Zero-Shot Visual Recognition via Bidirectional Latent Embedding

Supplementary Material

1 Overview

In this document, we describe our experiments conducted on two human action datasets, UCF101 and HMDB51, in detail. For each of two datasets, there are 30 training/test splits where training and test classes in different splits on a dataset are not mutually exclusive; i.e., a training class in one split may be a test class in another split. As described in Section 4.4 of the paper, the classwise cross-validation experiments have to be conducted on each split independently in order to evaluate the knowledge transfer performance reliably. Furthermore, such experiments have to be done multiple times for different scenarios that various visual and semantic representations are used in the experiments. Below, we first describe our experimental settings briefly and then report the detailed results in all the different scenarios appearing in our experiments.

2 Experimental Protocol

As a general evaluation protocol in *zero-short learning* (ZSL), the *classwise cross-validation* is necessary in seeking the optimal values of hyper-parameter parameters involved in a ZSL algorithm. The generic procedure is using only examples of training classes in a training set to find out the optimal hyper-parameter values for a ZSL algorithm and then apply those in evaluating the performance of this algorithm on a test set of instances in unseen classes. In the classwise cross-validation process, the training set is divided into two subsets: training and validation subsets. The training subset is used to train a learning model for parameter estimation while the validation subset is used to evaluate the performance of this learning model at all the candidate hyper-parameter values to find out the optimal values.

In our experiments, we strictly follow the aforementioned protocol for performance evaluation. For a training/test split on a human action dataset, we randomly divide its training set into two subsets: the training subset roughly consists of all the examples belonging to 80% training classes and the validation subset is composed of all the examples in the remaining 20% training classes. In detail, to form training and validation subsets for a split, 41 and 10 out of 51 training classes are randomly chosen respectively, for UCF101 (51/50); 65 and 16 out of 81 training classes are randomly chosen respectively, for UCF101 (81/20); and 21 and five out of 26 training classes are randomly chosen respectively, for HMDB51. For robustness, such a trial is always repeated three times for each split on two human datasets. Based on three-trial classwise cross-validation for a split in a specific scenario (i.e., specific visual and semantic representations are used), we apply the procedure presented in Section 4.4 to find out the optimal hyper-parameter values involved in our algorithm, α, d_y and k_G, as well as k_{ST} when the self-teaching technique is applied under the transductive setting. In addition, we use the protocol described in Section 4.6 to seek the optimal γ value when two semantic representations are jointly used.

For a split in a specific scenario, the set of optimal hyper-parameter values in the aforementioned manner are used only for this split to yield the performance on its test set of unseen class in this split.

3 Experimental Results

Tables 1-12 list all the experimental results for 30 splits of UCF101 (51/50, 81/50) and HMDB51 (26/25) in different scenarios. To simplify our presentation, we introduce the following notations to different semantic representations: A – Attributes, W – Word-Vectors, C – Joint use of two representations). Only the statistics of accuracies (Mean±SEM) on 30 splits in different scenarios are reported in Table 8.

Table 1: Optimal hyper-parameter values and ZSL accuracies(%) on test sets of 30 splits for UCF101 (81/20) with MBH features.

	α			d_y			k_G			k_{ST}			Accuracy (BiDiLEL)			Accuracy (BiDiLEL+ST)			Accuracy (BiDiLEL+SP)		
	A	W	C	A	W	C	A	W	C	A	W	C	A	W	C(γ)	A	W	C(γ)	A	W	C(γ)
Split 1	1	1	1	100	50	150	10	10	10	140	40	100	36.9	31.6	44.0(0.4)	45.5	34.7	55.1(0.5)	50.5	34.2	62.8(0.5)
Split 2	1	10	1	100	300	100	10	20	10	60	140	120	30.5	28.1	34.5(0.4)	39.1	31.6	41.7(0.4)	35.7	36.6	45.3(0.2)
Split 3	1	1	1	100	250	100	10	10	10	20	180	160	25.7	23.8	32.2(0.6)	31.0	26.1	41.6(0.3)	31.1	28.3	39.7(0.3)
Split 4	1	10	1	100	250	150	15	25	15	60	200	140	23.6	20.8	29.5(0.3)	29.0	22.3	38.2(0.3)	32.6	28.2	29.9(0.1)
Split 5	10	10	10	100	200	100	30	30	30	20	200	40	39.3	47.4	42.5(0.1)	45.1	50.7	44.3(0.0)	42.0	61.9	47.5(0.1)
Split 6	10	10	10	100	50	50	30	30	30	100	180	160	32.9	32.3	36.6(0.2)	47.2	38.1	45.3(0.2)	33.1	49.8	44.1(0.3)
Split 7	10	10	10	150	50	150	30	25	25	40	120	120	30.8	22.2	31.0(0.3)	36.4	23.5	38.8(0.3)	27.9	24.9	30.8(0.2)
Split 8	10	10	10	150	150	150	25	25	25	140	140	140	33.1	28.9	38.9(0.5)	43.9	32.3	43.4(0.4)	46.5	30.8	51.8(0.4)
Split 9	10	10	10	100	300	100	30	15	30	40	160	120	39.7	37.2	44.8(0.3)	54.2	44.4	56.5(0.1)	59.1	38.3	59.1(0.0)
Split 10	10	10	10	100	250	100	30	30	30	100	120	120	26.9	25.5	29.3(0.3)	29.3	28.3	35.7(0.4)	30.6	46.4	41.6(0.5)
Split 11	1	10	1	100	100	100	10	15	15	120	80	120	31.5	34.5	37.8(0.4)	39.1	38.6	45.7(0.3)	45.4	40.2	56.1(0.3)
Split 12	10	10	10	100	250	100	15	30	25	100	60	60	28.5	27.9	33.8(0.3)	35.0	31.8	41.0(0.3)	30.5	33.2	32.7(0.4)
Split 13	10	10	10	50	150	150	30	30	30	40	200	60	31.2	31.4	40.7(0.5)	39.5	34.2	54.6(0.4)	50.4	34.2	59.1(0.4)
Split 14	10	10	10	150	50	150	30	30	30	80	80	80	26.6	20.1	30.5(0.3)	38.0	25.9	43.1(0.3)	42.6	33.0	42.0(0.4)
Split 15	10	10	10	100	300	150	30	25	30	60	200	120	29.7	33.2	32.5(0.1)	33.3	41.5	39.2(0.1)	42.0	48.2	48.3(0.4)
Split 16	10	10	10	100	200	100	30	30	30	200	120	120	33.5	24.4	33.8(0.4)	37.6	25.6	36.3(0.4)	39.4	20.1	21.1(0.7)
Split 17	10	10	10	100	100	100	30	20	30	180	140	140	27.6	33.0	36.3(0.4)	34.3	37.4	40.8(0.3)	40.9	36.8	39.5(0.3)
Split 18	10	10	10	100	150	150	25	30	25	100	40	160	37.8	30.1	41.6(0.5)	48.1	31.4	49.1(0.4)	43.4	33.0	38.2(0.1)
Split 19	10	10	10	100	300	200	25	25	25	40	80	40	30.2	31.3	34.6(0.2)	41.2	37.8	42.3(0.2)	41.4	42.3	49.8(0.3)
Split 20	10	10	10	100	100	100	30	25	25	40	180	140	31.3	22.8	35.9(0.3)	38.9	25.1	41.5(0.2)	41.1	18.5	42.9(0.3)
Split 21	10	10	10	100	100	100	30	25	25	100	200	180	36.2	37.7	40.5(0.2)	43.6	46.7	47.0(0.3)	55.5	52.2	51.5(0.0)
Split 22	10	10	10	100	200	150	25	30	25	60	200	60	22.8	28.5	29.2(0.4)	22.7	28.5	25.4(0.2)	30.1	24.8	25.5(0.3)
Split 23	10	10	10	50	150	100	25	15	25	120	180	140	31.6	30.6	39.2(0.4)	40.4	37.3	46.9(0.4)	36.8	34.1	54.2(0.4)
Split 24	10	10	10	50	100	100	30	30	30	60	100	100	36.5	40.3	46.2(0.4)	47.5	48.7	56.0(0.3)	49.1	49.2	52.5(0.7)
Split 25	10	10	10	100	150	100	25	25	25	80	120	80	34.8	34.5	42.4(0.5)	44.0	39.9	48.4(0.6)	48.1	43.8	40.2(0.7)
Split 26	10	10	10	100	50	100	30	30	30	100	120	100	29.6	27.0	33.2(0.2)	35.8	37.1	38.4(0.1)	43.9	36.3	43.9(0.0)
Split 27	10	10	10	150	50	150	30	30	30	100	200	100	32.3	30.7	40.9(0.4)	38.3	37.5	47.8(0.3)	43.9	54.5	43.9(0.0)
Split 28	10	10	10	100	200	100	30	30	30	80	80	80	33.7	28.3	39.9(0.4)	40.7	32.2	45.2(0.4)	44.9	32.1	50.4(0.3)
Split 29	10	10	10	50	300	150	30	30	30	180	40	160	31.2	26.3	30.6(0.8)	37.8	23.5	29.1(0.8)	42.3	20.9	41.3(0.8)
Split 30	10	10	10	150	100	150	25	30	30	100	100	100	24.2	25.3	26.9(0.3)	32.1	31.3	33.7(0.3)	33.2	31.4	44.7(0.3)
Mean±SEM													31.3 ± 0.8	29.9 ± 1.1	36.3 ± 1.0	38.9 ± 1.2	34.1 ± 1.4	43.1 ± 1.3	41.1 ± 1.4	36.6 ± 1.9	44.3 ± 1.8

Table 2: Optimal hyper-parameter values and ZSL accuracies(%) on test sets of 30 splits for UCF101 (81/20) with IDT features.

	α			d_y			k_G			k_{ST}			Accuracy (BiDiLEL)			Accuracy (BiDiLEL+ST)			Accuracy (BiDiLEL+SP)		
	A	W	C	A	W	C	A	W	C	A	W	C	A	W	C(γ)	A	W	C(γ)	A	W	C(γ)
Split 1	0.01	0.01	0.01	150	250	300	10	10	10	100	120	100	42.8	35.2	46.9(0.5)	53.3	39.9	52.8(0.7)	68.0	42.7	67.1(0.3)
Split 2	0.01	0.1	0.01	100	200	100	10	25	10	100	160	160	35.4	34.1	40.4(0.3)	45.7	37.4	47.1(0.4)	51.6	40.2	49.8(0.3)
Split 3	0.01	0.01	0.01	100	200	100	10	10	10	120	180	120	33.1	27.9	39.0(0.5)	44.5	30.1	50.9(0.4)	52.6	25.7	52.7(0.1)
Split 4	0.1	0.1	0.1	100	150	100	30	15	20	80	120	120	29.7	25.2	37.1(0.3)	36.8	27.7	43.2(0.3)	48.8	43.7	56.8(0.4)
Split 5	0.1	0.1	0.1	100	100	100	15	25	15	60	200	60	43.6	47.8	46.0(0.1)	50.4	57.1	52.0(0.1)	61.0	64.7	58.1(0.4)
Split 6	0.1	0.01	0.1	50	100	100	20	10	10	80	100	100	35.7	36.4	43.7(0.3)	43.9	40.1	53.8(0.3)	48.2	45.7	60.8(0.4)
Split 7	0.1	0.01	0.1	100	300	100	10	10	10	160	200	200	29.8	26.8	31.2(0.4)	39.5	32.5	37.4(0.3)	35.8	31.0	38.3(0.1)
Split 8	0.01	0.01	0.01	100	200	100	10	10	10	120	120	120	33.5	30.4	40.9(0.4)	46.6	32.0	47.8(0.4)	46.9	39.3	51.6(0.4)
Split 9	0.01	0.1	0.01	100	300	100	10	10	10	100	80	80	38.5	39.6	46.6(0.2)	49.4	47.0	53.3(0.1)	55.7	39.2	66.5(0.2)
Split 10	0.01	0.1	0.01	100	300	100	10	20	10	100	180	100	29.9	28.2	31.7(0.3)	33.6	31.1	39.3(0.5)	52.0	39.6	40.7(0.2)
Split 11	0.01	0.1	0.1	150	300	100	10	25	10	200	60	200	35.2	37.5	42.4(0.3)	43.1	40.7	49.4(0.5)	48.2	40.3	52.4(0.3)
Split 12	0.1	0.1	0.1	100	300	150	10	15	10	80	160	40	32.3	31.1	37.3(0.4)	39.2	38.3	43.1(0.3)	43.6	40.8	47.3(0.1)
Split 13	0.01	0.01	0.01	100	200	100	15	10	10	100	180	180	33.9	35.6	43.1(0.4)	43.2	37.5	53.2(0.3)	50.7	39.3	51.4(0.3)
Split 14	0.1	0.1	0.1	150	300	200	10	10	10	160	120	120	32.3	22.8	34.1(0.3)	43.0	29.8	42.0(0.4)	41.6	41.4	53.6(0.3)
Split 15	0.1	0.01	0.1	100	250	100	25	10	25	80	100	100	31.4	37.1	36.0(0.1)	37.8	45.5	44.2(0.1)	43.0	55.5	58.0(0.3)
Split 16	0.01	0.1	0.01	100	150	100	10	10	10	140	120	140	35.2	27.3	36.1(0.4)	41.4	29.3	43.9(0.3)	45.4	29.4	34.7(0.5)
Split 17	0.1	0.1	0.1	300	300	300	15	10	15	160	180	180	29.8	34.3	38.6(0.6)	42.4	38.7	46.5(0.4)	40.3	40.7	55.4(0.2)
Split 18	0.01	0.1	0.1	50	100	100	15	15	15	200	20	100	37.3	33.8	41.2(0.7)	46.0	28.8	54.0(0.4)	41.8	29.8	53.9(0.6)
Split 19	0.1	0.01	0.1	100	300	100	15	10	15	140	140	140	32.6	32.5	39.2(0.2)	44.1	41.1	47.7(0.2)	49.2	42.8	48.5(0.2)
Split 20	0.01	1	1	100	50	100	10	20	10	100	160	140	33.7	21.9	36.5(0.3)	43.1	23.9	39.7(0.2)	49.4	25.6	26.2(0.1)
Split 21	0.1	0.1	0.1	100	100	100	15	10	15	120	160	120	37.4	39.3	42.4(0.3)	44.2	42.1	48.3(0.3)	48.8	37.5	64.2(0.2)
Split 22	0.1	0.1	0.1	100	100	100	20	15	20	100	120	120	23.1	32.1	30.0(0.3)	23.6	34.6	29.0(0.3)	28.0	30.6	29.9(0.4)
Split 23	0.1	0.1	0.1	100	100	100	25	10	25	120	200	160	38.1	34.9	43.3(0.4)	48.3	39.7	52.6(0.3)	52.4	49.4	54.6(0.6)
Split 24	0.1	1	1	50	100	100	10	25	25	100	60	120	40.0	42.2	49.9(0.4)	53.4	51.5	59.6(0.6)	53.3	45.6	54.4(0.4)
Split 25	0.1	0.1	0.1	100	250	100	20	30	30	100	40	100	36.6	37.2	45.9(0.5)	46.4	41.9	54.3(0.4)	57.9	51.0	66.9(0.3)
Split 26	0.1	0.1	0.1	150	100	150	15	25	15	100	120	160	32.4	25.0	38.5(0.3)	37.4	36.0	45.5(0.3)	38.3	33.3	38.3(0.0)
Split 27	0.1	1	0.1	100	50	100	25	20	25	100	140	100	33.8	31.9	41.7(0.3)	36.5	37.7	51.5(0.3)	32.9	53.7	53.2(0.3)
Split 28	0.1	0.1	0.1	100	100	100	15	30	20	120	100	120	38.2	29.5	44.8(0.4)	49.3	35.1	56.2(0.4)	64.2	39.1	61.5(0.3)
Split 29	0.1	0.1	0.1	50	300	50	25	15	25	140	100	140	31.4	29.5	33.4(0.6)	36.7	28.1	34.3(0.7)	50.8	38.0	35.8(0.5)
Split 30	0.1	0.1	0.1	100	200	100	20	10	20	40	120	120	28.1	31.8	30.7(0.4)	34.9	38.5	38.7(0.3)	49.4	33.7	46.1(0.3)
Mean±SEM													34.2 ± 0.8	32.6 ± 1.1	39.6 ± 1.0	42.6 ± 1.2	37.1 ± 1.3	47.0 ± 1.3	48.3 ± 1.6	40.3 ± 1.6	51.0 ± 2.0

Table 3: Optimal hyper-parameter values and ZSL accuracies(%) on test sets of 30 splits for UCF101 (81/20) with C3D features.

	α			d_y			k_G			k_{ST}			Accuracy (BiDiLEL)			Accuracy (BiDiLEL+ST)			Accuracy (BiDiLEL+SP)		
	A	W	C	A	W	C	A	W	C	A	W	C	A	W	C(γ)	A	W	C(γ)	A	W	C(γ)
Split 1	1000	1000	1000	50	100	50	15	10	5	140	180	160	43.0	44.1	56.1(0.5)	50.0	50.1	60.8(0.3)	49.5	56.3	52.5(0.1)
Split 2	10	1	10	50	150	50	5	5	5	100	160	100	42.9	41.8	53.3(0.3)	51.0	43.9	60.4(0.3)	36.6	44.9	63.8(0.5)
Split 3	10	100	1000	50	100	50	5	25	5	140	100	100	34.6	37.6	40.0(0.3)	43.1	42.6	46.5(0.3)	35.8	42.2	50.2(0.3)
Split 4	1000	10	100	150	100	150	15	5	5	80	160	160	40.8	33.8	48.0(0.4)	59.2	39.4	59.4(0.4)	62.6	39.2	60.3(0.5)
Split 5	1000	10	1000	150	200	150	30	5	5	100	120	120	40.6	55.1	56.2(0.3)	43.2	62.0	68.7(0.4)	47.7	81.5	68.5(0.2)
Split 6	1	10	10	100	100	100	15	10	15	120	200	180	38.3	43.9	49.3(0.5)	45.4	47.1	57.0(0.4)	57.0	49.8	68.8(0.4)
Split 7	10	1000	10	50	150	50	10	20	20	80	140	140	36.5	36.2	34.9(0.2)	41.3	46.5	43.9(0.4)	38.7	43.1	47.0(0.2)
Split 8	1000	100	100	50	100	50	10	30	30	140	200	160	38.0	29.4	42.2(0.5)	51.5	36.8	56.7(0.4)	54.7	44.6	61.1(0.5)
Split 9	100	100	100	50	100	100	30	20	25	140	160	200	45.5	42.1	53.8(0.3)	51.6	47.3	64.7(0.3)	61.6	46.0	71.7(0.3)
Split 10	10	100	100	50	250	100	30	30	30	40	140	140	29.5	33.9	36.9(0.5)	35.0	32.6	43.6(0.4)	38.2	28.5	39.9(0.5)
Split 11	10	100	10	100	250	100	10	10	10	40	120	120	42.5	39.8	51.6(0.4)	55.5	45.7	57.9(0.4)	58.5	44.4	58.5(0.3)
Split 12	10	10	10	50	150	50	10	5	10	140	200	200	28.9	30.8	34.6(0.4)	33.3	34.4	35.8(0.3)	33.8	36.6	42.4(0.2)
Split 13	100	100	100	200	50	50	5	15	10	200	40	40	39.0	39.9	53.2(0.4)	56.0	38.4	60.9(0.4)	44.2	47.6	61.8(0.5)
Split 14	100	10	100	50	150	50	15	30	15	100	100	100	36.6	33.5	44.2(0.3)	45.6	37.9	56.0(0.3)	45.3	35.4	59.0(0.3)
Split 15	10	100	100	50	50	50	20	10	20	120	40	120	33.4	48.6	47.6(0.4)	37.6	56.9	52.1(0.2)	39.5	59.4	47.1(0.2)
Split 16	1000	100	100	50	50	50	30	15	30	140	80	140	42.9	40.0	51.8(0.6)	45.8	42.6	64.0(0.6)	47.9	46.0	63.9(0.6)
Split 17	100	100	100	150	50	150	30	30	30	60	100	80	39.4	39.1	45.1(0.5)	48.1	44.9	55.3(0.5)	56.1	46.4	62.1(0.3)
Split 18	10	1000	1000	50	100	100	20	25	25	60	160	140	49.2	29.6	52.4(0.5)	54.8	32.0	62.1(0.3)	52.8	31.3	63.1(0.4)
Split 19	100	100	100	100	50	100	15	30	25	100	120	120	40.5	34.5	49.5(0.3)	51.0	40.1	61.9(0.4)	67.0	37.7	72.1(0.5)
Split 20	10	1000	1000	50	150	50	15	25	15	160	120	120	34.5	35.7	43.4(0.4)	39.0	41.4	53.8(0.4)	52.2	57.5	67.9(0.4)
Split 21	100	100	100	100	50	100	25	15	20	120	40	120	42.1	42.7	52.2(0.4)	44.4	47.4	60.5(0.3)	42.7	56.5	65.1(0.8)
Split 22	10	10	10	150	50	150	20	30	20	100	60	120	29.7	31.9	36.6(0.3)	45.4	35.3	50.9(0.2)	33.0	26.2	47.2(0.3)
Split 23	1000	10	100	150	50	150	25	25	25	80	60	100	35.3	41.7	53.8(0.3)	47.8	42.9	63.7(0.3)	38.0	56.9	78.1(0.3)
Split 24	1000	100	1000	100	50	50	30	20	20	120	200	200	51.3	43.1	58.2(0.5)	57.7	41.9	64.1(0.4)	76.0	51.5	60.5(0.5)
Split 25	100	100	100	100	100	100	25	30	25	100	180	100	36.4	46.0	50.1(0.3)	51.4	48.0	63.2(0.3)	49.2	48.6	49.2(0.0)
Split 26	10	100	100	50	100	100	5	25	10	120	200	200	42.5	34.1	48.0(0.3)	48.0	41.9	69.0(0.2)	60.4	38.7	65.4(0.6)
Split 27	10	100	100	100	100	100	10	30	30	60	180	140	44.6	38.6	55.5(0.5)	55.2	41.3	64.7(0.2)	57.5	44.7	58.7(0.0)
Split 28	10	1000	1000	100	100	100	10	15	15	100	100	100	46.3	27.4	43.7(0.4)	54.1	30.3	58.4(0.4)	69.6	37.2	55.1(0.2)
Split 29	10	100	10	100	300	100	15	25	15	180	180	180	40.0	41.9	47.3(0.6)	49.6	50.5	52.8(0.1)	52.8	50.8	46.9(0.1)
Split 30	10	10	10	100	250	100	20	25	20	120	160	160	29.8	31.2	36.2(0.4)	38.2	34.9	44.4(0.3)	45.2	39.5	40.3(0.1)
Mean±SEM													39.2 ± 1.0	38.3 ± 1.1	47.5 ± 1.3	47.7 ± 1.2	42.6 ± 1.3	57.1 ± 1.5	50.1 ± 2.0	45.6 ± 2.0	58.3 ± 1.8

Table 4: Optimal hyper-parameter values and ZSL accuracies(%) on test sets of 30 splits for UCF101 (81/20) with IDT+C3D features.

	α			d_y			k_G			k_{ST}			Accuracy (BiDiLEL)			Accuracy (BiDiLEL+ST)			Accuracy (BiDiLEL+SP)		
	A	W	C	A	W	C	A	W	C	A	W	C	A	W	C(γ)	A	W	C(γ)	A	W	C(γ)
Split 1	0.1	0.001	0.1	100	300	100	30	5	30	40	120	80	55.8	49.4	63.5(0.4)	70.8	54.4	75.9(0.4)	79.9	51.6	81.5(0.3)
Split 2	0.1	0.1	0.1	100	300	100	30	5	30	100	180	120	48.0	41.6	59.0(0.4)	57.8	45.3	65.7(0.4)	60.2	42.2	73.6(0.4)
Split 3	0.1	1	0.1	100	250	100	15	30	20	60	40	60	40.8	36.2	51.7(0.4)	58.1	38.4	65.8(0.5)	57.2	40.9	83.1(0.4)
Split 4	1	1	1	100	200	200	20	20	20	100	180	100	42.1	34.5	52.6(0.4)	50.5	36.2	64.7(0.3)	50.5	45.9	67.8(0.2)
Split 5	0.1	1	1	150	150	150	10	20	10	60	200	120	52.8	57.1	57.4(0.2)	59.4	62.6	68.7(0.2)	59.3	80.5	68.9(0.3)
Split 6	0.1	0.1	0.1	50	250	200	25	15	25	140	80	80	41.1	45.5	55.8(0.5)	53.2	51.8	67.3(0.5)	53.9	53.0	71.9(0.7)
Split 7	0.01	1	0.1	100	200	200	10	25	20	100	200	120	38.3	34.0	40.4(0.4)	43.7	43.4	46.7(0.3)	50.6	42.1	39.4(0.3)
Split 8	1	0.1	0.1	100	250	100	25	30	30	160	180	180	45.7	33.2	47.2(0.4)	61.9	38.9	61.8(0.3)	69.8	50.4	72.1(0.2)
Split 9	0.1	0.1	0.1	100	300	100	30	20	30	180	200	180	50.3	48.6	58.4(0.2)	56.4	58.0	70.3(0.4)	55.2	49.2	81.4(0.3)
Split 10	0.1	0.1	0.1	100	250	150	15	20	15	40	120	120	39.2	36.9	42.3(0.4)	44.8	38.1	49.4(0.4)	47.8	33.9	54.7(0.5)
Split 11	0.1	1	1	100	150	100	5	20	10	140	80	80	44.8	44.4	51.2(0.3)	55.6	52.2	59.8(0.4)	55.6	53.1	71.7(0.3)
Split 12	1	0.1	1	100	150	100	5	10	10	120	140	120	35.3	31.6	39.9(0.3)	42.7	37.3	48.3(0.3)	46.1	34.1	44.8(0.1)
Split 13	0.1	0.1	0.1	100	300	150	10	15	10	100	100	100	43.2	43.4	54.6(0.4)	51.9	42.7	63.5(0.3)	65.7	40.5	75.8(0.4)
Split 14	0.01	1	0.1	100	300	300	10	30	10	40	120	80	38.6	33.4	45.9(0.3)	48.4	38.6	58.4(0.3)	50.9	35.0	65.2(0.2)
Split 15	0.1	0.1	0.1	150	100	150	10	15	10	100	100	100	36.8	51.4	40.8(0.1)	45.8	62.1	63.8(0.4)	37.6	71.7	59.7(0.2)
Split 16	0.1	0.1	0.1	100	300	100	15	5	15	120	80	80	42.0	38.3	49.8(0.4)	50.7	42.0	52.1(0.5)	46.8	45.4	69.4(0.3)
Split 17	1	0.1	0.1	150	300	250	25	30	25	160	80	100	39.2	41.4	46.7(0.5)	52.0	52.1	56.6(0.5)	51.3	46.2	63.8(0.4)
Split 18	0.1	0.1	0.1	50	50	50	10	20	20	120	100	100	48.8	39.7	51.7(0.6)	56.3	40.7	62.2(0.6)	57.6	36.2	65.3(0.7)
Split 19	0.01	0.1	0.1	50	50	50	10	30	15	100	140	120	32.2	35.6	47.9(0.4)	49.1	40.9	59.4(0.4)	48.3	51.5	68.4(0.4)
Split 20	0.1	0.01	0.1	50	300	50	20	15	15	80	140	140	44.9	33.5	53.1(0.4)	56.6	36.4	64.6(0.4)	57.2	43.3	71.4(0.2)
Split 21	0.1	0.01	0.01	150	300	300	10	10	10	100	100	100	43.3	45.1	55.8(0.4)	53.5	60.7	66.4(0.3)	70.8	71.0	70.8(0.7)
Split 22	0.01	0.1	0.1	100	300	200	10	10	10	40	60	60	32.2	39.7	41.7(0.3)	44.3	47.2	52.4(0.2)	56.4	49.0	52.9(0.1)
Split 23	0.01	0.1	0.01	100	100	100	10	25	10	120	120	120	47.5	45.7	56.7(0.4)	48.2	56.4	70.2(0.3)	50.5	56.3	77.0(0.2)
Split 24	0.1	0.1	0.1	100	100	100	20	10	20	120	160	160	58.3	46.4	62.0(0.5)	65.4	56.0	63.7(0.6)	74.1	52.1	69.2(0.5)
Split 25	0.1	0.1	0.1	150	300	200	20	15	15	100	120	120	40.0	47.9	53.1(0.3)	51.9	51.8	64.1(0.3)	55.0	48.8	61.9(0.1)
Split 26	0.1	1	0.1	150	200	150	10	30	10	120	180	180	50.3	35.5	53.3(0.2)	54.4	43.9	58.6(0.1)	62.0	45.7	54.0(0.4)
Split 27	0.01	1	0.1	100	200	200	20	15	10	80	140	140	39.9	42.3	57.8(0.4)	44.9	48.5	68.6(0.3)	53.7	61.0	75.6(0.3)
Split 28	0.01	0.01	0.01	100	150	100	10	10	10	60	100	100	48.6	31.7	52.5(0.4)	58.5	37.1	54.3(0.6)	69.2	39.9	61.9(0.6)
Split 29	0.01	0.1	0.01	100	300	200	10	15	10	140	40	40	45.7	43.7	51.7(0.6)	56.9	46.8	59.9(0.6)	62.3	57.4	73.5(0.5)
Split 30	0.01	0.01	0.01	200	100	200	30	10	10	80	40	40	33.9	35.8	38.4(0.4)	40.2	43.5	49.4(0.4)	56.7	52.1	60.1(0.2)
Mean±SEM													43.3 ± 1.2	40.8 ± 1.2	51.1 ± 1.2	52.8 ± 1.3	46.8 ± 1.5	61.1 ± 1.3	57.1 ± 1.7	49.3 ± 2.0	66.9 ± 1.9

Table 5: Optimal hyper-parameter values and ZSL accuracies(%) on test sets of 30 splits for UCF101 (51/50) with MBH features.

	α			d_y			k_G			k_{ST}			Accuracy (BiDiLEL)			Accuracy (BiDiLEL+ST)			Accuracy (BiDiLEL+SP)		
	A	W	C	A	W	C	A	W	C	A	W	C	A	W	C(γ)	A	W	C(γ)	A	W	C(γ)
Split 1	1	10	1	50	100	50	10	25	10	20	140	140	14.8	15.6	15.4(0.1)	16.6	16.3	18.5(0.1)	17.7	19.5	26.9(0.3)
Split 2	1	1	1	50	250	50	5	10	5	20	200	140	13.2	16.5	15.9(0.4)	14.6	18.9	17.8(0.4)	16.2	18.3	14.6(0.4)
Split 3	1	1	1	100	100	100	15	5	5	140	140	140	17.4	12.9	14.3(0.8)	20.7	12.6	13.8(0.7)	20.2	11.8	11.7(0.7)
Split 4	0.1	1	1	100	200	100	5	10	5	60	200	200	13.5	13.4	19.2(0.5)	16.8	15.0	20.9(0.4)	17.8	20.6	16.4(0.2)
Split 5	10	1	1	100	200	100	20	5	20	100	60	100	16.1	13.9	17.0(0.2)	18.8	15.0	20.1(0.4)	19.9	17.1	23.1(0.5)
Split 6	10	10	10	50	100	100	20	25	30	20	100	20	15.3	13.4	16.9(0.3)	18.4	14.5	19.0(0.5)	19.3	14.7	18.9(0.5)
Split 7	10	10	10	200	100	200	30	25	30	20	140	140	15.7	15.6	18.9(0.4)	17.5	16.3	23.2(0.4)	24.3	19.5	27.6(0.4)
Split 8	10	10	10	50	150	50	30	25	30	120	200	120	15.9	17.7	17.7(0.4)	18.0	19.5	19.7(0.4)	19.9	18.8	19.0(0.3)
Split 9	10	10	10	50	150	50	25	20	25	200	40	40	18.1	13.2	16.4(0.5)	20.2	10.2	10.9(1.0)	18.0	12.5	11.5(0.9)
Split 10	10	10	10	50	50	50	25	20	20	200	200	200	16.5	13.9	16.0(0.8)	20.9	16.6	18.4(0.9)	16.6	12.8	18.5(0.5)
Split 11	10	10	10	100	300	150	30	20	30	60	140	60	12.4	12.0	14.3(0.6)	14.0	12.9	14.4(0.6)	13.4	10.4	14.2(0.6)
Split 12	10	100	10	200	200	200	30	25	30	200	180	180	15.2	11.6	16.9(0.2)	19.1	11.0	20.0(0.4)	14.8	11.4	16.6(0.3)
Split 13	10	10	10	100	300	100	30	15	15	160	140	140	17.3	14.0	20.0(0.5)	20.3	17.2	22.4(0.3)	16.0	15.5	21.2(0.5)
Split 14	10	10	10	100	150	100	15	30	15	200	40	200	13.4	13.4	16.5(0.6)	16.7	13.6	18.6(0.5)	12.7	17.4	20.8(0.5)
Split 15	10	10	10	150	250	150	30	15	30	80	20	20	12.1	12.4	15.4(0.5)	15.2	11.8	15.6(0.4)	18.3	16.1	16.6(0.8)
Split 16	10	10	10	100	100	100	30	30	30	20	200	180	14.0	17.1	18.6(0.3)	17.0	16.0	22.9(0.3)	18.2	16.2	26.4(0.5)
Split 17	10	10	10	50	50	50	30	25	30	160	140	160	14.3	16.6	18.3(0.4)	18.6	16.9	21.3(0.6)	16.4	17.6	21.3(0.4)
Split 18	10	1	10	100	250	100	30	10	30	20	60	60	15.0	11.8	15.0(0.0)	15.4	12.6	14.4(0.0)	10.8	16.2	10.8(0.0)
Split 19	10	10	10	200	150	250	30	25	30	60	80	80	17.1	15.1	20.0(0.2)	19.0	18.5	25.8(0.4)	21.7	16.1	16.4(0.0)
Split 20	10	10	10	50	250	50	30	30	30	60	40	40	16.5	13.5	19.0(0.4)	21.3	12.2	20.3(0.3)	22.0	12.8	22.5(0.4)
Split 21	10	10	10	50	300	50	15	25	15	60	120	120	14.8	15.3	15.5(0.7)	16.1	18.6	16.4(0.0)	15.7	13.4	21.7(0.4)
Split 22	1	10	1	50	150	200	10	20	10	100	140	100	15.4	13.6	15.2(0.6)	17.1	16.5	20.2(0.5)	17.5	13.7	16.3(0.7)
Split 23	1	100	10	50	300	250	10	20	10	60	200	160	15.5	15.9	18.3(0.4)	19.2	18.7	20.6(0.5)	18.0	18.5	20.7(0.4)
Split 24	10	1	1	100	150	100	25	10	20	60	80	60	14.5	12.4	16.8(0.3)	18.8	13.5	20.5(0.3)	20.1	14.5	26.2(0.2)
Split 25	10	1000	10	100	50	100	15	15	15	20	80	20	15.8	10.4	17.2(0.3)	19.1	9.4	19.1(0.2)	16.6	8.5	14.9(0.3)
Split 26	10	1	10	200	100	200	30	10	25	80	40	80	16.1	15.0	21.0(0.4)	21.4	15.3	23.7(0.4)	19.8	14.9	21.5(0.1)
Split 27	10	10	10	50	150	150	15	25	15	80	100	40	12.0	15.8	17.8(0.5)	13.4	15.8	21.5(0.4)	11.0	16.4	14.9(0.0)
Split 28	10	1	1	50	100	100	30	10	15	120	60	60	17.6	12.9	16.8(0.7)	19.9	14.6	23.8(0.5)	22.1	15.3	27.1(0.4)
Split 29	1	10	1	100	150	100	15	15	15	40	160	120	14.5	11.2	14.9(0.4)	17.1	10.7	17.2(0.4)	15.8	9.7	15.5(0.5)
Split 30	10	1	10	100	300	100	25	5	25	120	140	140	15.0	13.6	17.4(0.6)	17.5	16.7	20.0(0.5)	16.9	15.6	20.1(0.1)
Mean±SEM													15.2 ± 0.3	14.0 ± 0.3	17.1 ± 0.3	18.0 ± 0.4	14.9 ± 0.5	19.4 ± 0.6	17.6 ± 0.6	15.2 ± 0.6	19.1 ± 0.9

Table 6: Optimal hyper-parameter values and ZSL accuracies(%) on test sets of 30 splits for UCF101 (51/50) with IDT features.

	α			d_y			k_G			k_{ST}			Accuracy (BiDiLEL)			Accuracy (BiDiLEL+ST)			Accuracy (BiDiLEL+SP)		
	A	W	C	A	W	C	A	W	C	A	W	C	A	W	C(γ)	A	W	C(γ)	A	W	C(γ)
Split 1	1	0.1	0.01	100	150	100	10	10	10	40	100	100	16.1	17.2	22.1(0.3)	19.4	18.2	26.2(0.4)	15.9	13.2	24.5(0.5)
Split 2	0.1	1	0.1	100	200	100	10	15	10	80	160	80	17.3	18.4	18.5(0.2)	19.7	20.0	21.9(0.2)	22.8	18.4	22.1(0.2)
Split 3	0.01	0.1	0.01	100	250	100	25	5	10	40	100	100	19.8	14.3	17.1(0.6)	22.7	12.8	19.8(0.6)	25.1	15.4	14.2(0.9)
Split 4	0.01	0.1	0.01	50	100	50	10	15	10	200	200	200	18.2	16.6	22.4(0.4)	22.6	17.6	25.9(0.4)	21.3	16.5	29.6(0.3)
Split 5	0.1	0.01	0.1	50	50	50	10	15	10	40	120	120	15.8	14.8	15.8(0.0)	21.1	19.2	21.0(0.0)	19.9	21.6	23.9(0.3)
Split 6	0.001	0.001	0.001	50	150	50	15	10	15	20	200	60	16.3	12.7	18.1(0.3)	19.9	14.2	21.7(0.3)	25.1	15.6	25.1(0.0)
Split 7	0.1	0.1	0.1	200	50	200	10	15	10	100	100	100	16.8	17.1	20.5(0.4)	21.3	17.7	24.7(0.4)	22.4	13.6	21.7(0.5)
Split 8	0.1	1	0.1	100	200	100	10	15	10	80	160	80	17.3	18.4	18.5(0.2)	19.7	20.0	21.9(0.2)	22.8	18.4	22.1(0.2)
Split 9	0.01	0.1	0.01	100	250	100	25	5	10	40	100	100	19.8	14.3	17.1(0.6)	22.7	12.8	19.8(0.6)	25.1	15.4	14.2(0.9)
Split 10	0.1	0.01	0.1	100	50	100	10	5	10	200	200	200	18.6	13.9	23.2(0.6)	23.6	12.9	26.8(0.6)	24.6	13.8	25.8(0.8)
Split 11	0.1	0.01	0.1	50	100	50	5	10	10	100	120	80	12.1	14.1	16.2(0.5)	13.6	13.7	17.1(0.7)	12.5	12.0	17.6(0.2)
Split 12	0.1	0.01	0.1	50	250	50	20	5	20	100	80	100	16.5	13.0	20.7(0.4)	18.5	13.5	22.9(0.3)	24.5	18.4	24.6(0.6)
Split 13	10	0.1	0.1	200	300	200	25	15	25	40	80	80	17.6	15.9	25.0(0.6)	21.2	19.0	29.6(0.5)	19.1	20.3	29.3(0.7)
Split 14	0.01	1	1	200	250	200	30	30	30	200	100	200	13.7	14.6	17.5(0.6)	17.8	15.9	20.0(0.5)	19.6	15.5	25.6(0.5)
Split 15	0.1	1	1	100	50	100	30	30	30	60	100	100	13.3	13.6	16.2(0.5)	18.0	14.3	18.5(0.5)	20.2	15.6	22.1(0.4)
Split 16	1	0.1	1	200	50	200	30	20	30	160	180	180	15.4	19.8	21.1(0.4)	20.9	20.3	27.9(0.3)	22.1	20.6	28.5(0.1)
Split 17	0.1	0.1	0.1	250	100	200	30	30	30	180	60	180	15.7	18.4	21.2(0.4)	23.3	22.3	25.7(0.4)	27.0	22.2	26.4(0.4)
Split 18	1	0.01	0.1	50	300	50	20	15	20	20	80	80	17.5	12.6	21.1(0.4)	19.9	14.3	21.8(0.6)	15.6	11.5	20.0(0.1)
Split 19	0.1	1	0.1	50	250	50	20	15	20	100	100	100	19.4	15.7	20.5(0.1)	21.1	19.0	23.4(0.1)	26.4	15.3	26.4(0.0)
Split 20	0.1	1	0.1	100	100	100	25	30	25	100	100	100	17.9	13.6	18.6(0.3)	23.9	14.1	26.1(0.2)	24.8	16.0	29.3(0.2)
Split 21	0.1	0.1	0.1	100	200	100	10	5	10	20	160	100	17.7	16.5	19.2(0.6)	19.4	19.1	23.6(0.7)	21.7	18.7	25.1(0.6)
Split 22	0.01	0.1	0.01	50	200	50	10	30	10	120	60	120	18.7	15.3	17.2(0.8)	22.5	17.5	20.0(0.8)	20.8	18.2	18.1(0.6)
Split 23	0.01	0.1	0.1	50	150	50	10	10	10	120	140	120	16.4	19.1	21.9(0.4)	20.8	22.4	26.9(0.5)	20.8	17.8	25.6(0.6)
Split 24	0.01	0.01	0.01	50	150	50	25	15	25	120	100	120	15.8	14.6	19.3(0.4)	19.8	15.6	25.0(0.4)	23.5	18.1	26.4(0.6)
Split 25	0.1	0.1	0.1	250	300	250	5	5	5	40	60	60	15.4	14.7	17.9(0.3)	19.6	17.0	21.1(0.4)	14.6	16.4	17.0(0.1)
Split 26	0.01	0.01	0.01	150	100	100	5	5	5	60	40	60	16.7	15.6	20.6(0.4)	22.8	15.6	23.0(0.4)	21.6	22.8	24.0(0.4)
Split 27	0.1	0.01	0.01	300	100	300	25	5	5	20	160	120	13.8	16.9	19.0(0.6)	18.0	19.3	19.2(0.1)	21.5	16.9	18.7(0.0)
Split 28	0.001	0.001	0.001	100	50	100	10	10	10	100	40	80	16.2	12.9	18.2(0.7)	21.3	14.7	24.7(0.6)	24.8	19.7	25.2(0.8)
Split 29	0.01	0.1	0.01	100	150	100	15	10	10	20	120	160	16.6	12.5	18.4(0.4)	20.3	12.1	19.6(0.5)	18.5	11.6	19.3(0.5)
Split 30	0.01	0.001	0.01	100	300	100	15	25	30	180	60	180	16.7	14.9	20.8(0.5)	21.1	18.4	23.3(0.5)	28.4	21.0	25.9(0.1)
Mean±SEM													16.6 ± 0.3	15.4 ± 0.4	19.5 ± 0.4	20.6 ± 0.4	16.8 ± 0.5	23.0 ± 0.6	21.8 ± 0.7	17.0 ± 0.6	23.3 ± 0.8

Table 7: Optimal hyper-parameter values and ZSL accuracies(%) on test sets of 30 splits for UCF101 (51/50) with C3D features.

	α			d_y			k_G			k_{ST}			Accuracy (BiDiLEL)			Accuracy (BiDiLEL+ST)			Accuracy (BiDiLEL+SP)		
	A	W	C	A	W	C	A	W	C	A	W	C	A	W	C(γ)	A	W	C(γ)	A	W	C(γ)
Split 1	100	100	100	100	50	50	10	30	25	160	200	180	23.1	21.3	27.5(0.6)	29.0	23.9	34.0(0.4)	34.4	21.2	35.5(0.5)
Split 2	10	100	10	50	250	200	25	20	25	80	80	80	23.2	19.7	26.3(0.4)	28.1	19.1	35.9(0.4)	35.3	25.4	42.2(0.3)
Split 3	10	1000	10	100	100	100	10	20	10	180	200	200	21.1	17.0	21.4(0.5)	28.7	21.0	28.9(0.6)	36.9	19.7	30.2(0.6)
Split 4	1000	10	100	100	50	100	30	10	10	120	180	100	19.5	19.3	26.5(0.6)	29.3	16.3	36.0(0.6)	28.7	17.4	32.9(0.3)
Split 5	100	10	100	150	50	150	30	15	10	60	140	120	20.8	19.8	24.0(0.4)	25.1	22.3	31.6(0.3)	24.6	26.6	39.8(0.6)
Split 6	1	10	10	150	200	150	10	10	10	100	200	200	24.4	19.5	27.4(0.5)	32.1	21.2	31.8(0.4)	33.7	24.1	36.1(0.7)
Split 7	100	10	100	100	150	100	10	5	10	160	180	160	23.1	21.1	28.3(0.6)	29.0	24.2	36.0(0.5)	34.4	18.7	37.0(0.5)
Split 8	10	100	100	100	300	100	10	20	10	120	100	100	23.1	19.9	30.7(0.4)	31.6	19.3	37.3(0.4)	36.5	29.2	44.0(0.4)
Split 9	10	1000	10	100	100	100	10	20	10	180	200	200	21.1	17.0	21.4(0.5)	28.7	21.0	28.9(0.6)	36.9	19.7	30.2(0.6)
Split 10	1000	10	100	150	150	150	5	30	10	20	120	120	19.9	21.1	24.8(0.3)	29.7	21.2	31.1(0.2)	27.6	19.2	26.6(0.5)
Split 11	1000	1000	1000	200	50	200	20	5	20	20	200	200	15.2	14.6	17.5(0.5)	21.5	17.5	26.8(0.3)	21.2	15.1	24.6(0.1)
Split 12	10	1000	100	50	100	100	20	10	20	40	100	100	21.3	15.3	25.7(0.4)	24.8	18.8	29.9(0.2)	28.4	24.8	34.3(0.1)
Split 13	10	100	100	100	100	100	25	20	20	120	200	160	25.2	18.6	26.8(0.6)	28.7	18.7	33.2(0.4)	31.5	25.5	23.6(0.9)
Split 14	100	100	100	100	200	100	30	30	30	200	180	200	22.2	19.2	23.7(0.4)	30.6	23.2	31.4(0.3)	25.3	20.4	34.8(0.6)
Split 15	1000	1000	1000	50	50	50	5	15	5	160	60	160	16.6	22.8	24.5(0.4)	19.8	21.5	27.6(0.5)	17.3	22.6	26.0(0.5)
Split 16	1000	1000	1000	50	100	100	30	5	30	160	160	160	17.6	20.2	20.4(0.2)	22.5	22.5	28.2(0.3)	25.5	23.2	26.9(0.7)
Split 17	100	100	100	100	50	100	25	25	25	180	140	180	19.5	19.6	25.5(0.4)	28.6	19.8	32.7(0.3)	28.6	17.4	29.2(0.1)
Split 18	1	10	10	50	250	50	25	30	25	120	200	200	16.1	13.9	18.3(0.4)	19.2	15.5	22.2(0.1)	20.9	13.8	14.0(0.1)
Split 19	1	100	1	100	50	100	10	20	10	120	120	120	21.9	17.7	24.7(0.1)	27.0	20.4	30.8(0.1)	31.2	19.6	31.2(0.0)
Split 20	10	1000	1000	50	50	50	15	25	15	140	80	80	23.6	19.1	27.8(0.5)	30.3	18.1	31.3(0.5)	23.7	23.6	35.8(0.4)
Split 21	10	100	100	100	50	100	15	15	15	80	60	100	19.0	21.8	22.0(0.1)	25.8	26.4	28.8(0.1)	24.7	30.4	33.5(0.1)
Split 22	100	100	100	100	250	100	15	15	15	160	120	120	21.7	21.5	28.7(0.5)	27.2	23.8	29.5(0.7)	33.4	25.1	34.8(0.7)
Split 23	1000	1000	1000	100	100	100	20	10	20	160	180	180	19.1	21.2	26.8(0.5)	26.4	23.2	27.9(0.2)	26.8	23.8	26.8(0.0)
Split 24	10	1000	10	100	300	100	25	5	20	60	120	60	19.2	17.0	27.0(0.4)	23.1	15.5	30.3(0.5)	22.0	11.7	30.0(0.5)
Split 25	1000	100	1000	150	200	150	20	25	20	80	200	180	18.6	19.6	22.1(0.5)	26.6	19.3	30.3(0.5)	28.5	23.4	30.1(0.6)
Split 26	1000	1	1000	300	100	300	30	20	20	100	180	100	21.2	15.5	27.6(0.4)	31.2	15.3	30.5(0.5)	32.8	16.2	35.3(0.3)
Split 27	1000	10	1000	300	200	300	15	30	15	100	100	100	17.1	18.1	17.1(0.0)	25.5	21.3	25.5(0.0)	27.3	18.9	27.3(0.0)
Split 28	10	100	100	150	100	150	15	20	15	20	200	40	19.9	18.2	23.2(0.7)	21.1	19.8	27.1(0.5)	20.7	24.9	39.6(0.7)
Split 29	1	100	10	50	100	100	5	15	10	120	160	140	21.4	16.7	23.2(0.5)	24.8	16.2	31.4(0.3)	26.2	18.4	22.7(0.7)
Split 30	1	100	1000	100	50	100	5	15	10	80	60	60	20.3	20.0	22.3(0.3)	24.9	18.7	25.7(0.1)	24.1	21.4	32.6(0.3)
Mean±SEM													20.5 ± 0.5	18.9 ± 0.4	24.4 ± 0.6	26.7 ± 0.6	20.2 ± 0.5	30.4 ± 0.6	28.3 ± 1.0	21.4 ± 0.8	31.6 ± 1.2

Table 8: Optimal hyper-parameter values and ZSL accuracies(%) on test sets of 30 splits for UCF101 (51/50) with IDT+C3D features.

	α			d_y			k_G			k_{ST}			Accuracy (BiDiLEL)			Accuracy (BiDiLEL+ST)			Accuracy (BiDiLEL+SP)		
	A	W	C	A	W	C	A	W	C	A	W	C	A	W	C(γ)	A	W	C(γ)	A	W	C(γ)
Split 1	1	0.1	0.1	100	150	100	10	10	10	40	100	80	23.0	21.6	27.7(0.5)	28.5	24.6	37.6(0.3)	26.2	24.6	38.2(0.5)
Split 2	1	1	1	100	300	300	10	10	10	60	100	120	24.6	21.9	28.0(0.4)	32.6	23.5	38.4(0.3)	37.7	26.5	45.2(0.4)
Split 3	0.01	1	0.1	50	250	250	20	5	20	140	160	160	25.1	16.5	25.3(0.5)	30.9	16.4	30.4(0.6)	33.7	18.0	31.7(0.5)
Split 4	0.1	0.1	0.1	150	50	150	15	15	15	120	160	120	24.3	21.8	31.3(0.5)	29.8	23.0	38.4(0.3)	29.6	26.5	42.7(0.4)
Split 5	0.1	0.01	0.1	150	300	150	15	5	15	100	180	180	23.5	19.2	27.0(0.3)	26.3	25.8	34.0(0.5)	29.7	25.5	37.0(0.5)
Split 6	0.001	0.01	0.001	150	300	150	15	5	15	40	160	140	24.1	18.1	26.4(0.4)	33.7	21.5	32.5(0.5)	31.8	20.6	34.8(0.5)
Split 7	0.1	0.1	0.1	300	50	300	15	5	15	60	120	120	22.8	19.0	27.3(0.5)	31.9	19.4	36.8(0.4)	41.0	16.9	35.8(0.5)
Split 8	0.1	1	0.1	150	300	250	15	10	15	20	100	100	24.2	21.9	27.9(0.3)	29.5	23.5	38.8(0.3)	33.1	26.5	34.3(0.5)
Split 9	1	0.1	0.1	100	300	100	15	5	30	100	100	100	23.3	16.3	24.7(0.5)	31.0	15.8	29.4(0.6)	38.8	18.5	35.2(0.6)
Split 10	1	0.1	0.1	100	150	100	30	30	30	40	160	40	23.9	22.8	31.2(0.4)	32.5	23.9	37.8(0.5)	33.9	26.2	36.7(0.5)
Split 11	10	0.1	10	100	300	100	30	5	30	60	100	100	16.3	16.7	17.7(0.3)	19.6	17.5	21.9(0.4)	16.9	22.3	18.5(0.4)
Split 12	0.1	10	1	200	100	200	25	30	30	80	120	100	22.9	15.9	27.3(0.3)	29.2	14.6	33.0(0.3)	24.9	18.7	41.6(0.2)
Split 13	0.01	1	1	50	300	200	10	10	10	20	80	80	27.2	20.3	31.0(0.5)	31.7	23.0	32.6(0.6)	29.1	22.0	32.9(0.8)
Split 14	1	1	1	200	50	200	15	15	15	140	80	180	18.9	20.6	26.1(0.4)	26.5	22.0	34.9(0.4)	32.2	24.0	35.0(0.4)
Split 15	0.1	1	0.1	200	300	300	20	5	20	20	160	20	20.9	19.8	24.6(0.3)	26.5	24.7	26.9(0.2)	33.3	30.6	35.5(0.4)
Split 16	1	1	1	100	250	100	5	10	5	120	200	120	19.7	22.1	21.8(0.1)	26.1	24.0	35.0(0.4)	25.1	32.0	41.9(0.5)
Split 17	1	0.01	0.01	100	100	100	25	5	5	120	140	120	19.2	19.8	26.2(0.4)	31.0	24.6	34.6(0.3)	28.2	24.9	34.1(0.2)
Split 18	0.001	0.001	0.001	100	100	100	15	5	15	140	80	140	16.5	13.7	21.6(0.4)	23.1	15.5	26.0(0.5)	21.3	10.6	21.3(0.0)
Split 19	0.1	1	0.1	100	50	100	25	20	20	80	40	80	24.9	19.9	24.5(0.0)	29.9	23.9	33.6(0.1)	36.1	23.9	38.2(0.0)
Split 20	0.1	1	1	50	250	100	10	20	10	100	120	120	24.3	18.3	26.6(0.3)	31.5	18.4	32.7(0.3)	33.3	14.4	30.7(0.1)
Split 21	0.001	0.1	0.1	150	100	150	10	15	10	40	80	20	22.6	24.3	29.6(0.6)	27.6	28.7	28.5(0.0)	27.4	33.1	36.3(0.8)
Split 22	0.01	0.1	0.01	300	300	300	10	5	5	40	120	120	23.9	22.9	27.8(0.5)	28.0	26.5	32.8(0.7)	30.6	27.1	40.7(0.7)
Split 23	0.01	0.01	0.01	150	100	100	5	5	5	100	200	120	21.9	24.4	29.4(0.4)	29.9	27.2	33.4(0.3)	26.4	25.5	37.9(0.3)
Split 24	0.01	0.001	0.01	100	300	100	5	5	5	120	20	120	19.5	19.4	27.3(0.3)	25.8	21.7	36.1(0.5)	24.2	20.4	41.9(0.5)
Split 25	0.1	0.001	0.1	100	300	100	5	5	5	40	100	40	19.3	18.6	21.5(0.3)	27.6	23.9	27.6(0.0)	28.1	27.5	32.5(0.4)
Split 26	0.1	0.001	0.001	300	100	300	5	5	5	40	140	140	23.7	18.9	29.9(0.4)	34.9	18.2	38.5(0.4)	35.8	18.8	39.5(0.2)
Split 27	0.1	0.001	0.001	200	300	200	5	5	5	100	100	100	18.2	19.2	23.3(0.6)	25.4	20.8	33.6(0.5)	26.8	24.1	35.5(0.3)
Split 28	0.01	0.01	0.01	200	100	200	15	5	10	100	120	120	20.8	16.5	23.8(0.7)	24.4	18.1	29.8(0.6)	23.1	19.0	24.9(0.8)
Split 29	0.1	0.1	0.1	100	50	100	10	15	10	140	100	120	24.1	17.4	27.0(0.4)	32.2	15.6	34.0(0.3)	24.8	21.0	29.5(0.5)
Split 30	1	1	1	100	150	100	10	10	10	20	160	120	22.7	20.2	26.9(0.4)	29.8	22.2	31.0(0.6)	30.7	19.0	32.5(0.3)
Mean±SEM													22.2 ± 0.5	19.6 ± 0.5	26.4 ± 0.6	28.9 ± 0.6	21.6 ± 0.7	33.0 ± 0.8	29.8 ± 1.0	22.9 ± 0.9	35.1 ± 1.1

Table 9: Optimal hyper-parameter values and ZSL accuracies(%) on test sets of 30 splits for HMDB51 (26/25) with MBH features and Word-Vectors.

	α	d_y	k_G	k_{ST}	Accuracy (BiDiLEL)	Accuracy (BiDiLEL+ST)	Accuracy (BiDiLEL+SP)
Split 1	1	300	15	160	16.9	17.7	19.3
Split 2	10	250	15	160	19.7	18.4	16.3
Split 3	1	50	15	180	13.6	13.7	12.2
Split 4	1	50	10	140	14.9	15.6	15.2
Split 5	1	250	5	140	15.2	15.8	14.9
Split 6	1000	150	5	60	9.1	9.2	7.9
Split 7	1	50	5	40	15.6	15.5	13.5
Split 8	0.1	200	5	120	14.1	14.2	15.5
Split 9	1	100	5	20	13.4	13.0	12.4
Split 10	1	100	5	200	15.7	16.6	13.5
Split 11	1	150	5	80	15.2	16.0	14.5
Split 12	0.1	100	30	20	14.9	15.2	14.6
Split 13	10	50	30	140	15.0	15.6	14.6
Split 14	10	50	30	200	9.3	8.8	9.4
Split 15	10	50	30	60	15.6	15.2	14.1
Split 16	0.1	50	5	20	12.3	13.6	14.9
Split 17	0.001	100	15	80	8.6	8.8	9.4
Split 18	1	150	30	120	14.3	14.9	13.4
Split 19	10	150	30	40	20.9	19.5	18.5
Split 20	10	50	30	200	13.9	14.2	14.8
Split 21	10	100	30	160	17.9	17.5	14.3
Split 22	10	150	30	120	11.7	10.7	8.7
Split 23	1	50	25	120	8.8	9.3	9.2
Split 24	10	200	25	140	10.2	11.8	8.3
Split 25	0.1	50	15	140	13.0	13.4	13.1
Split 26	1	50	15	80	14.3	15.9	19.6
Split 27	1	100	15	120	9.3	10.2	11.4
Split 28	10	200	20	100	16.2	18.4	16.4
Split 29	10	100	25	60	16.9	15.0	14.5
Split 30	10	50	15	120	12.2	13.0	10.4
Mean±SEM					14.0 ± 0.6	14.2 ± 0.5	13.5 ± 0.6

Table 10: Optimal hyper-parameter values and ZSL accuracies(%) on test sets of 30 splits for HMDB51 (26/25) with IDT features and Word-Vectors.

	α	d_y	k_G	k_{ST}	Accuracy (BiDiLEL)	Accuracy (BiDiLEL+ST)	Accuracy (BiDiLEL+SP)
Split 1	0.1	50	10	60	19.5	19.9	21.4
Split 2	0.1	50	10	100	23.5	24.4	22.5
Split 3	0.1	300	5	100	17.2	17.3	16.3
Split 4	0.1	300	5	120	18.0	17.7	18.4
Split 5	0.01	250	10	80	18.1	18.4	17.0
Split 6	1	50	30	180	14.1	14.6	14.7
Split 7	10	200	30	20	16.6	17.4	10.9
Split 8	1	300	20	180	17.7	15.4	13.4
Split 9	1	50	20	40	14.8	15.0	13.0
Split 10	1	50	5	20	15.1	13.8	13.2
Split 11	0.1	300	5	20	19.1	21.3	17.3
Split 12	0.001	200	5	100	20.2	21.9	19.9
Split 13	0.1	150	5	160	17.6	17.8	17.9
Split 14	0.1	50	5	140	11.8	11.4	9.2
Split 15	0.1	50	5	60	17.7	17.9	18.4
Split 16	0.1	100	15	20	16.9	17.5	16.6
Split 17	0.1	100	30	100	11.8	12.2	14.2
Split 18	1	150	30	40	17.5	18.4	18.6
Split 19	1	200	25	40	24.2	22.5	23.3
Split 20	1	50	25	120	15.1	15.9	14.8
Split 21	0.01	50	20	60	16.1	17.4	13.7
Split 22	1	50	20	120	12.7	12.4	11.5
Split 23	0.001	50	20	180	9.4	10.4	10.5
Split 24	1	200	10	120	10.8	12.9	9.1
Split 25	0.001	100	20	200	17.4	17.7	14.3
Split 26	0.01	300	25	140	16.9	18.7	23.1
Split 27	0.01	100	25	80	10.4	10.9	15.4
Split 28	10	100	30	80	19.2	17.9	17.3
Split 29	0.001	50	5	20	18.2	17.8	20.4
Split 30	0.1	50	5	100	14.4	12.6	11.0
Mean±SEM					16.4 ± 0.6	16.6 ± 0.6	15.9 ± 0.7

Table 11: Optimal hyper-parameter values and ZSL accuracies(%) on test sets of 30 splits for HMDB51 (26/25) with C3D features and Word-Vectors.

	α	d_y	k_G	k_{ST}	Accuracy (BiDiLEL)	Accuracy (BiDiLEL+ST)	Accuracy (BiDiLEL+SP)
Split 1	100	100	20	80	22.3	23.8	19.2
Split 2	10	150	20	40	27.0	29.6	35.7
Split 3	100	300	10	60	16.0	16.0	16.6
Split 4	100	300	20	200	21.0	23.9	21.4
Split 5	1000	100	30	200	21.3	24.1	27.8
Split 6	10	50	30	40	16.7	16.8	16.5
Split 7	100	100	30	80	18.8	22.1	17.7
Split 8	10	100	15	20	20.6	19.0	24.1
Split 9	10	150	20	100	14.9	15.6	11.1
Split 10	1000	150	15	140	16.6	17.7	11.2
Split 11	1000	50	30	120	21.3	22.5	23.7
Split 12	10	50	30	140	26.3	27.4	27.5
Split 13	10	50	30	180	19.0	20.1	19.4
Split 14	10	150	20	180	12.9	13.9	9.7
Split 15	1000	50	30	80	19.5	19.7	16.6
Split 16	1000	150	20	200	20.2	22.1	20.6
Split 17	10	50	10	80	15.9	17.9	9.0
Split 18	1000	300	5	20	20.7	18.8	22.2
Split 19	1000	50	25	200	24.7	25.7	25.2
Split 20	1000	100	5	100	19.0	19.2	19.6
Split 21	1	100	5	200	19.1	20.8	24.4
Split 22	10	50	10	60	13.7	16.3	11.1
Split 23	1	50	25	20	11.7	15.2	14.8
Split 24	10	50	15	20	12.4	11.1	11.6
Split 25	100	50	25	20	20.0	16.7	21.1
Split 26	10	200	30	160	19.5	22.9	24.1
Split 27	1	100	10	60	13.4	14.4	15.7
Split 28	100	50	5	20	22.1	19.6	18.2
Split 29	0.1	100	5	140	14.3	15.5	18.3
Split 30	1	200	10	140	16.7	16.4	12.8
Mean±SEM					18.6 ± 0.7	19.5 ± 0.8	18.9 ± 1.1

Table 12: Optimal hyper-parameter values and ZSL accuracies(%) on test sets of 30 splits for HMDB51 (26/25) with IDT+C3D features and Word-Vectors.

	α	d_y	k_G	k_{ST}	Accuracy (BiDiLEL)	Accuracy (BiDiLEL+ST)	Accuracy (BiDiLEL+SP)
Split 1	0.001	300	5	60	23.0	21.2	27.2
Split 2	1	300	10	200	29.2	31.2	31.9
Split 3	1	200	10	60	17.8	21.4	20.7
Split 4	1	250	10	140	22.0	23.5	25.2
Split 5	10	150	10	120	21.5	22.1	24.0
Split 6	0.1	50	5	20	17.0	18.8	13.9
Split 7	1	50	5	80	22.0	25.0	24.2
Split 8	0.1	100	10	40	23.5	22.2	24.6
Split 9	0.1	300	5	20	17.5	16.8	15.3
Split 10	1	100	5	200	18.8	19.1	21.1
Split 11	1	150	5	200	25.3	29.0	25.6
Split 12	0.1	100	10	140	29.3	32.7	35.6
Split 13	0.1	100	25	140	20.9	21.3	20.0
Split 14	1	100	25	200	13.9	16.0	13.3
Split 15	1	50	10	60	22.3	23.5	22.2
Split 16	0.1	300	10	200	21.2	23.1	27.6
Split 17	0.1	200	10	80	15.9	17.3	16.9
Split 18	1	50	15	20	22.3	22.0	20.4
Split 19	0.01	100	15	140	28.1	29.7	33.2
Split 20	0.1	150	10	40	21.7	22.0	23.8
Split 21	0.1	150	10	80	22.0	23.7	26.7
Split 22	1	300	30	80	15.0	15.3	18.1
Split 23	0.01	250	30	20	13.1	13.8	19.2
Split 24	10	250	30	20	12.4	14.9	12.3
Split 25	10	50	30	200	20.6	21.9	20.1
Split 26	0.1	100	20	40	22.0	22.3	24.6
Split 27	0.001	50	20	80	13.4	14.7	15.5
Split 28	10	200	30	120	25.0	25.2	24.3
Split 29	0.1	50	20	40	21.6	22.0	24.9
Split 30	1	100	10	100	19.8	17.9	17.5
Mean±SEM					20.6 ± 0.8	21.7 ± 0.9	22.3 ± 1.0