Supplementary Material to "Hyperparameter-Free Out-of-Distribution Detection Using Cosine Similarity"

A. Detailed Results of Less-Biased Evaluation

In the main paper, we report results of the less-biased evaluation in Fig. 1. We show here additional, more detailed results of the same experiments including two additional metrics, i.e., accuracy at TPR= 95% and AUPR-In, in Table 4. The details of the experimental configurations are provided in Sec. 4.3 of the main paper.

Table 4. More detailed results of OOD detection performance measured by the less-biased evaluation. The same four methods as those considered in the main paper are compared.

Network	ID	OOD	Accuracy at TPR= 95%	AUROC	AUPR-In
			Baseline [1] / ODIN [2] / Mahalanobis [3] / Ours	Baseline [1] / ODIN [2] / Mahalanobis [3] / Ours	Baseline [1] / ODIN [2] / Mahalanobis [3] / Ours
Dense-100-12	CIFAR-10	TIN (c)*	74.53(1.93) / 87.45(3.49) / 81.94(11.54) / **94.34(0.61)**	93.26(0.85) / 96.02(1.64) / 90.16(11.53) / **98.74(0.23)**	94.61(0.80) / 95.87(2.20) / 89.54(13.12) / **98.86(0.19)**
		TIN (r)	73.51(2.48) / 88.42(4.02) / 86.52(12.24) / **94.67(0.60)**	92.67(1.23) / 96.43(1.64) / 92.97(10.27) / **98.82(0.29)**	94.06(1.17) / 96.42(1.92) / 92.36(11.57) / **98.89(0.26)**
		LSUN (c)*	75.35(1.90) / 85.40(2.07) / 74.04(9.96) / **94.54(0.39)**	93.72(0.39) / 94.57(1.40) / 83.64(16.27) / **98.83(0.18)**	95.06(0.27) / 93.63(2.32) / 83.67(16.41) / **98.88(0.17)**
		LSUN (r)	76.74(1.40) / 92.05(2.55) / 87.07(12.11) / **95.72(0.56)**	94.28(0.52) / 97.86(0.97) / 94.21(7.96) / **99.19(0.22)**	95.60(0.44) / 97.99(1.01) / 94.22(8.49) / **99.26(0.20)**
		iSUN	75.12(2.08) / 90.60(2.99) / 86.53(12.74) / **95.62(0.51)**	93.62(0.83) / 97.33(1.15) / 93.33(9.83) / **99.20(0.19)**	95.48(0.66) / 97.69(1.14) / 93.70(9.85) / **99.33(0.16)**
		SVNH	68.84(2.90) / 76.81(7.84) / 81.63(17.75) / **95.36(0.87)**	90.28(2.47) / 89.81(5.11) / 82.92(27.86) / **99.11(0.36)**	82.90(7.23) / 76.03(11.04) / 78.05(30.89) / **97.99(0.73)**
		Food-101	67.93(0.59) / 71.83(5.12) / 56.14(4.56) / **79.79(1.03)**	89.87(0.44) / 87.43(4.92) / 73.10(8.68) / **93.98(0.54)**	83.58(0.96) / 73.45(11.31) / 58.06(11.76) / **89.99(0.90)**
		MNIST	76.35(3.52) / **95.81(2.11)** / 91.93(11.67) / 95.15(1.51)	94.54(1.02) / **99.24(0.68)** / 96.60(7.90) / 98.90(0.49)	95.98(0.83) / **99.36(0.55)** / 97.66(5.91) / 99.06(0.42)
		F-MNIST	81.65(2.11) / **95.70(1.25)** / 79.22(9.62) / 94.83(0.71)	95.76(0.50) / **99.20(0.47)** / 92.86(6.69) / 98.84(0.21)	96.76(0.35) / **99.28(0.39)** / 94.15(6.49) / 98.94(0.17)
		NotMNIST	75.95(3.71) / 90.83(5.11) / 89.22(7.87) / **95.75(1.09)**	93.72(1.49) / 97.33(1.75) / 94.99(7.17) / **99.01(0.30)**	91.90(2.37) / 95.26(2.89) / 89.81(11.58) / **98.62(0.45)**
		Gaussian	63.72(14.12) / 90.27(16.11) / 95.02(10.42) / **97.50(0.00)**	91.96(4.29) / 97.92(3.28) / 97.51(13.79) / **100.00(0.00)**	95.17(2.27) / 98.71(1.98) / 98.35(9.25) / **100.00(0.00)**
		Uniform	60.28(19.27) / 82.27(21.01) / 94.94(10.75) / **97.50(0.00)**	88.72(7.18) / 94.66(7.88) / 97.42(13.85) / **100.00(0.00)**	93.28(4.22) / 96.61(5.07) / 98.20(9.49) / **100.00(0.00)**
	CIFAR-100	TIN (c)*	60.26(1.93) / 70.35(5.42) / 65.48(12.80) / **89.81(1.52)**	79.32(4.14) / 86.48(4.87) / 71.81(23.34) / **97.31(0.45)**	80.66(6.76) / 85.96(6.62) / 73.56(20.11) / **97.55(0.37)**
		TIN (r)	58.66(2.35) / 70.94(6.67) / 70.66(16.66) / **91.37(1.59)**	77.07(6.35) / 86.12(6.70) / 75.25(25.95) / **97.82(0.53)**	78.60(9.30) / 85.48(8.86) / 77.31(21.32) / **97.99(0.45)**
		LSUN (c)*	58.61(0.57) / 67.31(3.92) / 59.41(7.88) / **85.26(0.79)**	78.46(0.91) / 84.87(2.21) / 63.89(22.87) / **95.52(0.32)**	80.86(0.93) / 85.02(1.94) / 66.59(20.06) / **95.82(0.29)**
		LSUN (r)	59.32(2.47) / 72.23(7.36) / 70.16(17.28) / **90.69(2.23)**	78.44(5.41) / 87.80(5.81) / 76.61(25.13) / **97.59(0.75)**	80.74(6.55) / 87.99(6.59) / 79.78(19.97) / **97.83(0.65)**
		iSUN	58.37(2.76) / 70.66(7.07) / 69.86(17.11) / **90.48(2.17)**	76.89(6.28) / 86.28(6.40) / 75.20(25.92) / **97.45(0.73)**	80.56(7.56) / 87.43(6.90) / 79.64(19.95) / **97.88(0.56)**
		SVNH	56.40(1.82) / 60.28(8.31) / 64.99(14.82) / **88.42(2.57)**	77.36(2.83) / 80.18(5.87) / 68.85(29.66) / **96.90(0.79)**	66.58(4.07) / 67.51(7.64) / 60.65(31.79) / **93.95(1.33)**
		Food-101	62.64(0.63) / 61.81(5.88) / 50.09(2.38) / **68.29(1.18)**	84.38(0.48) / 83.91(5.60) / 62.73(10.63) / **90.79(0.49)**	77.21(0.77) / 74.57(8.77) / 48.80(12.33) / **86.96(0.59)**
		STL-10	57.82(1.32) / 67.22(4.44) / 64.71(13.15) / **75.20(3.96)**	76.53(2.23) / 83.14(3.86) / 70.19(26.16) / **90.28(1.95)**	81.56(2.67) / 85.23(3.91) / 76.73(20.01) / **92.43(1.54)**
		MNIST	62.68(2.68) / **87.24(6.78)** / 64.53(20.93) / 86.62(5.51)	81.56(3.83) / 96.09(3.00) / 83.64(22.90) / **96.17(2.06)**	84.50(3.62) / 96.49(2.65) / 89.05(16.34) / **96.62(1.82)**
		F-MNIST	70.15(1.95) / 90.24(3.60) / 62.67(18.30) / **94.69(1.10)**	88.52(1.04) / 97.33(1.27) / 79.12(19.24) / **98.92(0.35)**	90.30(0.80) / 97.54(1.07) / 84.07(15.08) / **99.02(0.31)**
		NotMNIST	59.04(1.67) / 79.64(6.86) / 71.91(16.07) / **84.44(3.09)**	79.97(1.37) / 92.35(3.38) / 82.46(22.02) / **95.80(0.86)**	73.28(2.54) / 87.56(4.71) / 78.13(22.69) / **93.87(1.12)**
		Gaussian	47.54(0.05) / 55.72(14.42) / 75.98(24.43) / **97.50(0.00)**	53.73(13.50) / 61.56(31.80) / 68.81(40.93) / **99.74(0.52)**	69.06(10.42) / 73.30(23.12) / 78.59(28.01) / **99.84(0.30)**
		Uniform	48.34(1.81) / 60.07(20.04) / 77.50(23.34) / **97.50(0.01)**	63.59(20.05) / 75.66(20.60) / 73.64(39.00) / **99.71(0.56)**	75.90(13.16) / 83.94(14.22) / 81.48(26.97) / **99.82(0.34)**
WRN-28-10	CIFAR-10	TIN (c)*	76.10(1.38) / 81.36(3.70) / 89.67(7.11) / **92.63(1.26)**	91.79(1.57) / 90.35(3.81) / 96.50(4.12) / **98.17(0.33)**	90.94(2.91) / 87.44(5.17) / 96.28(5.14) / **98.42(0.27)**
		TIN (r)	72.35(2.13) / 79.39(4.11) / **91.47(7.96)** / 91.05(2.24)	89.21(2.65) / 89.43(3.78) / 96.96(4.98) / **97.65(0.66)**	87.62(4.65) / 86.83(5.01) / 96.60(6.01) / **97.94(0.54)**
		LSUN (c)*	78.31(2.05) / 81.76(2.78) / 85.97(2.24) / **94.96(0.16)**	93.67(0.50) / 90.12(3.69) / 95.69(1.16) / **98.98(0.07)**	93.90(0.56) / 86.47(5.93) / 95.98(1.79) / **99.06(0.05)**
		LSUN (r)	76.39(2.41) / 84.92(3.58) / 92.85(7.86) / **94.02(1.29)**	92.45(1.48) / 93.48(2.45) / 97.78(4.34) / **98.59(0.34)**	92.33(2.31) / 92.19(3.13) / 97.94(4.23) / **98.79(0.28)**
		iSUN	74.82(2.19) / 83.11(3.82) / 92.54(7.77) / **93.47(1.35)**	91.22(2.05) / 92.21(2.94) / 97.64(4.37) / **98.48(0.36)**	91.40(3.31) / 91.44(3.60) / 97.89(4.47) / **98.82(0.26)**
		SVNH	80.66(2.52) / 81.60(5.57) / 94.14(1.97) / **96.50(0.69)**	94.43(1.30) / 90.52(4.39) / 98.63(0.83) / **99.52(0.24)**	88.55(4.75) / 74.03(11.15) / 97.11(2.52) / **98.94(0.52)**
		Food-101	71.61(1.04) / 70.21(5.85) / 63.31(5.20) / **78.73(1.42)**	89.71(0.90) / 80.29(8.31) / 84.19(5.85) / **93.95(0.41)**	76.04(3.29) / 55.33(13.49) / 73.64(9.95) / **90.41(0.47)**
		MNIST	72.35(5.94) / 87.91(6.39) / **95.08(4.88)** / 94.60(1.22)	91.16(3.19) / 95.67(2.84) / **98.83(1.22)** / 98.60(0.39)	91.37(3.95) / 95.22(3.27) / **99.19(0.86)** / 98.91(0.28)
		F-MNIST	81.20(1.34) / 90.65(2.12) / 92.05(5.25) / **94.03(0.72)**	94.59(0.61) / 96.71(0.96) / 97.73(1.85) / **98.60(0.24)**	94.91(0.79) / 96.13(1.20) / 98.21(1.85) / **98.78(0.20)**
		NotMNIST	81.27(2.34) / 92.38(3.23) / 95.95(2.67) / **96.33(0.62)**	95.00(0.58) / 97.60(1.06) / **99.28(0.85)** / 99.11(0.28)	92.37(1.43) / 94.82(1.96) / **98.85(1.40)** / 98.84(0.32)
		Gaussian	82.94(17.44) / 93.87(7.97) / 97.12(2.80) / **97.50(0.00)**	95.16(6.00) / 98.52(2.71) / 99.60(2.91) / **99.98(0.02)**	96.47(4.70) / 98.80(2.29) / 99.39(4.51) / **99.99(0.01)**
		Uniform	78.59(14.28) / 93.38(5.71) / 96.25(6.97) / **97.50(0.00)**	95.30(2.90) / 98.52(1.69) / 98.01(13.34) / **99.99(0.01)**	96.70(2.10) / 98.81(1.38) / 98.47(9.15) / **99.99(0.01)**
	CIFAR-100	TIN (c)*	61.96(0.78) / 69.18(2.82) / 77.40(12.03) / **85.01(1.35)**	80.90(0.90) / 85.73(1.93) / 87.95(13.71) / **95.91(0.42)**	81.38(1.79) / 85.44(2.16) / 88.31(13.86) / **96.48(0.31)**
		TIN (r)	58.89(0.99) / 68.94(4.03) / 80.24(14.04) / **84.94(2.40)**	76.67(2.03) / 84.60(3.21) / 88.31(16.07) / **95.84(0.67)**	76.74(3.62) / 84.20(3.69) / 88.70(15.65) / **96.40(0.47)**
		LSUN (c)*	58.99(0.77) / 66.46(5.62) / 69.79(7.98) / **82.97(1.77)**	79.17(1.25) / 83.37(3.97) / 83.87(11.80) / **94.92(0.65)**	80.88(1.99) / 82.91(4.16) / 84.43(12.89) / **95.45(0.57)**
		LSUN (r)	58.98(1.47) / 69.64(4.44) / 79.14(14.57) / **82.76(2.40)**	78.00(1.95) / 86.05(2.90) / 88.30(15.18) / **95.18(0.86)**	79.25(2.28) / 86.09(2.87) / 88.98(14.72) / **95.92(0.68)**
		iSUN	58.54(1.43) / 68.94(4.43) / 79.29(14.03) / **83.73(1.92)**	77.29(2.15) / 85.38(3.03) / 88.01(15.49) / **95.39(0.55)**	80.27(2.59) / 86.73(2.80) / 89.40(14.30) / **96.40(0.35)**
		SVNH	58.13(2.90) / 66.73(10.20) / 76.30(14.18) / **90.28(1.57)**	79.82(2.49) / 83.05(7.38) / 86.67(16.70) / **97.52(0.41)**	66.44(4.78) / 68.06(11.64) / 79.01(22.03) / **95.13(0.54)**
		Food-101	69.12(0.76) / 63.20(4.76) / 58.46(6.74) / **72.68(1.01)**	89.25(0.40) / 83.76(4.39) / 80.49(11.90) / **92.53(0.38)**	83.20(0.70) / 70.63(8.14) / 73.20(16.92) / **89.37(0.54)**
		STL-10	58.23(0.55) / 64.30(2.64) / **72.25(11.96)** / 71.03(1.17)	77.68(0.61) / 81.20(2.27) / 84.18(16.28) / **88.89(0.51)**	81.66(1.01) / 83.70(2.31) / 87.95(12.62) / **91.70(0.43)**
		MNIST	61.79(5.62) / 83.33(7.90) / 72.71(13.36) / **85.60(3.96)**	82.64(4.73) / 95.07(3.39) / 87.62(12.89) / **96.03(1.49)**	85.99(3.87) / 95.84(2.82) / 89.95(11.51) / **96.59(1.25)**
		F-MNIST	72.39(2.13) / 86.47(3.21) / 76.60(10.40) / **92.48(1.22)**	90.33(1.02) / 95.93(1.09) / 90.71(10.09) / **98.27(0.36)**	91.74(0.87) / 96.18(0.97) / 92.33(8.75) / **98.46(0.31)**
		NotMNIST	56.15(1.61) / 76.13(7.89) / **82.57(14.47)** / 77.23(2.62)	80.00(2.79) / 91.23(3.99) / 89.53(17.24) / **93.05(1.47)**	73.99(4.65) / 86.76(5.07) / 85.80(21.25) / **90.53(2.00)**
		Gaussian	47.54(0.07) / 75.96(21.36) / 88.34(18.59) / **97.50(0.00)**	59.59(30.02) / 82.89(24.64) / 88.04(30.26) / **99.82(0.15)**	73.02(23.16) / 88.04(17.98) / 91.67(20.57) / **99.88(0.09)**

In the above experiments, we used TIN(c)* and LSUN(c)*, i.e., our corrected version of the cropped images from TinyImageNet and LSUN; see Sec. F. For the sake of completeness, we also conducted the same experiments using TIN(c) and LSUN(c), their original versions having a two-pixel black frame, supplied by the GitHub repo of the authors of ODIN [2]. Table 5 shows the results.

Table 5. More detailed results of OOD detection performance measured by the less-biased evaluation. The original cropped images are used instead of their '*' version.

Network	ID	OOD	Accuracy at TPR= 95%	AUROC	AUPR-In
			Baseline [1] / ODIN [2] / Mahalanobis [3] / Ours		
Dense-100-12	CIFAR-10	TIN (c)	78.86(1.37) / 93.31(2.04) / 75.77(7.50) / **94.83(0.68)**	94.90(0.43) / 98.31(0.82) / 86.44(8.15) / **98.89(0.24)**	96.09(0.36) / 98.39(0.90) / 85.19(9.46) / **98.97(0.20)**
		TIN (r)	73.51(2.48) / 88.47(3.99) / 82.87(13.81) / **94.67(0.60)**	92.67(1.23) / 96.44(1.63) / 90.45(11.13) / **98.82(0.29)**	94.06(1.17) / 96.42(1.92) / 89.51(12.38) / **98.89(0.26)**
		LSUN (c)	81.22(1.46) / 92.22(1.49) / 65.60(6.43) / **95.27(0.19)**	95.57(0.20) / 97.78(0.77) / 76.89(9.64) / **99.09(0.12)**	96.59(0.11) / 97.62(1.11) / 75.44(10.64) / **99.12(0.11)**
		LSUN (r)	76.74(1.40) / 92.09(2.51) / 83.55(13.63) / **95.72(0.56)**	94.28(0.52) / 97.87(0.96) / 92.18(8.81) / **99.19(0.22)**	95.60(0.44) / 97.99(1.00) / 92.19(9.12) / **99.26(0.20)**
		iSUN	75.12(2.08) / 90.64(2.95) / 82.53(14.57) / **95.62(0.51)**	93.62(0.83) / 97.34(1.14) / 90.59(11.06) / **99.20(0.19)**	95.48(0.66) / 97.69(1.14) / 91.08(10.81) / **99.33(0.16)**
		SVNH	68.84(2.90) / 76.56(8.01) / 74.45(20.13) / **95.36(0.87)**	90.28(2.47) / 89.62(5.30) / 72.18(32.66) / **99.11(0.36)**	82.90(7.23) / 75.67(11.31) / 65.64(35.76) / **97.99(0.73)**
		Food-101	67.93(0.59) / 71.93(5.11) / 56.95(4.79) / **79.79(1.03)**	89.87(0.44) / 87.48(4.91) / 73.17(8.51) / **93.98(0.54)**	83.58(0.96) / 73.56(11.24) / 57.03(11.25) / **89.99(0.90)**
		MNIST	76.35(3.52) / **95.86(2.06)** / 91.42(11.63) / 95.15(1.51)	94.54(1.02) / **99.26(0.67)** / 96.59(7.93) / 98.90(0.49)	95.98(0.83) / **99.37(0.53)** / 97.60(5.92) / 99.06(0.42)
		F-MNIST	81.65(2.11) / **95.72(1.25)** / 79.24(10.83) / 94.83(0.71)	95.76(0.50) / **99.20(0.47)** / 92.32(7.38) / 98.84(0.21)	96.76(0.35) / **99.29(0.39)** / 93.38(7.38) / 98.94(0.17)
		NotMNIST	75.95(3.71) / 90.85(5.01) / 88.61(9.04) / **95.75(1.09)**	93.72(1.49) / 97.33(1.72) / 94.06(8.89) / **99.01(0.30)**	91.90(2.37) / 95.24(2.86) / 88.25(14.73) / **98.62(0.45)**
		Gaussian	63.72(14.12) / 90.36(15.81) / 93.22(13.48) / **97.50(0.00)**	91.96(4.29) / 97.95(3.19) / 96.12(15.44) / **100.00(0.00)**	95.17(2.27) / 98.73(1.92) / 97.43(10.34) / **100.00(0.00)**
		Uniform	60.28(19.27) / 81.82(21.23) / 92.92(13.69) / **97.50(0.00)**	88.72(7.18) / 94.63(7.73) / 96.62(14.15) / **100.00(0.00)**	93.28(4.22) / 96.59(4.96) / 97.67(9.68) / **100.00(0.00)**
	CIFAR-100	TIN (c)	64.67(2.28) / 81.15(6.13) / 66.07(10.16) / **91.71(0.85)**	83.70(4.00) / 92.79(3.90) / 73.92(19.34) / **97.90(0.29)**	84.98(6.13) / 92.52(5.05) / 73.78(15.87) / **98.03(0.24)**
		TIN (r)	58.66(2.35) / 71.32(6.55) / 68.00(16.07) / **91.37(1.59)**	77.07(6.35) / 86.35(6.63) / 71.75(25.16) / **97.82(0.53)**	78.60(9.30) / 85.68(8.80) / 73.14(20.57) / **97.99(0.45)**
		LSUN (c)	62.53(0.41) / 79.02(3.86) / 60.97(11.23) / **88.48(0.77)**	82.92(0.59) / 92.58(1.87) / 66.52(19.93) / **96.73(0.31)**	85.41(0.77) / 92.98(1.75) / 67.46(18.44) / **96.89(0.28)**
		LSUN (r)	59.32(2.47) / 72.75(7.20) / 67.95(16.61) / **90.69(2.23)**	78.44(5.41) / 88.13(5.65) / 73.90(24.51) / **97.59(0.75)**	80.74(6.55) / 88.29(6.42) / 76.66(19.51) / **97.83(0.65)**
		iSUN	58.37(2.76) / 71.08(6.98) / 67.10(16.53) / **90.48(2.17)**	76.89(6.28) / 86.56(6.29) / 71.71(25.16) / **97.45(0.73)**	80.56(7.56) / 87.67(6.78) / 76.00(19.33) / **97.88(0.56)**
		SVNH	56.40(1.82) / 59.66(7.63) / 60.25(13.81) / **88.42(2.57)**	77.36(2.83) / 79.74(5.50) / 61.99(27.81) / **96.90(0.79)**	66.58(4.07) / 66.79(7.23) / 50.78(29.99) / **93.95(1.33)**
		Food-101	62.64(0.63) / 62.29(5.44) / 50.50(2.39) / **68.29(1.18)**	84.38(0.48) / 84.41(5.15) / 61.97(10.18) / **90.79(0.49)**	77.21(0.77) / 75.20(8.23) / 46.60(11.77) / **86.96(0.59)**
		STL-10	57.82(1.32) / 67.57(4.27) / 64.44(12.97) / **75.20(3.96)**	76.53(2.23) / 83.43(3.67) / 67.71(25.77) / **90.28(1.95)**	81.56(2.67) / 85.48(3.72) / 73.69(19.52) / **92.43(1.54)**
		MNIST	62.68(2.68) / **87.43(6.85)** / 71.45(22.63) / 86.62(5.51)	81.56(3.83) / 96.16(3.01) / 85.24(23.54) / **96.17(2.06)**	84.50(3.62) / 96.55(2.66) / 89.93(16.70) / **96.62(1.82)**
		F-MNIST	70.15(1.95) / 90.46(3.67) / 67.74(19.52) / **94.69(1.10)**	88.52(1.04) / 97.41(1.28) / 80.36(20.33) / **98.92(0.35)**	90.30(0.80) / 97.61(1.09) / 84.05(16.58) / **99.02(0.31)**
		NotMNIST	59.04(1.67) / 79.54(6.79) / 75.28(16.97) / **84.44(3.09)**	79.97(1.37) / 92.29(3.37) / 83.24(22.35) / **95.80(0.86)**	73.28(2.54) / 87.43(4.71) / 78.33(22.92) / **93.87(1.12)**
		Gaussian	47.54(0.05) / 54.60(13.58) / 70.35(24.18) / **97.50(0.00)**	53.73(13.50) / 59.75(31.22) / 62.78(41.05) / **99.74(0.52)**	69.06(10.42) / 72.10(22.75) / 74.21(27.99) / **99.84(0.30)**
		Uniform	48.34(1.81) / 59.13(19.58) / 72.29(23.29) / **97.50(0.01)**	63.59(20.05) / 74.60(20.42) / 68.71(38.75) / **99.71(0.56)**	75.90(13.16) / 83.24(14.11) / 77.56(27.12) / **99.82(0.34)**
WRN-28-10	CIFAR-10	TIN (c)	78.71(1.31) / 86.55(2.87) / 78.05(7.26) / **93.26(0.96)**	93.86(0.90) / 95.03(1.74) / 90.53(5.96) / **98.35(0.32)**	94.45(1.23) / 94.50(2.05) / 90.09(6.58) / **98.53(0.27)**
		TIN (r)	72.35(2.13) / 79.50(4.13) / 90.84(7.94) / **91.05(2.24)**	89.21(2.65) / 89.43(3.78) / 96.62(4.95) / **97.65(0.66)**	87.62(4.65) / 86.82(4.98) / 96.15(5.98) / **97.94(0.54)**
		LSUN (c)	82.07(1.93) / 87.51(1.97) / 69.63(5.03) / **95.58(0.21)**	95.41(0.26) / 94.92(1.72) / 85.47(5.73) / **99.19(0.07)**	96.19(0.18) / 93.83(2.66) / 85.34(7.15) / **99.23(0.07)**
		LSUN (r)	76.39(2.41) / 85.04(3.58) / 92.36(7.84) / **94.02(1.29)**	92.45(1.48) / 93.49(2.45) / 97.58(4.32) / **98.59(0.34)**	92.33(2.31) / 92.19(3.12) / 97.72(4.22) / **98.79(0.28)**
		iSUN	74.82(2.19) / 83.22(3.82) / 91.92(7.76) / **93.47(1.35)**	91.22(2.05) / 92.22(2.94) / 97.38(4.35) / **98.48(0.36)**	91.40(3.31) / 91.44(3.58) / 97.62(4.45) / **98.82(0.26)**
		SVNH	80.66(2.52) / 81.36(5.60) / 93.77(2.04) / **96.50(0.69)**	94.43(1.30) / 90.31(4.41) / 98.47(0.86) / **99.52(0.24)**	88.55(4.75) / 73.47(11.23) / 96.80(2.55) / **98.94(0.52)**
		Food-101	71.61(1.04) / 70.11(5.79) / 63.73(5.36) / **78.73(1.42)**	89.71(0.90) / 80.07(8.16) / 84.27(5.84) / **93.95(0.41)**	76.04(3.29) / 54.80(13.10) / 73.44(9.85) / **90.41(0.47)**
		MNIST	72.35(5.94) / 88.24(5.90) / **94.88(5.09)** / 94.60(1.22)	91.16(3.19) / 95.80(2.62) / **98.77(1.33)** / 98.60(0.39)	91.37(3.95) / 95.36(3.02) / **99.13(0.98)** / 98.91(0.28)
		F-MNIST	81.20(1.34) / 90.75(2.10) / 91.51(5.27) / **94.03(0.72)**	94.59(0.61) / 96.73(0.96) / 97.54(1.86) / **98.60(0.24)**	94.91(0.79) / 96.15(1.20) / 98.01(1.88) / **98.78(0.20)**
		NotMNIST	81.27(2.34) / 92.55(3.10) / 95.61(2.86) / **96.33(0.62)**	95.00(0.58) / 97.66(1.01) / 99.08(1.08) / **99.11(0.28)**	92.37(1.43) / 94.90(1.86) / 98.39(2.27) / **98.84(0.32)**
		Gaussian	82.94(17.44) / 94.05(7.44) / 97.12(2.80) / **97.50(0.00)**	95.16(6.00) / 98.61(2.50) / 99.60(2.91) / **99.98(0.02)**	96.47(4.70) / 98.87(2.11) / 99.39(4.51) / **99.99(0.01)**
		Uniform	78.59(14.28) / 93.77(5.26) / 96.25(6.97) / **97.50(0.00)**	95.30(2.90) / 98.61(1.58) / 98.01(13.34) / **99.99(0.01)**	96.70(2.10) / 98.87(1.30) / 98.47(9.15) / **99.99(0.01)**
	CIFAR-100	TIN (c)	65.24(1.62) / 75.01(3.51) / 67.17(8.92) / **87.94(1.16)**	84.47(1.24) / 90.67(1.73) / 81.80(11.04) / **96.76(0.34)**	86.08(1.27) / 91.31(1.49) / 81.95(11.95) / **97.11(0.25)**
		TIN (r)	58.89(0.99) / 68.95(3.98) / 79.33(13.77) / **84.94(2.40)**	76.67(2.03) / 84.62(3.16) / 87.65(15.93) / **95.84(0.67)**	76.74(3.62) / 84.22(3.63) / 87.92(15.56) / **96.40(0.47)**
		LSUN (c)	60.99(1.01) / 71.10(5.89) / 59.21(5.80) / **86.49(1.74)**	81.91(1.31) / 88.32(3.51) / 74.40(5.23) / **96.09(0.62)**	84.68(1.45) / 89.14(3.00) / 74.50(5.80) / **96.41(0.56)**
		LSUN (r)	58.98(1.47) / 69.67(4.41) / 78.24(14.33) / **82.76(2.40)**	78.00(1.95) / 86.07(2.87) / 87.56(15.15) / **95.18(0.86)**	79.25(2.28) / 86.11(2.84) / 88.12(14.79) / **95.92(0.68)**
		iSUN	58.54(1.43) / 68.97(4.40) / 78.27(13.79) / **83.73(1.92)**	77.29(2.15) / 85.40(3.01) / 87.20(15.42) / **95.39(0.55)**	80.27(2.59) / 86.75(2.78) / 88.57(14.29) / **96.40(0.35)**
		SVNH	58.13(2.90) / 66.89(10.04) / 73.78(15.04) / **90.28(1.57)**	79.82(2.49) / 83.23(7.27) / 83.92(18.34) / **97.52(0.41)**	66.44(4.78) / 68.31(11.47) / 74.78(24.30) / **95.13(0.54)**
		Food-101	69.12(0.76) / 63.17(4.72) / 58.03(6.90) / **72.68(1.01)**	89.25(0.40) / 83.72(4.37) / 79.23(12.65) / **92.53(0.38)**	83.20(0.70) / 70.54(8.15) / 71.23(18.04) / **89.37(0.54)**
		STL-10	58.23(0.55) / 64.29(2.56) / **71.78(11.79)** / 71.03(1.17)	77.68(0.61) / 81.19(2.19) / 83.70(16.12) / **88.89(0.51)**	81.66(1.01) / 83.70(2.23) / 87.45(12.48) / **91.70(0.43)**
		MNIST	61.79(5.62) / 83.44(7.86) / 72.43(13.40) / **85.60(3.96)**	82.64(4.73) / 95.11(3.39) / 87.26(12.91) / **96.03(1.49)**	85.99(3.87) / 95.87(2.82) / 89.60(11.51) / **96.59(1.25)**
		F-MNIST	72.39(2.13) / 86.51(3.21) / 75.80(10.71) / **92.48(1.22)**	90.33(1.02) / 95.94(1.09) / 90.00(10.31) / **98.27(0.36)**	91.74(0.87) / 96.19(0.97) / 91.63(8.96) / **98.46(0.31)**
		NotMNIST	56.15(1.61) / 76.13(7.88) / **80.87(15.35)** / 77.23(2.62)	80.00(2.79) / 91.24(4.00) / 87.56(18.87) / **93.05(1.47)**	73.99(4.65) / 86.78(5.08) / 83.07(23.07) / **90.53(2.00)**
		Gaussian	47.54(0.07) / 75.81(21.68) / 87.95(18.57) / **97.50(0.00)**	59.59(30.02) / 83.00(24.41) / 87.92(30.23) / **99.82(0.15)**	73.02(23.16) / 88.14(17.78) / 91.59(20.54) / **99.88(0.09)**
		Uniform	47.51(0.02) / 68.50(20.65) / 88.96(17.14) / **97.50(0.00)**	60.88(14.02) / 88.19(12.01) / 88.33(29.70) / **99.95(0.10)**	74.03(12.70) / 92.15(8.43) / 91.62(20.71) / **99.97(0.07)**

B. Dependency on an OOD Validation Dataset: Full Version

In Fig. 2 of the main paper, we demonstrate the dependency of the previous methods on the assumed OOD dataset used for hyperparameter determination, where only TinyImageNet (resized) and F-MNIST are used as the assumed datasets. We show here the complete results in Fig. 5; it shows AUROC of detecting OOD samples given in the horizontal axis when CIFAR-100 is the ID dataset and WRN-28-10 is employed.

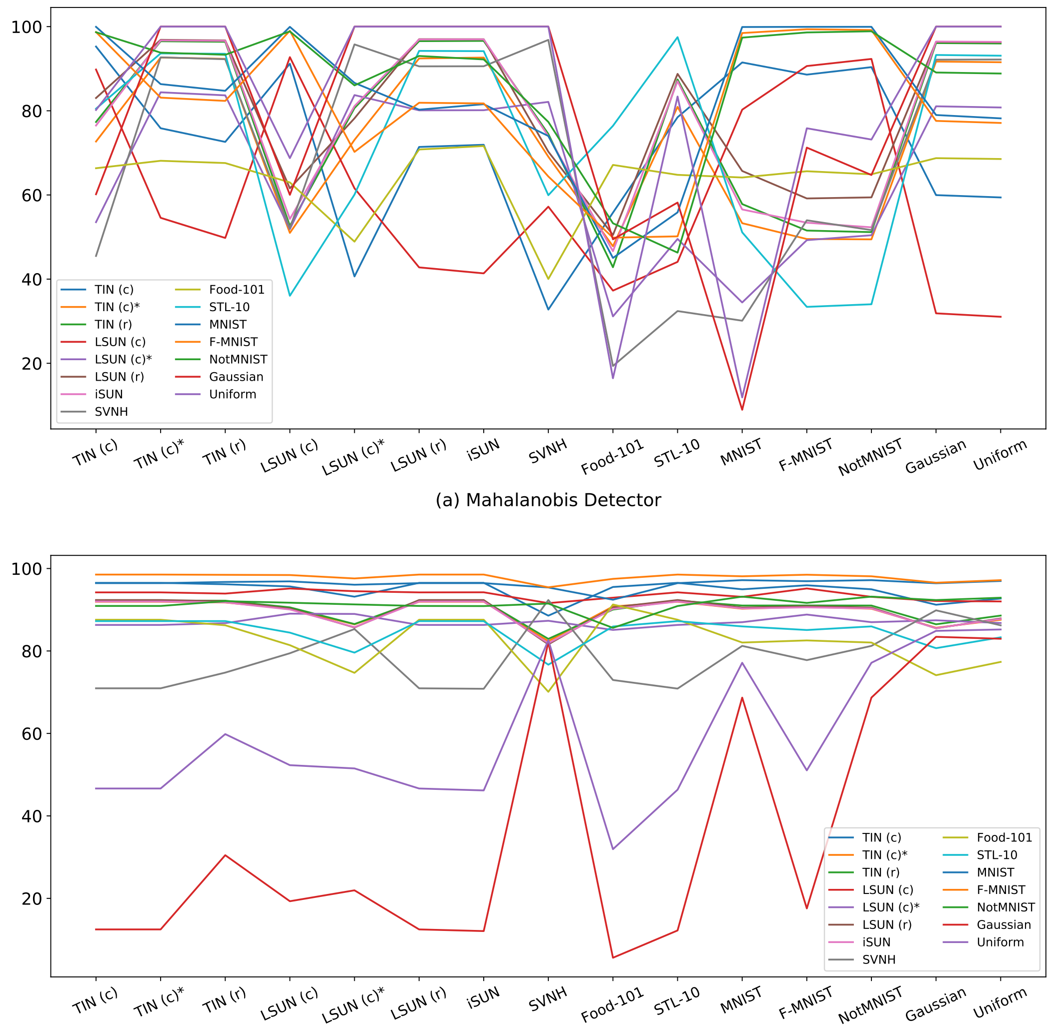

Figure 5. Dependency of (a) Mahalanobis Detector and (b) ODIN on the assumed OOD dataset used for hyperparameter determination. AUROC of detecting OOD samples given in the horizontal axis. The line colors indicate the assumed OOD dataset.

C. Mahalanobis Detector with Hyperparameters Tuned by Adversarial Samples

As mentioned in the main paper, the Mahalanobis detector [3] has two modes of selecting its hyperparameters. One is to use the explicit OOD samples and the other is to create adversarial examples from the ID samples and assume them as OOD samples. Although the latter does not need explicit OOD samples, it incorporates another hyperparameter(s) for the creation of the adversarial examples, and thus will not be an ideal solution, as we point out in the main paper. One may wonder, however, how is the performance on this scenario. As there is no mention of the intuition of its hyperparameters choosing, we follow the one provided by the authors of [3].[1] We show its results in Table 6.

As shown in the table, the results show similar instability to the case of using explicit OOD samples; the method shows good performance with some OOD datasets but not with others. This is illustrated more clearly illustrated in Fig. 6. We suspect that it performs well only if the created adversarial examples resemble the true OOD examples. We cannot expect this is always the case in the real world problems. In short, our conclusion remains the same with this method.

Table 6. OOD detection performance of the Mahalanobis Detector [3] using the adversarial samples for its hyperparameters tuning. The results are averaged from 5 runs.

	ID	OOD	AUROC
Dense-100-12	CIFAR-10	TIN (c)	87.77(3.71)
		TIN (c)*	96.84(0.89)
		TIN (r)	98.62(0.41)
		LSUN (c)	73.16(3.51)
		LSUN (c)*	91.49(1.73)
		LSUN (r)	98.79(0.37)
		iSUN	98.72(0.37)
		SVNH	97.21(1.84)
		Food-101	77.22(4.29)
		MNIST	98.51(0.26)
		F-MNIST	93.83(1.14)
		NotMNIST	96.60(3.07)
		Gaus. Noise	100.0(0.0)
		Unif. Noise	100.0(0.0)
	CIFAR-100	TIN (c)	79.75(3.69)
		TIN (c)*	92.70(0.39)
		TIN (r)	96.45(0.30)
		LSUN (c)	62.37(8.15)
		LSUN (c)*	84.24(2.72)
		LSUN (r)	96.66(0.29)
		iSUN	96.64(0.38)
		SVNH	93.16(1.16)
		Food-101	72.54(1.12)
		STL-10	93.19(1.15)
		MNIST	87.82(8.88)
		F-MNIST	80.33(3.47)
		NotMNIST	91.61(3.05)
		Gaus. Noise	100.0(0.0)
		Unif. Noise	100.0(0.0)

	ID	OOD	AUROC
WRN-28-10	CIFAR-10	TIN (c)	87.79(1.48)
		TIN (c)*	97.54(0.53)
		TIN (r)	98.65(0.29)
		LSUN (c)	70.97(1.90)
		LSUN (c)*	93.53(0.91)
		LSUN (r)	99.16(0.21)
		iSUN	99.07(0.21)
		SVNH	98.03(0.55)
		Food-101	73.55(6.09)
		MNIST	98.89(0.72)
		F-MNIST	97.89(0.59)
		NotMNIST	99.41(0.28)
		Gaus. Noise	100.0(0.0)
		Unif. Noise	100.0(0.0)
	CIFAR-100	TIN (c)	86.61(1.13)
		TIN (c)*	96.24(0.13)
		TIN (r)	97.69(0.19)
		LSUN (c)	67.07(3.41)
		LSUN (c)*	87.00(1.34)
		LSUN (r)	97.67(0.23)
		iSUN	97.62(0.19)
		SVNH	92.95(1.03)
		Food-101	86.78(1.39)
		STL-10	94.73(0.59)
		MNIST	84.63(7.77)
		F-MNIST	93.41(2.11)
		NotMNIST	97.37(0.82)
		Gaus. Noise	100.0(0.0)
		Unif. Noise	100.0(0.0)

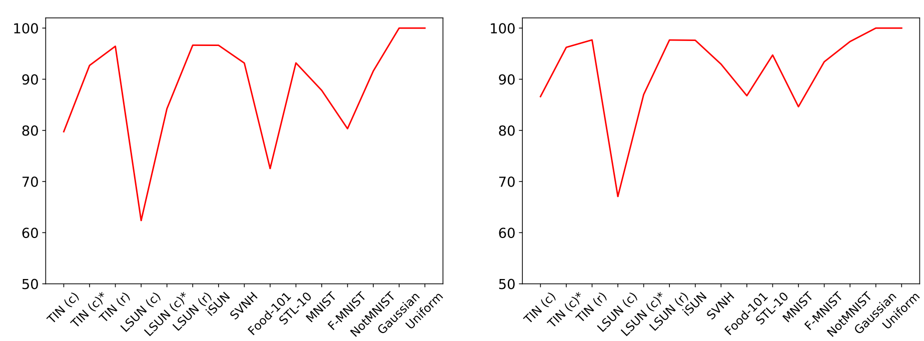

Figure 6. The instability of the OOD detection performance for Mahalanobis Detector using adversarial samples in its hyperparameters tuning (ID = CIFAR-100).

[1] https://github.com/pokaxpoka/deep_Mahalanobis_detector

D. More Complete Results of One-vs-one Evaluation

Table 7 shows a more complete version of Table 2 in the main paper. It shows the performances measured by the two additional metrics as above.

Table 7. Performance of four out-of-distribution detection methods on a single network using one-vs-one evaluation.

Network	ID	OOD	Accuracy at TPR= 95%	AUROC	AUPR-In
			Baseline [1] / ODIN [2] / Mahalanobis [3] / Ours		
Dense-100-12	CIFAR-10	TIN (c)	78.86(1.37) / 94.59(0.80) / 85.51(2.28) / **94.83(0.68)**	94.90(0.43) / 98.79(0.32) / 94.48(1.19) / **98.89(0.24)**	96.09(0.36) / 98.86(0.28) / 93.76(1.67) / **98.97(0.20)**
		TIN (c)*	74.53(1.93) / 88.97(2.54) / 90.84(0.96) / **94.34(0.61)**	93.26(0.85) / 96.67(0.97) / 97.36(0.39) / **98.74(0.23)**	94.61(0.80) / 96.64(0.96) / 97.64(0.37) / **98.86(0.19)**
		TIN (r)	73.51(2.48) / 90.39(2.98) / **95.00(0.54)** / 94.67(0.60)	92.67(1.23) / 97.20(1.17) / **98.91(0.23)** / 98.82(0.29)	94.06(1.17) / 97.27(1.10) / **99.04(0.20)** / 98.89(0.26)
		LSUN (c)	81.22(1.46) / 93.67(0.53) / 74.91(5.87) / **95.27(0.19)**	95.57(0.20) / 98.48(0.14) / 89.06(3.21) / **99.09(0.12)**	96.59(0.11) / 98.62(0.16) / 89.00(2.32) / **99.12(0.11)**
		LSUN (c)*	75.35(1.90) / 87.61(1.40) / 82.51(1.62) / **94.54(0.39)**	93.72(0.39) / 96.41(0.52) / 93.63(0.69) / **98.83(0.18)**	95.06(0.27) / 96.69(0.53) / 94.21(0.58) / **98.88(0.17)**
		LSUN (r)	76.74(1.40) / 93.63(1.37) / 95.48(0.43) / **95.72(0.56)**	94.28(0.52) / 98.43(0.49) / 99.00(0.23) / **99.19(0.22)**	95.60(0.44) / 98.52(0.44) / 99.15(0.20) / **99.26(0.20)**
		iSUN	75.12(2.08) / 92.26(1.99) / 95.09(0.51) / **95.62(0.51)**	93.62(0.83) / 97.92(0.71) / 98.95(0.21) / **99.20(0.19)**	95.48(0.66) / 98.21(0.58) / 99.22(0.15) / **99.33(0.16)**
		SVNH	68.84(2.90) / 88.83(0.28) / 95.01(0.78) / **95.36(0.87)**	90.28(2.47) / 95.11(0.48) / 98.89(0.37) / **99.11(0.36)**	82.90(7.23) / 83.30(1.91) / 97.67(0.73) / **97.99(0.73)**
		Food-101	67.93(0.59) / 76.90(1.39) / 64.14(1.46) / **79.79(1.03)**	89.87(0.44) / 92.06(0.71) / 80.38(3.83) / **93.98(0.54)**	83.58(0.96) / 85.30(1.54) / 63.50(8.01) / **89.99(0.90)**
		MNIST	76.35(3.52) / 97.00(0.49) / **97.50(0.00)** / 95.15(1.51)	94.54(1.02) / **99.69(0.20)** / 99.43(0.44) / 98.90(0.49)	95.98(0.83) / **99.72(0.18)** / 99.68(0.25) / 99.06(0.42)
		F-MNIST	81.65(2.11) / **96.49(0.39)** / 92.79(4.59) / 94.83(0.71)	95.76(0.50) / **99.51(0.13)** / 97.87(2.00) / 98.84(0.21)	96.76(0.35) / **99.54(0.11)** / 97.95(2.26) / 98.94(0.17)
		NotMNIST	75.95(3.71) / 94.44(2.12) / **96.04(1.24)** / 95.75(1.09)	93.72(1.49) / 98.61(0.95) / **99.18(0.60)** / 99.01(0.30)	91.90(2.37) / 97.04(2.34) / **98.98(0.63)** / 98.62(0.45)
		Gaussian	63.72(14.12) / 97.48(0.03) / **97.50(0.00)** / **97.50(0.00)**	91.96(4.29) / 99.30(0.47) / **100.00(0.00)** / **100.00(0.00)**	95.17(2.27) / 99.54(0.26) / **100.00(0.00)** / **100.00(0.00)**
		Uniform	60.28(19.27) / 96.79(1.52) / **97.50(0.00)** / **97.50(0.00)**	88.72(7.18) / 98.79(0.95) / **100.00(0.00)** / **100.00(0.00)**	93.28(4.22) / 99.23(0.57) / **100.00(0.00)** / **100.00(0.00)**
	CIFAR-100	TIN (c)	64.67(2.28) / 84.84(4.02) / 81.53(4.16) / **91.71(0.85)**	83.70(4.00) / 94.48(3.21) / 92.97(1.63) / **97.90(0.29)**	84.98(6.13) / 94.16(4.45) / 93.00(1.86) / **98.03(0.24)**
		TIN (c)*	60.26(1.93) / 73.44(4.06) / 80.13(0.82) / **89.81(1.52)**	79.32(4.14) / 88.54(4.27) / 93.18(0.39) / **97.31(0.45)**	80.66(6.76) / 87.97(6.39) / 94.05(0.42) / **97.55(0.37)**
		TIN (r)	58.66(2.35) / 74.66(5.82) / 88.95(0.58) / **91.37(1.59)**	77.07(6.35) / 88.14(6.92) / 96.81(0.27) / **97.82(0.53)**	78.60(9.30) / 87.18(9.82) / 97.26(0.30) / **97.99(0.45)**
		LSUN (c)	62.53(0.41) / 84.21(1.09) / 77.94(5.23) / **88.48(0.77)**	82.92(0.59) / 94.72(0.59) / 91.65(2.96) / **96.73(0.31)**	85.41(0.77) / 94.80(0.69) / 91.67(2.98) / **96.89(0.28)**
		LSUN (c)*	58.61(0.57) / 73.30(1.74) / 70.53(0.95) / **85.26(0.79)**	78.46(0.91) / 87.89(1.13) / 85.44(1.85) / **95.52(0.32)**	80.86(0.93) / 87.55(1.35) / 86.39(2.20) / **95.82(0.29)**
		LSUN (r)	59.32(2.47) / 76.53(5.59) / 89.82(0.48) / **90.69(2.23)**	78.44(5.41) / 90.38(4.76) / 97.00(0.15) / **97.59(0.75)**	80.74(6.55) / 90.49(5.57) / 97.54(0.10) / **97.83(0.65)**
		iSUN	58.37(2.76) / 74.54(6.13) / 89.43(0.20) / **90.48(2.17)**	76.89(6.28) / 88.27(6.49) / 97.04(0.10) / **97.45(0.73)**	80.56(7.56) / 89.01(7.25) / 97.80(0.13) / **97.88(0.56)**
		SVNH	56.40(1.82) / 78.49(1.49) / 87.06(2.51) / **88.42(2.57)**	77.36(2.83) / 91.60(0.73) / 96.48(0.68) / **96.90(0.79)**	66.58(4.07) / 82.08(1.58) / **94.33(0.78)** / 93.95(1.33)
		Food-101	62.64(0.63) / **70.96(1.24)** / 55.43(2.48) / 68.29(1.18)	84.38(0.48) / **90.82(0.60)** / 67.14(1.39) / 90.79(0.49)	77.21(0.77) / 85.64(1.04) / 46.59(4.01) / **86.96(0.59)**
		STL-10	57.82(1.32) / 70.35(2.12) / **85.77(6.70)** / 75.20(3.96)	76.53(2.23) / 85.41(2.55) / **91.64(5.03)** / 90.28(1.95)	81.56(2.67) / 87.27(2.78) / 91.32(5.15) / **92.43(1.54)**
		MNIST	62.68(2.68) / 91.17(5.19) / **97.47(0.07)** / 86.62(5.51)	81.56(3.83) / 97.57(2.07) / **99.81(0.19)** / 96.17(2.06)	84.50(3.62) / 97.74(1.94) / **99.88(0.12)** / 96.62(1.82)
		F-MNIST	70.15(1.95) / 93.01(1.50) / **94.79(2.94)** / 94.69(1.10)	88.52(1.04) / 98.27(0.49) / 98.58(1.11) / **98.92(0.35)**	90.30(0.80) / 98.33(0.48) / 98.66(1.18) / **99.02(0.31)**
		NotMNIST	59.04(1.67) / 85.20(2.34) / **94.73(2.98)** / 84.44(3.09)	79.97(1.37) / 94.73(1.37) / **98.69(1.02)** / 95.80(0.86)	73.28(2.54) / 90.74(2.83) / **97.98(0.88)** / 93.87(1.12)
		Gaussian	47.54(0.05) / 77.72(19.57) / **97.50(0.00)** / **97.50(0.00)**	53.73(13.50) / 93.44(6.60) / **100.00(0.00)** / 99.74(0.52)	69.06(10.42) / 95.41(4.73) / **100.00(0.00)** / 99.84(0.30)
		Uniform	48.34(1.81) / 79.64(23.92) / **97.50(0.00)** / **97.50(0.00)**	63.59(20.05) / 94.60(6.66) / **100.00(0.00)** / 99.71(0.56)	75.90(13.16) / 96.41(4.48) / **100.00(0.00)** / 99.82(0.34)
WRN-28-10	CIFAR-10	TIN (c)	78.71(1.31) / 88.38(1.69) / 86.46(2.18) / **93.26(0.96)**	93.86(0.90) / 95.88(1.01) / 95.99(1.04) / **98.35(0.32)**	94.45(1.23) / 95.38(1.23) / 96.55(0.98) / **98.53(0.27)**
		TIN (c)*	76.10(1.38) / 83.16(2.07) / **93.57(0.31)** / 92.63(1.26)	91.79(1.57) / 92.17(2.19) / **98.50(0.11)** / 98.17(0.33)	90.94(2.91) / 89.77(3.56) / **98.72(0.10)** / 98.42(0.27)
		TIN (r)	72.35(2.13) / 81.86(3.29) / **95.59(0.34)** / 91.05(2.24)	89.21(2.65) / 90.60(3.21) / **99.15(0.18)** / 97.65(0.66)	87.62(4.65) / 87.99(4.53) / **99.25(0.19)** / 97.94(0.54)
		LSUN (c)	82.07(1.93) / 90.24(0.84) / 78.82(2.25) / **95.58(0.21)**	95.41(0.26) / 97.20(0.15) / 92.65(1.33) / **99.19(0.07)**	96.19(0.18) / 97.28(0.17) / 93.12(1.38) / **99.23(0.07)**
		LSUN (c)*	78.31(2.05) / 85.89(1.53) / 88.26(1.26) / **94.96(0.16)**	93.67(0.50) / 95.08(0.42) / 96.90(0.35) / **98.98(0.07)**	93.90(0.56) / 94.42(0.56) / 97.46(0.27) / **99.06(0.05)**
		LSUN (r)	76.39(2.41) / 87.33(2.22) / **96.40(0.31)** / 94.02(1.29)	92.45(1.48) / 94.48(1.70) / **99.37(0.13)** / 98.59(0.34)	92.33(2.31) / 93.12(2.42) / **99.47(0.10)** / 98.79(0.28)
		iSUN	74.82(2.19) / 85.49(2.99) / **96.08(0.20)** / 93.47(1.35)	91.22(2.05) / 93.25(2.43) / **99.29(0.10)** / 98.48(0.36)	91.40(3.31) / 92.35(3.24) / **99.46(0.08)** / 98.82(0.26)
		SVNH	80.66(2.52) / 87.37(3.32) / 95.79(0.22) / **96.50(0.69)**	94.43(1.30) / 93.34(3.60) / 99.28(0.09) / **99.52(0.24)**	88.55(4.75) / 79.63(11.13) / 98.51(0.16) / **98.94(0.52)**
		Food-101	71.61(1.04) / 75.92(1.90) / 71.73(1.64) / **78.73(1.42)**	89.71(0.90) / 89.18(2.37) / 90.43(1.54) / **93.95(0.41)**	76.04(3.29) / 71.88(6.62) / 84.07(3.15) / **90.41(0.47)**
		MNIST	72.35(5.94) / 92.32(2.53) / **97.42(0.05)** / 94.60(1.22)	91.16(3.19) / 97.36(1.50) / **99.56(0.11)** / 98.60(0.39)	91.37(3.95) / 97.03(1.79) / **99.71(0.07)** / 98.91(0.28)
		F-MNIST	81.20(1.34) / 92.25(1.25) / **96.24(0.68)** / 94.03(0.72)	94.59(0.61) / 97.28(0.65) / **99.03(0.23)** / 98.60(0.24)	94.91(0.79) / 96.65(0.91) / **99.28(0.21)** / 98.78(0.20)
		NotMNIST	81.27(2.34) / 94.93(0.51) / **97.33(0.14)** / 96.33(0.62)	95.00(0.58) / 98.48(0.38) / **99.77(0.07)** / 99.11(0.28)	92.37(1.43) / 96.20(1.28) / **99.65(0.10)** / 98.84(0.32)
		Gaussian	82.94(17.44) / 96.33(2.54) / **97.50(0.00)** / **97.50(0.00)**	95.16(6.00) / 99.39(0.94) / **100.00(0.00)** / 99.98(0.02)	96.47(4.70) / 99.48(0.82) / **100.00(0.00)** / 99.99(0.01)
		Uniform	78.59(14.28) / 96.65(1.53) / **97.50(0.00)** / **97.50(0.00)**	95.30(2.90) / 99.41(0.53) / **100.00(0.00)** / 99.99(0.01)	96.70(2.10) / 99.48(0.53) / **100.00(0.00)** / 99.99(0.01)
	CIFAR-100	TIN (c)	65.24(1.62) / 77.12(2.53) / 79.69(5.23) / **87.94(1.16)**	84.47(1.24) / 91.72(1.10) / 92.58(2.60) / **96.76(0.34)**	86.08(1.27) / 92.21(0.95) / 93.37(2.43) / **97.11(0.25)**
		TIN (c)*	61.96(0.78) / 71.32(1.31) / **87.88(0.94)** / 85.01(1.35)	80.90(0.90) / 87.08(1.29) / **96.45(0.30)** / 95.91(0.42)	81.38(1.79) / 86.72(1.71) / **97.02(0.29)** / 96.48(0.31)
		TIN (r)	58.89(0.99) / 71.53(2.26) / **91.88(0.30)** / 84.94(2.40)	76.67(2.03) / 86.28(2.43) / **97.82(0.13)** / 95.84(0.67)	76.74(3.62) / 85.82(3.03) / **98.09(0.10)** / 96.40(0.47)
		LSUN (c)	60.99(1.01) / 78.04(0.67) / 68.64(0.78) / **86.49(1.74)**	81.91(1.31) / 91.75(0.44) / 80.48(1.14) / **96.09(0.62)**	84.68(1.45) / 91.90(0.47) / 79.46(1.59) / **96.41(0.56)**
		LSUN (c)*	58.99(0.77) / 74.15(0.57) / 77.82(1.07) / **82.97(1.77)**	79.17(1.25) / 88.06(0.46) / 91.13(0.52) / **94.92(0.65)**	80.88(1.99) / 87.28(0.65) / 92.04(0.52) / **95.45(0.57)**
		LSUN (r)	58.98(1.47) / 72.74(2.41) / **91.98(0.32)** / 82.76(2.40)	78.00(1.95) / 87.90(1.83) / **97.80(0.15)** / 95.18(0.86)	79.25(2.28) / 87.83(1.99) / **98.12(0.13)** / 95.92(0.68)
		iSUN	58.54(1.43) / 71.72(2.57) / **91.69(0.46)** / 83.73(1.92)	77.29(2.15) / 87.07(2.00) / **97.66(0.14)** / 95.39(0.55)	80.27(2.59) / 88.13(1.99) / **98.18(0.10)** / 96.40(0.35)
		SVNH	58.13(2.90) / 83.04(1.69) / **92.39(1.42)** / 90.28(1.57)	79.82(2.49) / 93.46(1.05) / **97.96(0.49)** / 97.52(0.41)	66.44(4.78) / 84.81(3.06) / **96.05(0.68)** / 95.13(0.54)
		Food-101	69.12(0.76) / 71.12(0.79) / 70.23(1.61) / **72.68(1.01)**	89.25(0.40) / 90.76(0.35) / 91.15(0.66) / **92.53(0.38)**	83.20(0.70) / 84.74(0.78) / 87.69(0.85) / **89.37(0.54)**
		STL-10	58.23(0.55) / 66.14(0.39) / **86.69(2.54)** / 71.03(1.17)	77.68(0.61) / 83.02(1.12) / **94.73(1.36)** / 88.89(0.51)	81.66(1.01) / 85.27(1.49) / **95.52(1.95)** / 91.70(0.43)
		MNIST	61.79(5.62) / 87.27(4.78) / **94.15(3.68)** / 85.60(3.96)	82.64(4.73) / 96.71(1.39) / **98.54(1.01)** / 96.03(1.49)	85.99(3.87) / 97.18(1.17) / **98.89(0.65)** / 96.59(1.25)
		F-MNIST	72.39(2.13) / 88.50(1.70) / 87.63(0.67) / **92.48(1.22)**	90.33(1.02) / 96.61(0.68) / 96.61(0.30) / **98.27(0.36)**	91.74(0.87) / 96.71(0.75) / 97.36(0.24) / **98.46(0.31)**
		NotMNIST	56.15(1.61) / 81.37(2.36) / **96.48(0.38)** / 77.23(2.62)	80.00(2.79) / 93.47(1.35) / **98.93(0.13)** / 93.05(1.47)	73.99(4.65) / 89.37(2.60) / **98.84(0.15)** / 90.53(2.00)
		Gaussian	47.54(0.07) / 86.50(21.83) / **97.50(0.00)** / **97.50(0.00)**	59.59(30.02) / 80.04(41.24) / **100.00(0.00)** / 99.82(0.15)	73.02(23.16) / 85.54(30.09) / **100.00(0.00)** / 99.88(0.09)
		Uniform	47.51(0.02) / 75.44(20.61) / **97.50(0.00)** / **97.50(0.00)**	60.88(14.02) / 92.66(8.46) / **100.00(0.00)** / 99.95(0.10)	74.03(12.70) / 95.08(6.01) / **100.00(0.00)** / 99.97(0.07)

E. OOD Detection Using an Ensemble of Networks

The leave-out ensemble proposed in [4] uses multiple networks and is reported to achieve high OOD detection performance in the one-vs-one evaluation. To make a fair comparison, we consider an extension of our method to an ensemble model. The underlying thought is that the use of an ensemble of multiple models will yield better results, as seen in many inference tasks. To be specific, in the training step, we train multiple networks on the target classification task; in our experiments, we trained models of the same architecture initialized with different random weights. At test time, given an input sample, we make the networks output the cosine similarities and calculate their averages over different networks. Table 8 shows the results. For the leave-out ensemble, it shows the performances reported in [4] and those obtained in our own experiments (indicated by *); we used a public code[2] suggested by the author of [4]. It is seen that our method shows better or at least comparable performance as compared with the leave-out ensemble, even in the one-vs-one evaluation. Note that iSUN is chosen as the validation OOD dataset for the hyperparameter determination of the leave-out ensemble, following [4].

Table 8. Performance of OOD detection by ensemble models (five networks) in the one-vs-one evaluation.

Network	ID	OOD	Accuracy at TPR= 95%	AUROC	AUPR-In
			Leave-out[38] / Leave-out* / Ours		
Dense-100-12	CIFAR-10	TinyIm (c)	96.89 / 96.76 / 96.43	99.65 / 99.66 / 99.43	99.68 / 99.67 / 99.48
		TinyIm (c)*	- / 94.83 / 96.21	- / 98.98 / 99.33	- / 99.05 / 99.39
		TinyIm (r)	96.04 / 96.21 / 96.14	99.34 / 99.45 / 99.36	99.37 / 99.48 / 99.40
		LSUN (c)	95.79 / 95.65 / 96.51	99.25 / 99.27 / 99.51	99.29 / 99.32 / 99.53
		LSUN (c)*	- / 91.04 / 96.06	- / 97.83 / 99.33	- / 98.00 / 99.36
		LSUN (r)	97.12 / 96.71 / 96.79	99.75 / 99.67 / 99.61	99.77 / 99.68 / 99.64
		iSUN	- / 96.47 / 96.69	- / 99.60 / 99.61	- / 99.62 / 99.67
		SVHN	- / 81.09 / 96.53	- / 94.39 / 99.54	- / 95.06 / 98.93
		Food-101	- / 75.64 / 85.06	- / 92.85 / 95.89	- / 94.13 / 93.25
		MNIST	- / 97.19 / 97.01	- / 99.76 / 99.53	- / 99.79 / 99.61
		F-MNIST	- / 96.59 / 96.60	- / 99.58 / 99.45	- / 99.62 / 99.51
		NotMNIST	- / 93.39 / 97.11	- / 98.64 / 99.45	- / 98.83 / 99.24
		Gausian	96.20 / 97.50 / 97.50	98.55 / 99.99 / 100.00	98.94 / 99.99 / 100.00
		Uniform	97.50 / 97.50 / 97.50	99.84 / 99.96 / 100.00	99.89 / 99.97 / 100.00
	CIFAR-100	TinyIm (c)	93.36 / 95.11 / 94.44	98.43 / 99.00 / 98.78	98.58 / 99.05 / 98.86
		TinyIm (c)*	- / 88.78 / 93.09	- / 96.79 / 98.30	- / 97.03 / 98.46
		TinyIm (r)	87.24 / 91.45 / 93.89	96.27 / 97.80 / 98.60	96.66 / 98.01 / 98.72
		LSUN (c)	90.16 / 89.34 / 91.54	97.37 / 97.05 / 97.80	97.62 / 97.26 / 97.91
		LSUN (c)*	- / 75.23 / 88.55	- / 90.75 / 96.74	- / 91.27 / 96.99
		LSUN (r)	89.39 / 93.25 / 93.16	97.03 / 98.37 / 98.38	97.37 / 98.52 / 98.55
		iSUN	- / 90.91 / 92.93	- / 97.53 / 98.23	- / 97.66 / 98.53
		SVHN	- / 50.84 / 92.82	- / 75.79 / 98.22	- / 81.16 / 96.39
		Food-101	- / 74.44 / 76.42	- / 92.39 / 93.76	- / 93.82 / 91.23
		STL-10	- / 86.56 / 78.48	- / 96.34 / 92.04	- / 96.78 / 93.93
		MNIST	- / 96.35 / 89.23	- / 99.27 / 97.35	- / 99.39 / 97.68
		F-MNIST	- / 96.73 / 96.88	- / 99.66 / 99.64	- / 99.67 / 99.67
		NotMNIST	- / 92.20 / 87.92	- / 98.07 / 96.97	- / 98.25 / 95.57
		Gausian	57.64 / 81.18 / 97.50	92.00 / 95.57 / 100.00	94.77 / 97.36 / 100.00
		Uniform	78.24 / 95.72 / 97.50	94.89 / 97.73 / 100.00	96.36 / 98.61 / 100.00
WRN-28-10	CIFAR-10	TinyIm (c)	97.09 / 96.35 / 94.83	99.75 / 99.54 / 98.93	99.77 / 99.57 / 99.05
		TinyIm (c)*	- / 93.47 / 94.62	- / 98.56 / 98.77	- / 98.65 / 98.95
		TinyIm (r)	96.03 / 95.09 / 93.41	99.36 / 99.10 / 98.41	99.40 / 99.13 / 98.62
		LSUN (c)	96.54 / 94.97 / 96.42	99.55 / 99.09 / 99.46	99.57 / 99.16 / 99.49
		LSUN (c)*	- / 88.93 / 95.91	- / 97.14 / 99.30	- / 97.33 / 99.35
		LSUN (r)	97.06 / 95.88 / 95.74	99.70 / 99.39 / 99.14	99.72 / 99.37 / 99.27
		iSUN	- / 95.33 / 95.53	- / 99.22 / 99.06	- / 99.22 / 99.28
		SVHN	- / 73.78 / 96.99	- / 91.80 / 99.73	- / 93.15 / 99.36
		Food-101	- / 66.64 / 81.60	- / 87.37 / 95.10	- / 89.23 / 92.34
		MNIST	- / 95.52 / 96.12	- / 99.09 / 98.98	- / 99.22 / 99.22
		F-MNIST	- / 96.59 / 95.33	- / 99.59 / 99.04	- / 99.60 / 99.16
		NotMNIST	- / 92.33 / 96.99	- / 97.91 / 99.38	- / 98.05 / 99.19
		Gausian	89.31 / 97.50 / 97.50	96.77 / 99.97 / 100.00	97.78 / 99.98 / 100.00
		Uniform	97.50 / 97.50 / 97.50	99.58 / 99.98 / 100.00	99.71 / 99.98 / 100.00
	CIFAR-100	TinyIm (c)	92.92 / 92.88 / 90.58	98.22 / 98.33 / 97.62	98.39 / 98.46 / 97.89
		TinyIm (c)*	- / 84.19 / 87.83	- / 95.34 / 96.80	- / 95.69 / 97.26
		TinyIm (r)	85.24 / 88.74 / 87.09	95.18 / 96.89 / 96.64	95.50 / 97.16 / 97.11
		LSUN (c)	90.39 / 83.34 / 88.61	97.38 / 95.43 / 97.00	97.62 / 96.03 / 97.26
		LSUN (c)*	- / 68.83 / 85.23	- / 87.66 / 95.87	- / 88.55 / 96.33
		LSUN (r)	89.24 / 92.17 / 84.58	96.77 / 97.98 / 95.97	97.03 / 98.13 / 96.65
		iSUN	- / 90.33 / 85.66	- / 97.31 / 96.17	- / 97.41 / 97.05
		SVHN	- / 51.65 / 92.66	- / 76.30 / 98.20	- / 80.87 / 96.41
		Food-101	- / 68.62 / 78.00	- / 89.87 / 94.38	- / 91.49 / 92.02
		STL-10	- / 80.86 / 72.86	- / 94.33 / 90.16	- / 95.00 / 92.72
		MNIST	- / 93.84 / 86.94	- / 98.62 / 96.79	- / 98.82 / 97.23
		F-MNIST	- / 97.05 / 95.37	- / 99.77 / 99.16	- / 99.79 / 99.24
		NotMNIST	- / 86.31 / 78.95	- / 96.53 / 94.32	- / 97.03 / 92.40
		Gausian	47.55 / 97.50 / 97.50	83.44 / 99.65 / 99.98	89.43 / 99.79 / 99.99
		Uniform	48.37 / 97.50 / 97.50	93.04 / 99.60 / 100.00	88.64 / 99.76 / 100.00

[2] https://github.com/YU1ut/Ensemble-of-Leave-out-Classifiers

F. Black Frame in the Cropped OOD Images

The OOD datasets, i.e., LSUN (cropped & resized), TinyImageNet (cropped & resized), and iSUN, provided in the authors' GitHub repo of ODIN [2] [3] are used in many studies [2, 4, 7]. As mentioned briefly in the main paper, we found that every image in the datasets of cropped images, i.e., Tiny ImageNet (cropped) and LSUN (cropped), unexpectedly has a black frame with two-pixel widths, as shown in Fig. 7. Those images is of 36×36 pixels (4 pixels larger than CIFAR images), implying that it is a mistake of the authors. In any case, adding a black frame is not invalid by itself, as any image could be an OOD sample. However, it will ease the problem without a doubt.

In our experiments, we used both of the corrected versions (indicated by *) and the original version. The results show that the proposed method achieves similar performance on both versions of the datasets. On the other hand, the other methods, ODIN [2], Mahalanobis detector [3] and Leave-out Ensemble [4], show more sensitive behaviors to the difference, as observable in Tables 5 - 8 in this article.

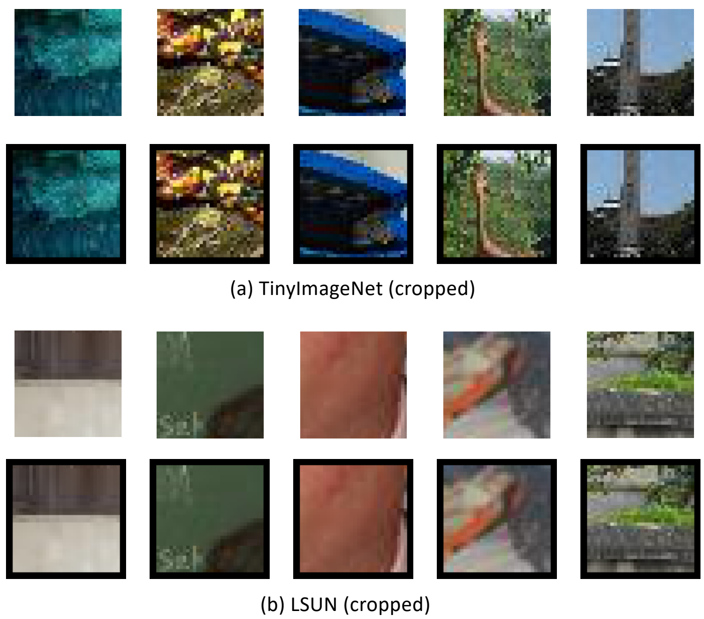

Figure 7. The images with and without a black frame. (a) TinyImageNet (cropped). (b) LSUN (cropped).

[3] https://github.com/facebookresearch/odin

G. Equivalence Between Max-softmax With a High Temperature and Max-logit

In the main paper, we mention that when a high temperature is used in the softmax function, using the max-softmax criteria for OOD detection is equivalent to using the max-logit criteria. A brief proof is given below.

When employing a temperature, the score (or posterior probability) p_i of class $i \in [1, C]$ is given by

$$p_i = \text{softmax}_i(x/t) = \frac{e^{x_i/t}}{\sum_{i=1}^{C} e^{x_j/t}},$$

where x_i is the logit of class i and t is the temperature. As shown in Hinton et al. [38], when t is large, p_i can be approximated as

$$p_i \approx \frac{1 + x_i/t}{N}.$$

The ODIN [2] employs the max-softmax criteria with a high temperature for OOD detection, which is written using the above approximation as

$$\frac{1 + x_{\max}/t}{N} < \tau,$$

where $x_{\max}$ is the maximum of the logits. This is rewritten as

$$x_{\max} < t(N\tau - 1).$$

By regarding the rhs as a new threshold, this coincides with the max-logit criteria.

H. Computational Cost

While the proposed method needs only the standard forward propagation to perform OOD detection, the previous methods, particularly those showing good performance in the one-vs-one evaluation, employ a lot more complicated computation, such as input perturbation [2, 3]. We measure the computational time that ODIN, the Mahalanobis detector, and ours need to get the results. Table 9 shows the average time per batch containing 128 samples.

Table 9. Comparison of computational time (per batch of 128 samples) of the three methods.

Network	Time (second)		
	Mahalanobis	ODIN	Cosine
Dense-100-12	0.67	0.19	**0.08**
WRN-28-10	1.61	0.61	**0.22**