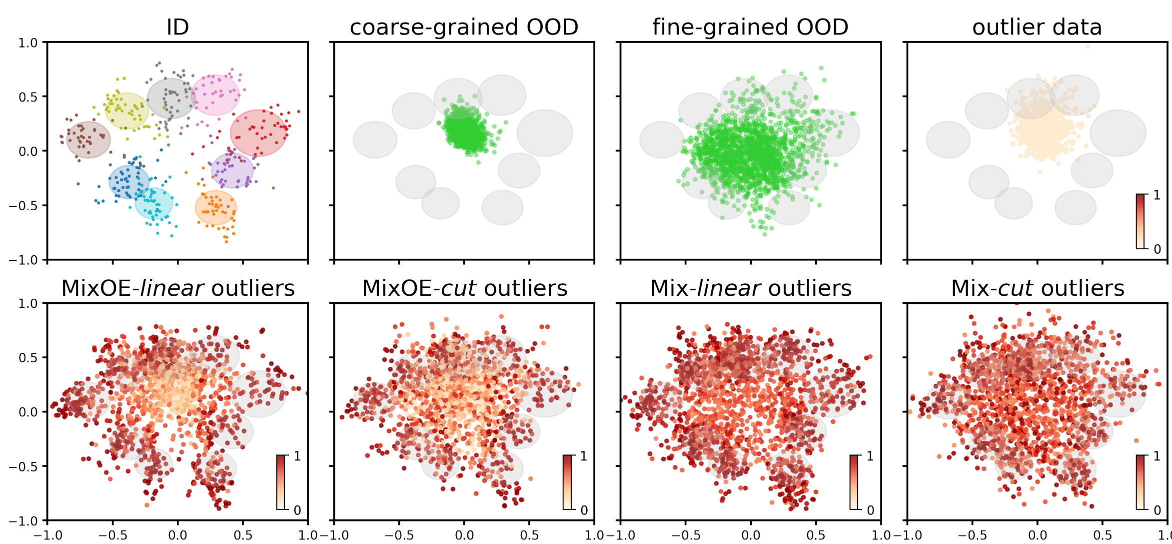

Figure 13. 2D visualization of ID/OOD/training outlier data in the feature space for the *Car* dataset.

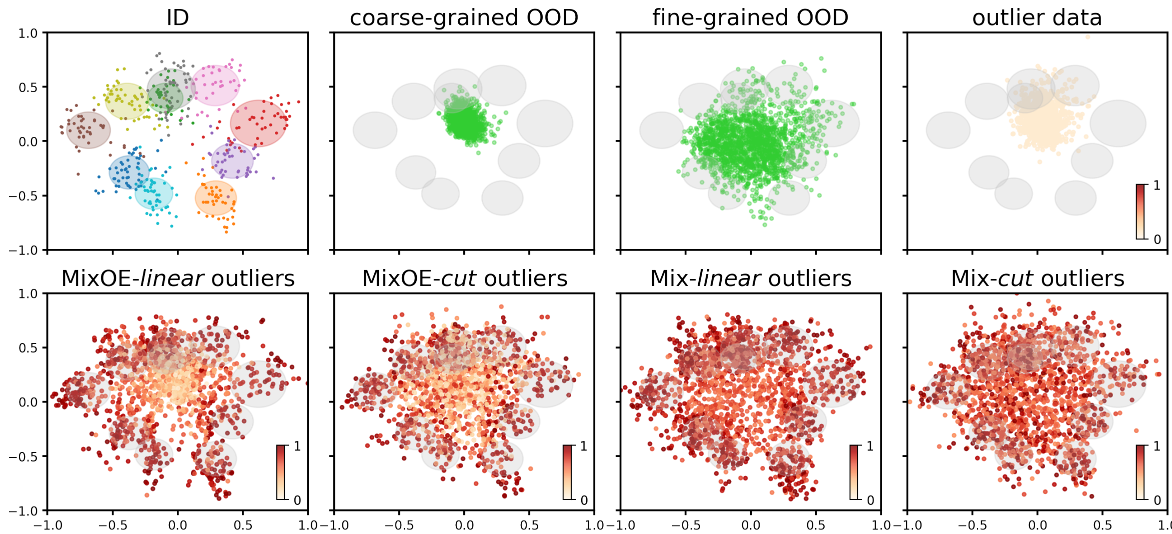

Figure 14. 2D visualization of ID/OOD/training outlier data in the feature space for the *Butterfly* dataset.

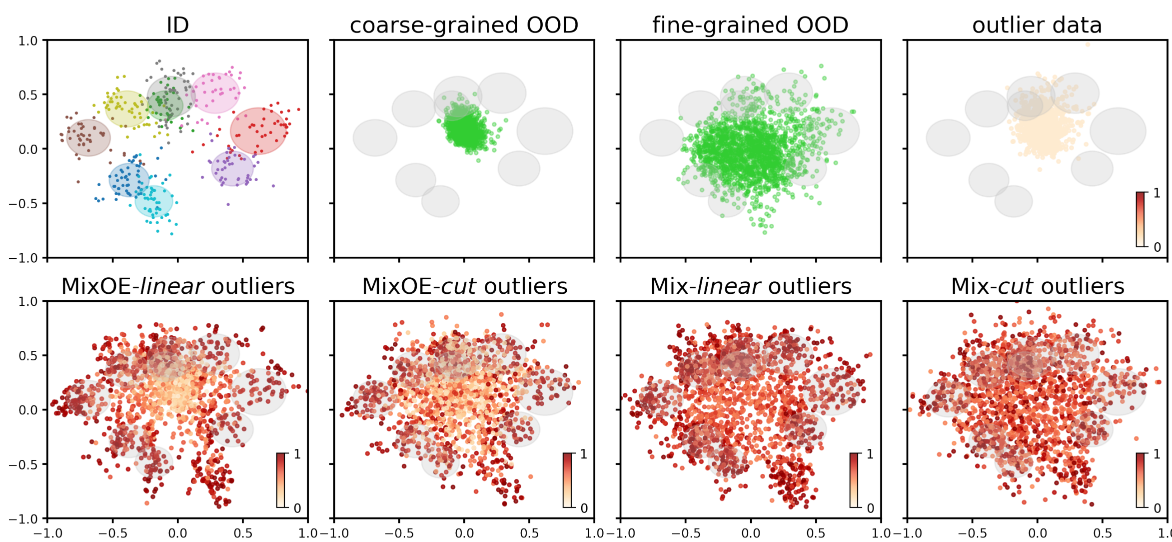

Figure 15. 2D visualization of ID/OOD/training outlier data in the feature space for the *Bird* dataset.

Table 7. Full accuracy results on each split of each dataset.

$\mathcal{D}_{\text{in}}$	Method	Split 1	Split 2	Split 3
Aircraft	Standard	89.53	89.41	89.94
	Rotation [1]	88.20	88.31	89.01
	OE [12]	88.57	88.87	90.08
	OE-M [2]	89.50	88.77	89.54
	EnergyOE [26]	89.27	88.81	89.88
	MixOE-*linear*	89.93	90.81	90.64
	MixOE-*cut*	89.77	90.21	90.31
Car	Standard	91.74	92.19	91.57
	Rotation [1]	91.38	91.64	90.82
	OE [12]	91.56	91.75	91.53
	OE-M [2]	90.58	91.22	91.40
	EnergyOE [26]	91.61	92.16	91.76
	MixOE-*linear*	92.53	93.53	92.76
	MixOE-*cut*	92.74	93.46	92.56
Butterfly	Standard	90.21	87.28	89.38
	Rotation [1]	89.75	87.88	88.88
	OE [12]	89.74	86.13	88.41
	OE-M [2]	89.99	85.62	88.86
	EnergyOE [26]	90.21	87.22	88.86
	MixOE-*linear*	90.71	88.04	89.10
	MixOE-*cut*	91.33	88.46	90.53
Bird	Standard	83.30	82.03	80.96
	Rotation [1]	82.47	82.25	81.26
	OE [12]	83.32	82.03	81.75
	OE-M [2]	83.35	82.70	81.93
	EnergyOE [26]	82.89	82.57	81.36
	MixOE-*linear*	84.18	83.29	82.75
	MixOE-*cut*	84.37	83.44	82.57