Transductive Few-shot Learning with Prototype-based Label Propagation by Iterative Graph Refinement

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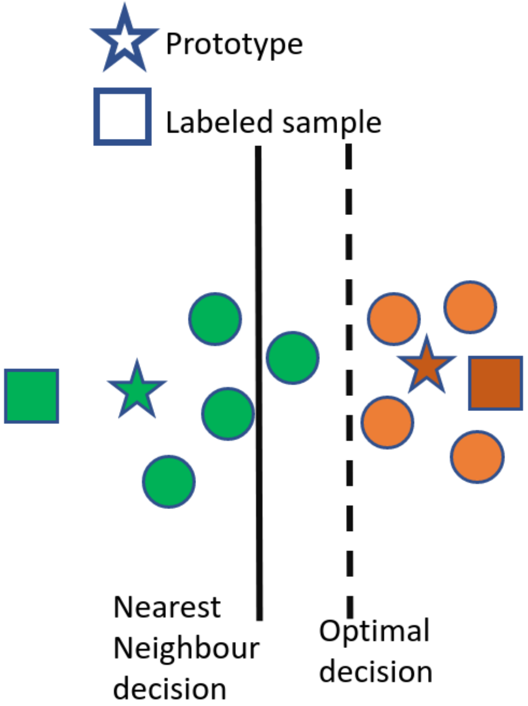
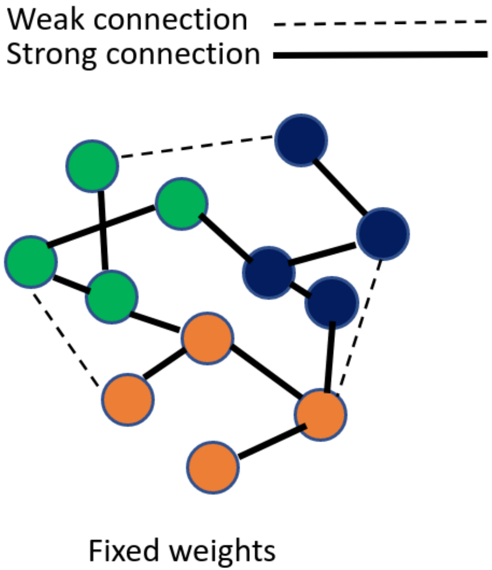
Problems

- What are the issues affecting transductive methods?
  - Prototype-based methods
  - Graph-based method

- How to avoid them
  - Graph construction based on sample-to-prototype affinity
  - Label Propagation for estimating prototypes

The issues of prototype and graph-based methods





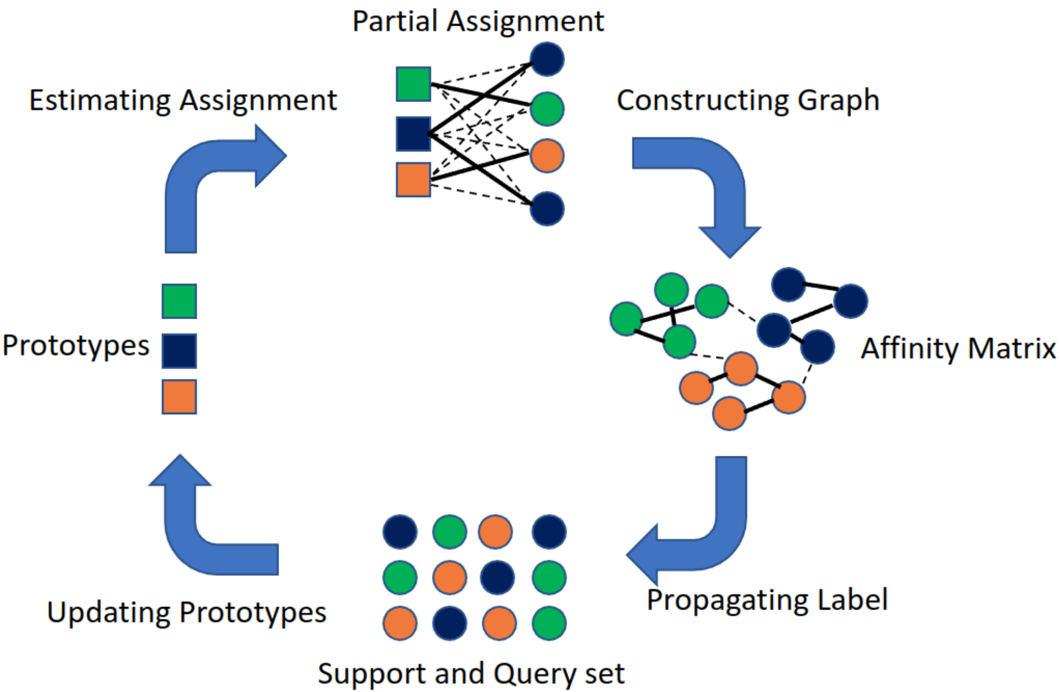
Prototype-based methods:

1. sensitive to the large within-class variance and low between-class variance
2. estimate prototypes inaccurately by the soft-label assignment alone.

Graph-based methods:

1. determined graph with noisy links
2. propagating labels based on the graph

Our Method: Prototypes-based Label Propagation



Algorithm 1: Prototype-based Label Propagation.

Input: $\boldsymbol{X}, \boldsymbol{Y}, \lambda, \alpha, n_{step}$

Init: $\tilde{\mathbf{c}}_k = \frac{1}{|S_k|} \sum_{(\boldsymbol{x}_i, y_i) \in S_k} \boldsymbol{x}_i, k = 0;$

while $k < n_{step}$ **do**

Estimating Assignment:

$Z_{ij} = \frac{\exp(-\|\boldsymbol{x}_i - \tilde{\boldsymbol{c}}_j\|_2^2)}{\sum_{j'} exp(-\|\boldsymbol{x}_i - \tilde{\boldsymbol{c}}_{j'}\|_2^2)};$

Constructing Graph:

$\Lambda_{kk} = \sum_i Z_{ik}$ and $\boldsymbol{W} = \boldsymbol{Z}_t \boldsymbol{\Lambda}^{-1} \boldsymbol{Z}_t^\top;$

Propagating Label:

$\tilde{\mathbf{Y}} = \boldsymbol{Z}_t \left(\boldsymbol{Z}_L^\top \boldsymbol{Z}_L + \lambda \boldsymbol{Z}_t^\top (\boldsymbol{I} - \boldsymbol{W}) \boldsymbol{Z}_t \right)^{-1} \boldsymbol{Z}_t^\top \boldsymbol{Y};$

Updating Prototypes:

$\tilde{\mathbf{C}} \leftarrow (1 - \alpha) \tilde{\mathbf{C}} + \alpha \tilde{\boldsymbol{Y}} \boldsymbol{X};$

$k \leftarrow k + 1$

end

return $y_i = \arg\max_j \tilde{Y}_{i,j}$

Results

Table 1. Comparison of test accuracy against state-of-the-art methods for 1-shot and 5-shot classification. (*: inference aug., §4.2.3)

			mini-ImageNet		tiered-ImageNet	
Methods	Setting	Network	1-shot	5-shot	1-shot	5-shot
MAML [8]	Inductive	ResNet-18	49.61 ± 0.92	65.72 ± 0.77	–	–
RelationNet [45]	Inductive	ResNet-18	52.48 ± 0.86	69.83 ± 0.68	–	–
MatchingNet [47]	Inductive	ResNet-18	52.91 ± 0.88	68.88 ± 0.69	–	–
ProtoNet [44]	Inductive	ResNet-18	54.16 ± 0.82	73.68 ± 0.65	–	–
TPN [29]	transductive	ResNet-12	59.46	75.64	–	–
TEAM [35]	transductive	ResNet-18	60.07	75.9	–	–
Transductive tuning [6]	Transductive	ResNet-12	62.35 ± 0.66	74.53 ± 0.54	–	–
MetaoptNet [24]	Transductive	ResNet-12	62.64 ± 0.61	78.63 ± 0.46	65.99 ± 0.72	81.56 ± 0.53
CAN+T [11]	Transductive	ResNet-12	67.19 ± 0.55	80.64 ± 0.35	73.21 ± 0.58	84.93 ± 0.38
DSN-MR [43]	Transductive	ResNet-12	64.60 ± 0.72	79.51 ± 0.50	67.39 ± 0.82	82.85 ± 0.56
ODC* [34]	Transductive	ResNet-18	77.20 ± 0.36	87.11 ± 0.42	83.73 ± 0.36	90.46 ± 0.46
MCT* [21]	Transductive	ResNet-12	78.55 ± 0.86	86.03 ± 0.42	82.32 ± 0.81	87.36 ± 0.50
EASY* [1]	Transductive	ResNet-12	82.31 ± 0.24	88.57 ± 0.12	83.98 ± 0.24	89.26 ± 0.14
protoLP (ours)	Transductive	ResNet-12	70.77 ± 0.30	80.85 ± 0.16	84.69 ± 0.29	89.47 ± 0.15
protoLP* (ours)	Transductive	ResNet-12	84.35 ± 0.24	90.22 ± 0.11	86.27 ± 0.25	91.19 ± 0.14
protoLP (ours)	Transductive	ResNet-18	75.77 ± 0.29	84.00 ± 0.16	82.32 ± 0.27	88.09 ± 0.15
protoLP* (ours)	Transductive	ResNet-18	85.13 ± 0.24	90.45 ± 0.11	83.05 ± 0.25	88.62 ± 0.14
ProtoNet [44]	Inductive	WRN-28-10	62.60 ± 0.20	79.97 ± 0.14	–	–
MatchingNet [47]	Inductive	WRN-28-10	64.03 ± 0.20	76.32 ± 0.16	–	–
SimpleShot [50]	Inductive	WRN-28-10	65.87 ± 0.20	82.09 ± 0.14	70.90 ± 0.22	85.76 ± 0.15
S2M2-R [31]	Inductive	WRN-28-10	64.93 ± 0.18	83.18 ± 0.11	-	-
Transductive tuning [6]	Transductive	WRN-28-10	65.73 ± 0.68	78.40 ± 0.52	73.34 ± 0.71	85.50 ± 0.50
SIB [13]	Transductive	WRN-28-10	70.00 ± 0.60	79.20 ± 0.40	–	–
BD-CSPN [27]	Transductive	WRN-28-10	70.31 ± 0.93	81.89 ± 0.60	78.74 ± 0.95	86.92 ± 0.63
EPNet [38]	Transductive	WRN-28-10	70.74 ± 0.85	84.34 ± 0.53	78.50 ± 0.91	88.36 ± 0.57
LaplacianShot [61]	Transductive	WRN-28-10	74.86 ± 0.19	84.13 ± 0.14	80.18 ± 0.21	87.56 ± 0.15
ODC [34]	Transductive	WRN-28-10	80.22	88.22	84.70	91.20
iLPC [22]	Transductive	WRN-28-10	83.05 ± 0.79	88.82 ± 0.42	88.50 ± 0.75	92.46 ± 0.42
protoLP (ours)	Transductive	WRN-28-10	83.07 ± 0.25	89.04 ± 0.13	89.04 ± 0.23	92.80 ± 0.13
protoLP* (ours)	Transductive	WRN-28-10	84.32 ± 0.21	90.02 ± 0.12	89.65 ± 0.22	93.21 ± 0.13

Table 2. Test accuracy *vs.* the state of the art (transductive inference, 1- and 5-shot classification, CUB). (*: inference aug., §4.2.3)

	CUB		
Method	Backbone	1-shot	5-shot
LaplacianShot [61]	ResNet-18	80.96	88.68
LR+ICI [51]	ResNet-12	86.53±0.79	92.11±0.35
iLPC [22]	ResNet-12	89.00±0.70	92.74±0.35
protoLP (ours)	ResNet-12	90.13±0.20	92.85±0.11
protoLP* (ours)	ResNet-12	91.82±0.18	94.65±0.10
BD-CSPN [27]	WRN-28-10	87.45	91.74
TIM-GD [2]	WRN-28-10	88.35±0.19	92.14±0.10
PT+MAP [14]	WRN-28-10	91.37±0.61	93.93±0.32
LR+ICI [51]	WRN-28-10	90.18±0.65	93.35±0.30
iLPC [22]	WRN-28-10	91.03±0.63	94.11±0.30
protoLP (ours)	WRN-28-10	91.69±0.18	94.18±0.09

Table 3. Test accuracy *vs.* state of the art (transductive inference, 1- and 5-shot classification, CIFAR-FS). (*: inference aug., §4.2.3)

	CIFAR-FS		
Method	Backbone	1-shot	5-shot
LR+ICI [51]	ResNet-12	75.36±0.97	84.57±0.57
iLPC [22]	ResNet-12	77.14±0.95	85.23±0.55
DSN-MR [43]	ResNet-12	75.60±0.90	85.10±0.60
SSR [41]	ResNet-12	76.80±0.60	83.70±0.40
protoLP (ours)	ResNet-12	78.66±0.24	85.85±0.17
protoLP* (ours)	ResNet-12	88.22 ±0.21	91.52±0.15
SIB [13]	WRN-28-10	80.00±0.60	85.30±0.40
PT+MAP [14]	WRN-28-10	86.91±0.72	90.50±0.49
LR+ICI [51]	WRN-28-10	84.88±0.79	89.75±0.48
iLPC [22]	WRN-28-10	86.51±0.75	90.60±0.48
protoLP (ours)	WRN-28-10	87.69±0.23	90.82±0.15

Other Results

Table 4. Comparison of test accuracy against state-of-the-art methods for 1-shot and 5-shot classification under the semi-supervised few-shot learning setting. CUB 5-shot omitted: no class has the required 70 examples.

			mini-ImageNet		tiered-ImageNet		CIFAR-FS		CUB	
Methods	Backbone	Setting	1-shot	5-shot	1-shot	5-shot	1-shot	5-shot	1-shot	5-shot
LR+ICI [51]	ResNet-12	30/50	$67.57_{\pm0.97}$	$79.07_{\pm0.56}$	$83.32_{\pm0.87}$	$89.06_{\pm0.51}$	$75.99_{\pm0.98}$	$84.01_{\pm0.62}$	$88.50_{\pm0.71}$	-
iLPC [22]	ResNet-12	30/50	$70.99_{\pm0.91}$	$81.06_{\pm0.49}$	$85.04_{\pm0.79}$	$89.63_{\pm0.47}$	$78.57_{\pm0.80}$	$85.84_{\pm0.56}$	$90.11_{\pm0.64}$	-
protoLP (ours)	ResNet-12	30/50	$72.21_{\pm0.88}$	$81.48_{\pm0.49}$	$85.22_{\pm0.79}$	$89.64_{\pm0.46}$	$80.02_{\pm0.88}$	$86.16_{\pm0.53}$	$90.26_{\pm0.65}$	-
LR+ICI [51]	WRN-28-10	30/50	$81.31_{\pm0.84}$	$88.53_{\pm0.43}$	$88.48_{\pm0.67}$	$92.03_{\pm0.43}$	$86.03_{\pm0.77}$	$89.57_{\pm0.53}$	$90.82_{\pm0.59}$	-
PT+MAP [14]	WRN-28-10	30/50	$83.14_{\pm0.72}$	$88.95_{\pm0.38}$	$89.16_{\pm0.61}$	$92.30_{\pm0.39}$	$87.05_{\pm0.69}$	$89.98_{\pm0.49}$	$91.52_{\pm0.53}$	-
iLPC [22]	WRN-28-10	30/50	$83.58_{\pm0.79}$	$89.68_{\pm0.37}$	$89.35_{\pm0.68}$	$92.61_{\pm0.39}$	$87.03_{\pm0.72}$	$90.34_{\pm0.50}$	$91.69_{\pm0.55}$	-
protoLP (ours)	WRN-28-10	30/50	$84.25_{\pm0.75}$	$89.48_{\pm0.39}$	$90.10_{\pm0.63}$	$92.49_{\pm0.40}$	$87.92_{\pm0.69}$	$90.51_{\pm0.48}$	$92.01_{\pm0.57}$	-

Table 5. Comparison of test accuracy against state-of-the-art methods (DenseNet and MobileNet, 1- and 5-shot protocols). Notice SimpleShot is an inductive method based on the above backbone.

	mini-ImageNet		tiered-ImageNet	
Methods (DenseNet)	1-shot	5-shot	1-shot	5-shot
SimpleShot [50]	65.77 ± 0.19	82.23 ± 0.13	71.20 ± 0.22	86.33 ± 0.15
LaplacianShot [61]	75.57 ± 0.19	84.72 ± 0.13	80.30 ± 0.20	87.93 ± 0.15
RAP-LaplacianShot [10]	75.58 ± 0.20	85.63 ± 0.13	-	-
TAFSSL(PCA) [26]	70.53 ± 0.25	80.71 ± 0.16	80.07 ± 0.25	86.42 ± 0.17
TAFSSL(ICA) [26]	72.10 ± 0.25	81.85 ± 0.16	80.82 ± 0.25	86.97 ± 0.17
TAFSSL(ICA+MSP) [26]	77.06 ± 0.26	84.99 ± 0.14	84.29 ± 0.25	89.31 ± 0.15
protoLP (ours)	79.27 ± 0.27	85.88 ± 0.14	86.17 ± 0.25	90.50 ± 0.15
Methods (MobileNet)	1-shot	5-shot	1-shot	5-shot
SimpleShot [32]	61.55 ± 0.20	77.70 ± 0.15	69.50 ± 0.22	84.91 ± 0.15
LaplacianShot [61]	70.27 ± 0.19	80.10 ± 0.15	79.13 ± 0.21	86.75 ± 0.15
protoLP (ours)	72.04 ± 0.23	82.11 ± 0.20	80.68 ± 0.24	87.45 ± 0.19

Table 8. Test accuracy against the state of the art in the class-unbalanced setting (WRN-28-10, 1- and 5-shot protocols).

	mini-ImageNet		tiered-ImageNet	
Methods	1-shot	5-shot	1-shot	5-shot
Entropy-min	60.4	76.2	62.9	77.3
PT-MAP	60.6	66.8	65.1	71.0
LaplacianShot	68.1	83.2	73.5	86.8
TIM	69.8	81.6	75.8	85.4
BD-CSPN	70.4	82.3	75.4	85.9
α-TIM	69.8	84.8	76.0	87.8
protoLP (ours)	73.7	85.2	81.0	89.0

Table 9. Test accuracy against the state of the art in the class unbalanced setting (ResNet-12, 1-shot protocols, CUB).

CUB	unbalanced	balanced
Method	1-shot	1-shot
PT-MAP [14]	65.1	85.5
LaplacianShot [61]	73.7	78.9
BD-CSPN [27]	74.5	77.9
TIM [2]	74.8	80.3
α-TIM [46]	75.7	–
protoLP	82.22	90.13

Table 6. The uniform class prior (Sinkhorn *vs.* no Sinkhorn).

			mini-ImageNet	
Method	Sinkhorn	Backbone	1-shot	5-shot
LP		ResNet-12	61.09±0.70	75.32±0.50
EASE		ResNet-12	57.00±0.26	75.07±0.21
EASE	✓	ResNet-12	70.47±0.30	80.73±0.16
iLPC		ResNet-12	65.57±0.89	78.03±0.54
iLPC	✓	ResNet-12	69.79±0.99	79.82±0.55
protoLP		ResNet-12	70.04±0.29	79.80±0.16
protoLP	✓	ResNet-12	70.77±0.30	80.85±0.16
LP		WRN-28-10	74.24±0.68	84.09±0.42
PT-MAP		WRN-28-10	82.92±0.26	88.82±0.13
EASE		WRN-28-10	67.42±0.27	84.45±0.18
EASE	✓	WRN-28-10	83.00±0.21	88.92±0.13
iLPC		WRN-28-10	78.29±0.76	87.62±0.41
iLPC	✓	WRN-28-10	83.05±0.79	88.82±0.42
protoLP		WRN-28-10	81.91±0.25	87.85±0.13
protoLP	✓	WRN-28-10	83.07±0.25	89.04±0.13

Table 7. The uniform class prior (Sinkhorn *vs.* no Sinkhorn).

			tiered-ImageNet	
Method	Sinkhorn	Backbone	1-shot	5-shot
LP		ResNet-12	73.29±0.35	86.32±0.30
EASE		ResNet-12	69.74±0.31	85.17±0.21
EASE	✓	ResNet-12	84.54±0.27	89.63±0.15
protoLP		ResNet-12	83.59±0.25	88.60±0.15
protoLP	✓	ResNet-12	84.69±0.29	89.47±0.15
LP		WRN-28-10	76.24±0.30	85.09±0.25
EASE		WRN-28-10	75.87±0.29	85.17±0.21
EASE	✓	WRN-28-10	88.96±0.23	92.63±0.13
protoLP		WRN-28-10	87.91±0.25	91.60±0.13
protoLP	✓	WRN-28-10	89.04±0.23	92.80±0.13

Thank you.

Code will be available at: https://github.com/allenhaozhu/protoLP