Cost-Sensitive Batch Mode Active Learning: Designing Astronomical Observation by Optimizing Telescope Time and Telescope Choice

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Planet
Nebula
Constellation
Star cluster
Galaxy
…
…

Questions:

1. Which instance should be selected?
2. How about observing multiple instances at one time?
3. What’s the cost?
4. Which telescope should we choose?

1. Which instance should be selected? *- Active Learning!*

Single-instance Active Learning

Suppose we have a labeled set S of K input features x_k and labels y_k: {(x0, y0), . . . , (x_{K-1}, y_{K-1})}. Our goal is to select the next instance x_K to label to minimize the expected loss on the remaining data $x_n \ni S$:

$$\min_{K} \quad \mathbb{E}_{y_K, y_n \ni S}\Big[\sum_{x_n \ni S} L(\hat{y_n}, y_n)\Big] \tag{2.1}$$

where $\hat{y_n} = f_S(x_n)$, $f_S(x)$ is the classifier trained with the labeled set S, and $L(\cdot)$ is the loss function.

1. Which instance should be selected? *- Active Learning!*

Score Function: Expected Uncertainty Reduction

Our goal is to choose instances to minimize the total label uncertainty across all the unlabeled instances.

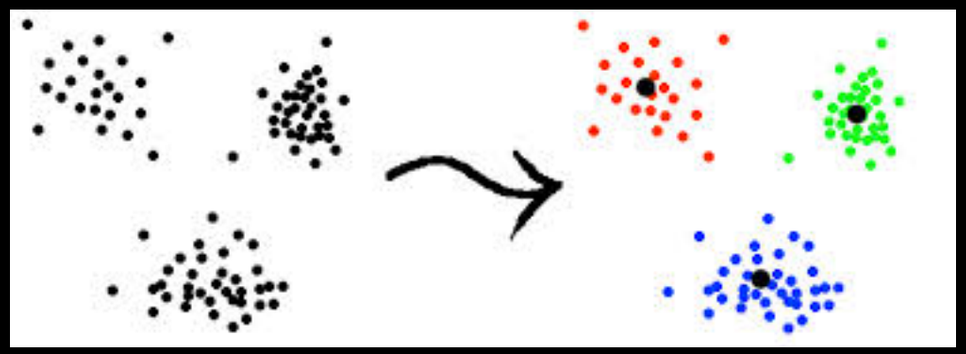
$$\min_{x_k} \mathbb{E}_{y_k}[\sum_{x_n \ni S \cup x_k} 1 - (p(\hat{y}_n))] \tag{3.3}$$

where $p(\hat{y}_n)$ is the probability of the most probable label for the observation x_n.

1. Which instance should be selected? *- Active Learning!*

Pre-Clustering:

We assume that each point x_k in the cluster c, if it were to be labeled, will label some proportion of its cluster, depending on on how close it is to the center of its cluster.



$$\text{score}(x_k) = \text{rep}(x_k, c_{x_k}) \sum_{x_i \in c} 1 - p(\hat{y}_i) \tag{3.5}$$

$$\text{rep}(x_k, c_{x_k}) \propto \exp(\text{-dist}(x_k, c_{x_k})) \tag{3.4}$$

where c_{x_k} is the center of the cluster of x_k.

2. How long it will take to observe the selected ones?

- Cost-sensitive Active Learning

$$\min_{K} \mathbb{E}_{y_K, y_n \ni S}[\sum_{x_n \ni S} L(\hat{y_n}, y_n)]$$
$$\text{subject to } C(S) \leq B.$$

Observing time cost:

$$C(\{x_i\}) \propto \sum_{x_i \in \{x_i\}} 10^{0.4 mag_{x_i}}.$$

$$score_{cost}(\{x_i\}) = score(\{x_i\}) + \lambda C(\{x_i\}). \quad (4.11)$$

where λ is the weight of cost that depends on how much budget we have.

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- Cost-sensitive Active Learning

Data Sets:

- *MACHO (3063*64)*
- *EROS (8317*64)*

Table 1: MACHO Data Set Composition

	Class	Number of objects
1	Non variable	966
2	Quasars	59
3	Be Stars	101
4	Cepheid	610
5	RR Lyrae	255
6	Eclipsing Binaries	126
7	MicroLensing	580
8	Long Period Variable	365

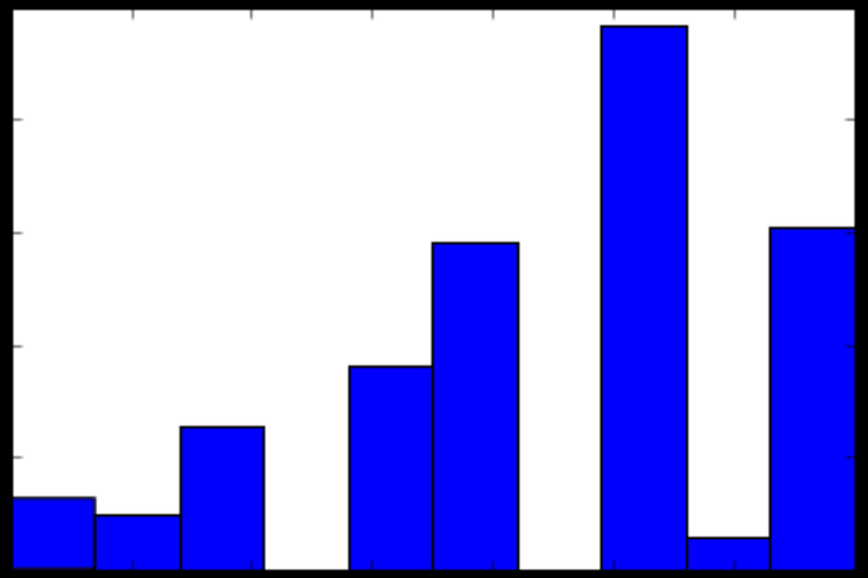
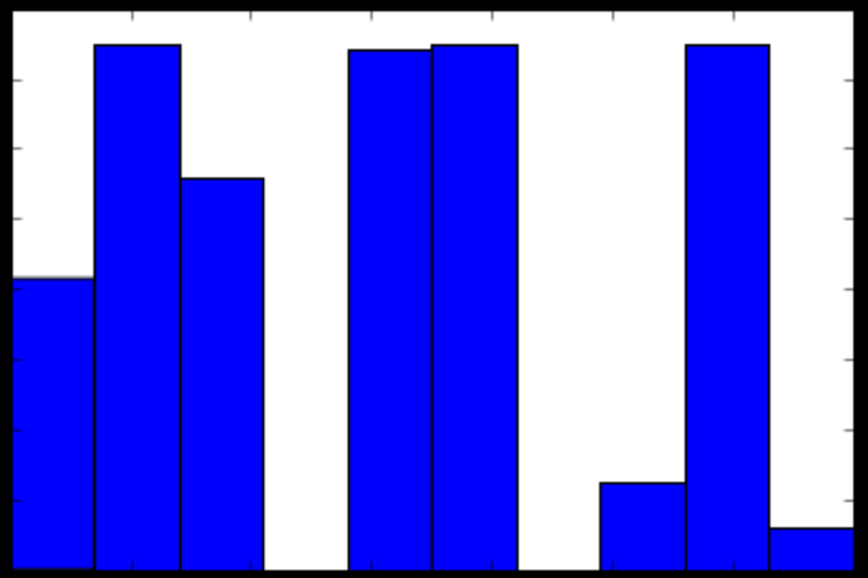


Table 2: EROS Data Set Composition

	Class	Number of objects
1	BV	829
2	CEP	1500
3	DSCT	1114
4	EB	1484
5	LPV	1500
6	QSO	251
7	RRLYR	1499
8	T2CEP	123



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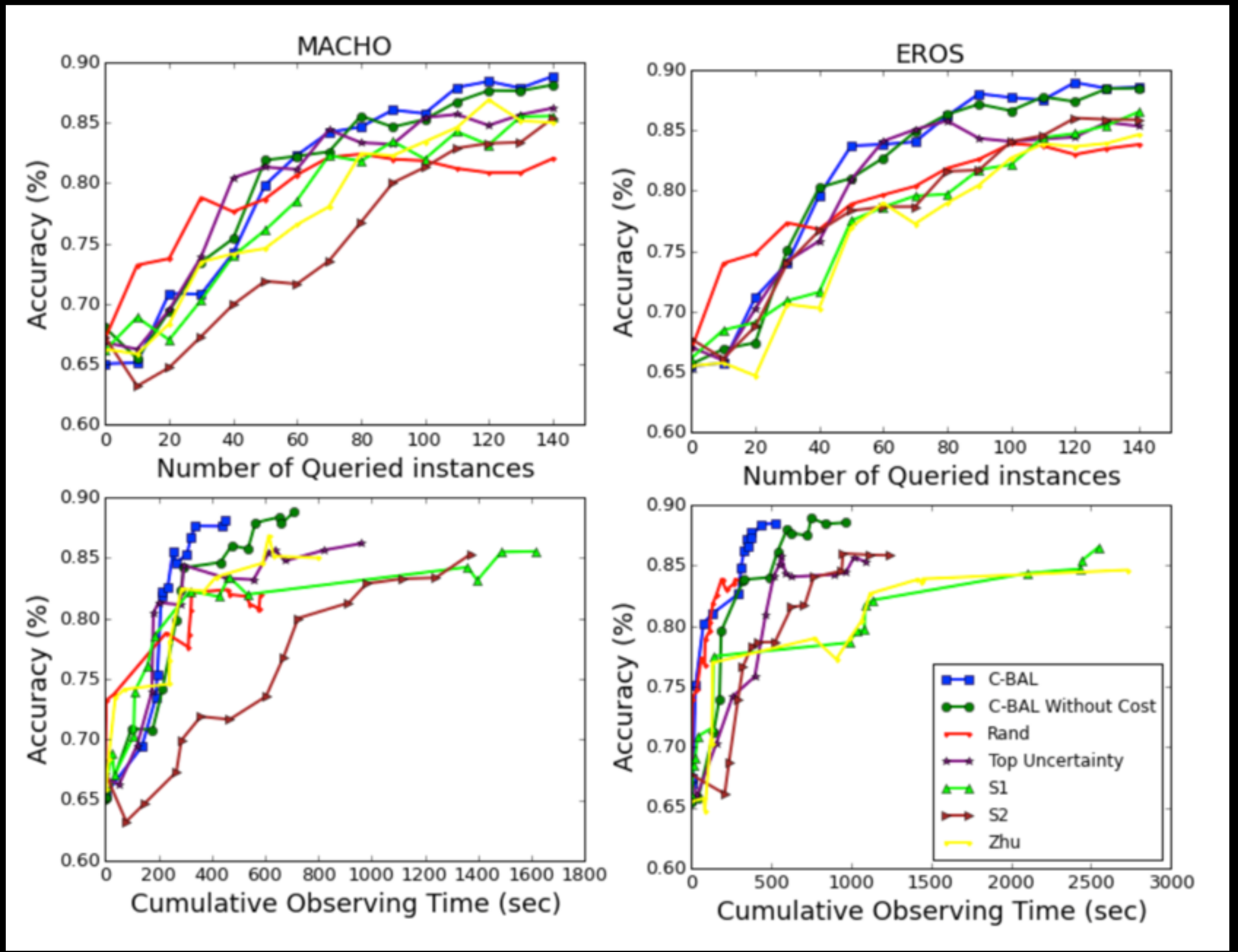
- Cost-sensitive Active Learning



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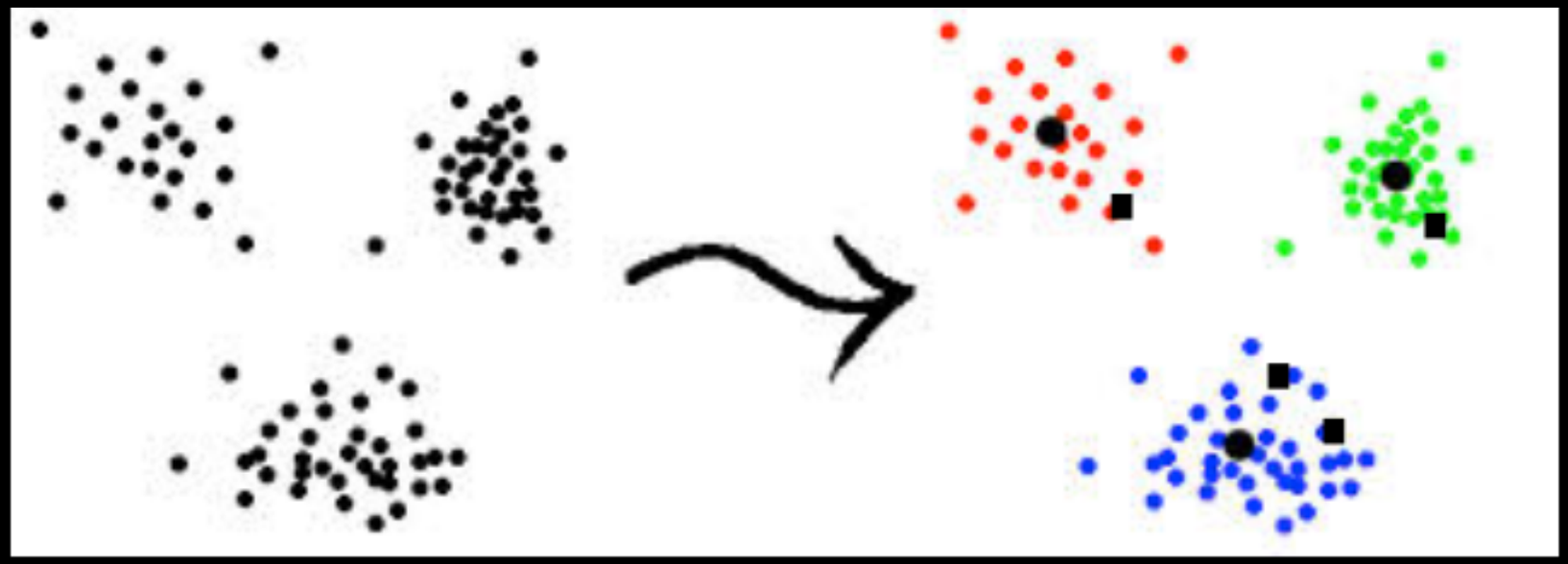

$$\text{score}(p_i) = \sum_{c \in p_i} \max_{x_k \in c \cup p_i} (\text{rep}(x_k, c)) \sum_{x_i \in c} 1 - \max(p(\hat{y}_i))$$

where $c \in p_i$ are all the clusters associated with the observations in the pointing p_i.

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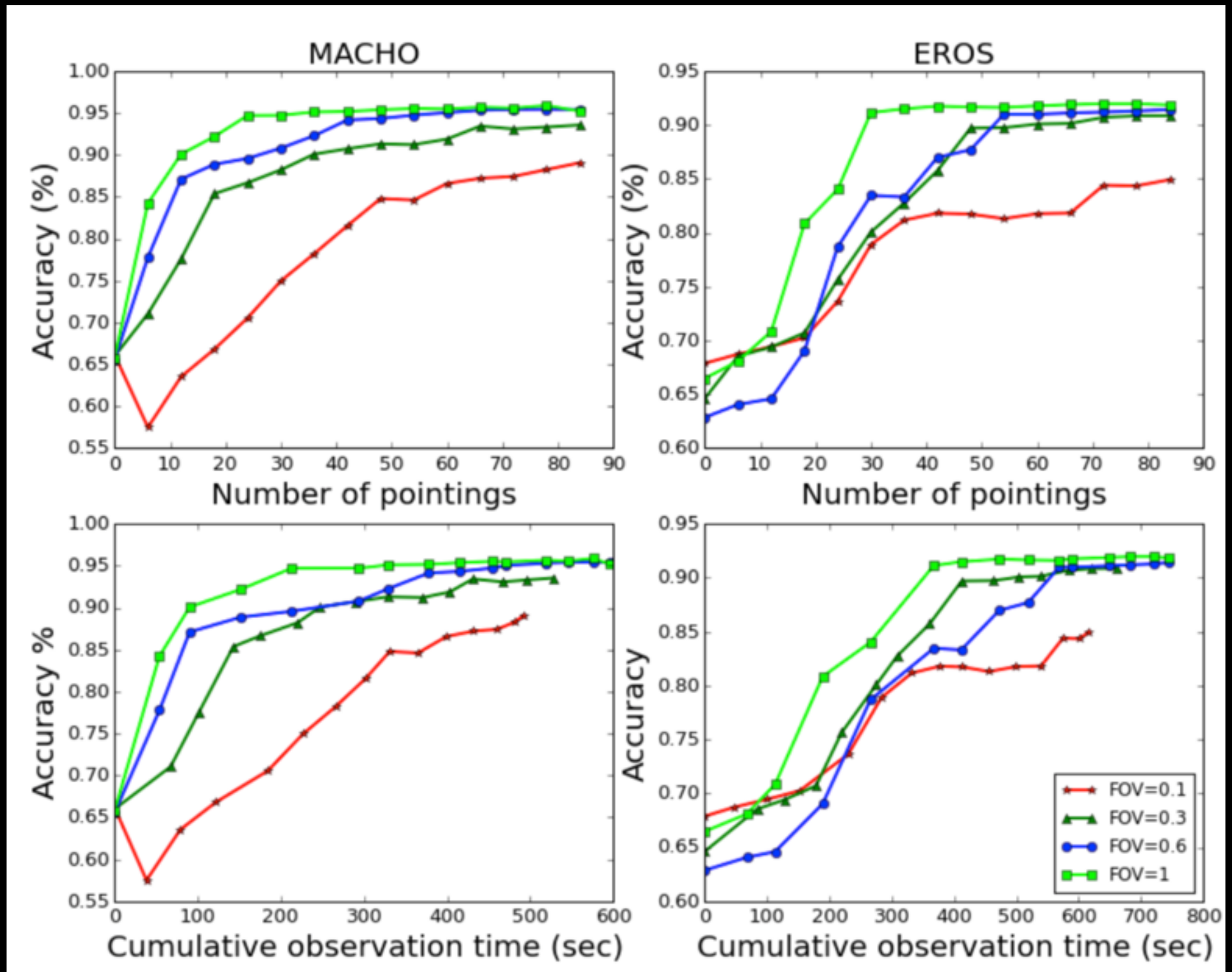

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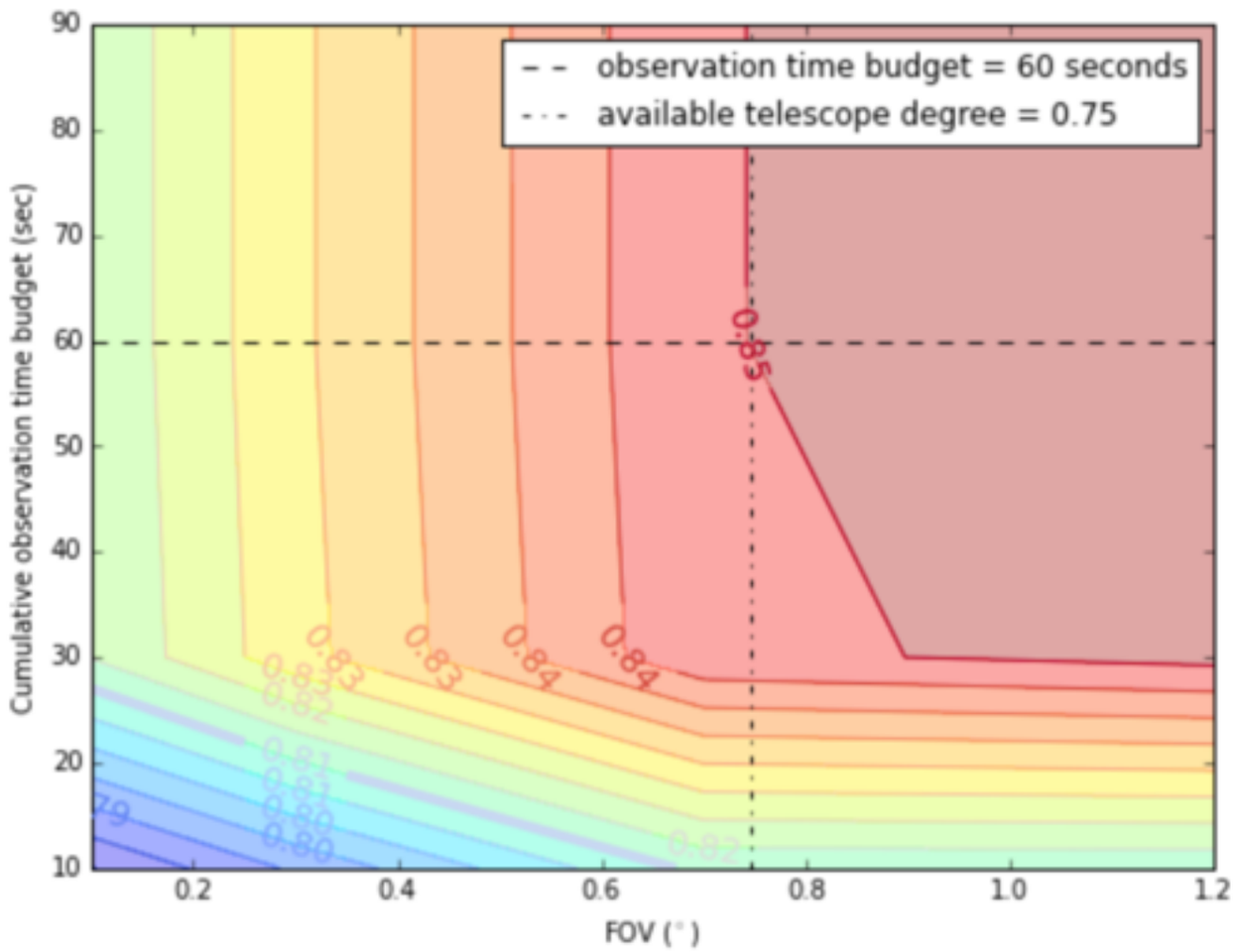

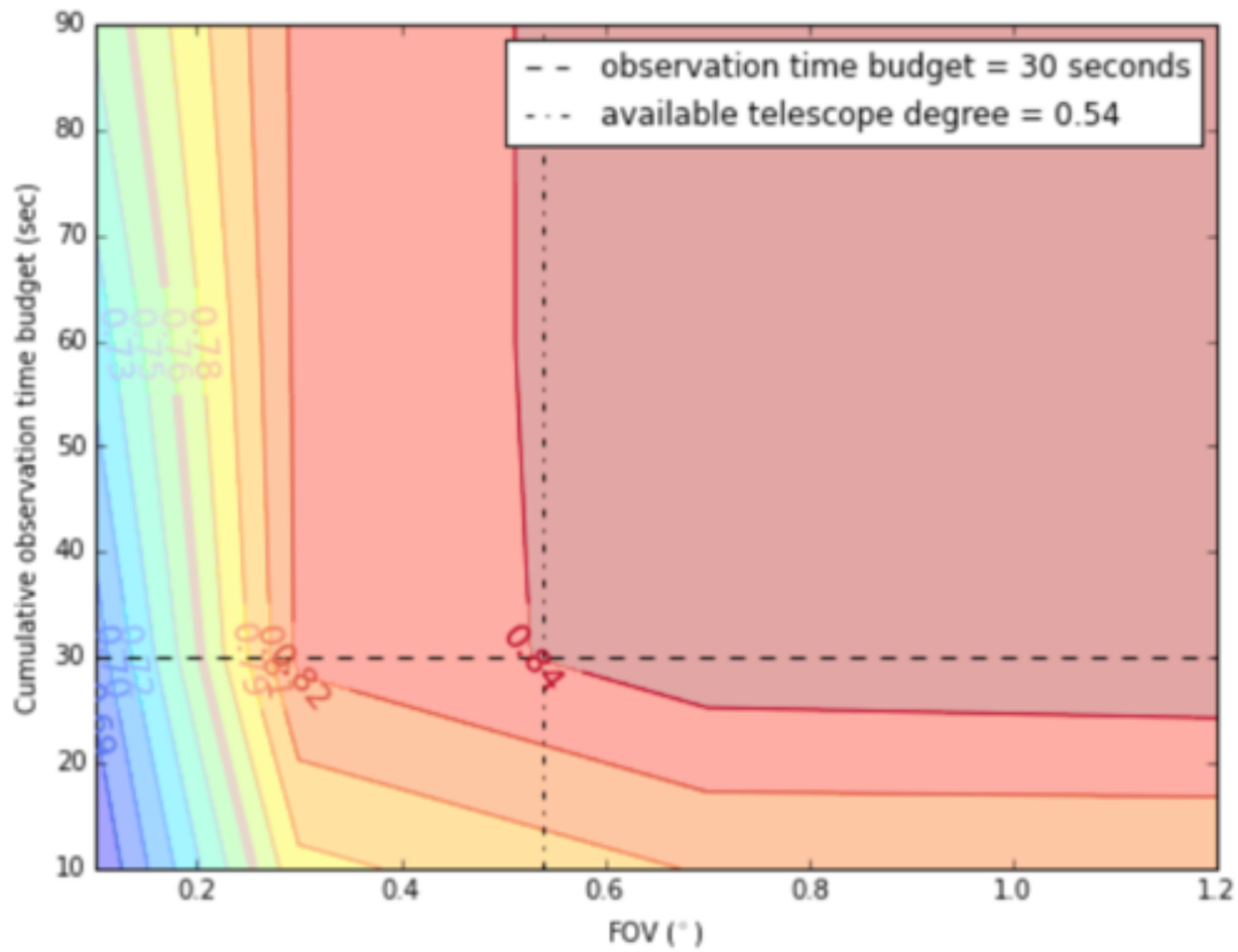

4. Which telescope?

- Application of the proposed Cost-Sensitive Batch Mode Active Learning

$$\boldsymbol{C(x, T)} = \frac{\mu}{R_T^2} 10^{0.4 mag_x}.$$

Table 3: Real-World Telescope Data

	Country	Observatory	Telescope	Instrument	Apperture	FOV (arcmin)
1	Chile	Las Campanas	Bode	Mega Cam	6.1	25*25
2	Chile	Las Campanas	Bode	IMACS	6.1	21*21
3	Chile	Cerro Tololo	Blanco 4m	ISPI	4	10.25*10.25
4	Chile	Cerro Tololo	Blanco 4m	DECam	4	132*132
5	Chile	Cerro Tololo	SOAR	SOAR Imager (SOI)	4.1	5.2*5.2
6	Chile	Cerro Tololo	SMARTS 1m	Y4K CAM	1	20*20
7	Tuscon	Kitt Peak	Mayall 4m	KOSMOS	3.7	36*36
8	Hawaii	Mauna Kea	CFHT	Mega Cam	3.6	60*60
9	Chile	La Silla	MPG/ESO 2.2-metre	WFI	2.2	33*33
10	Chile	Paranal	Very large telescopeX4	MUSE	8.2	1*1
11	Chile	Gemini	Gemini 9m	GSAOI	9	1.333*1.333

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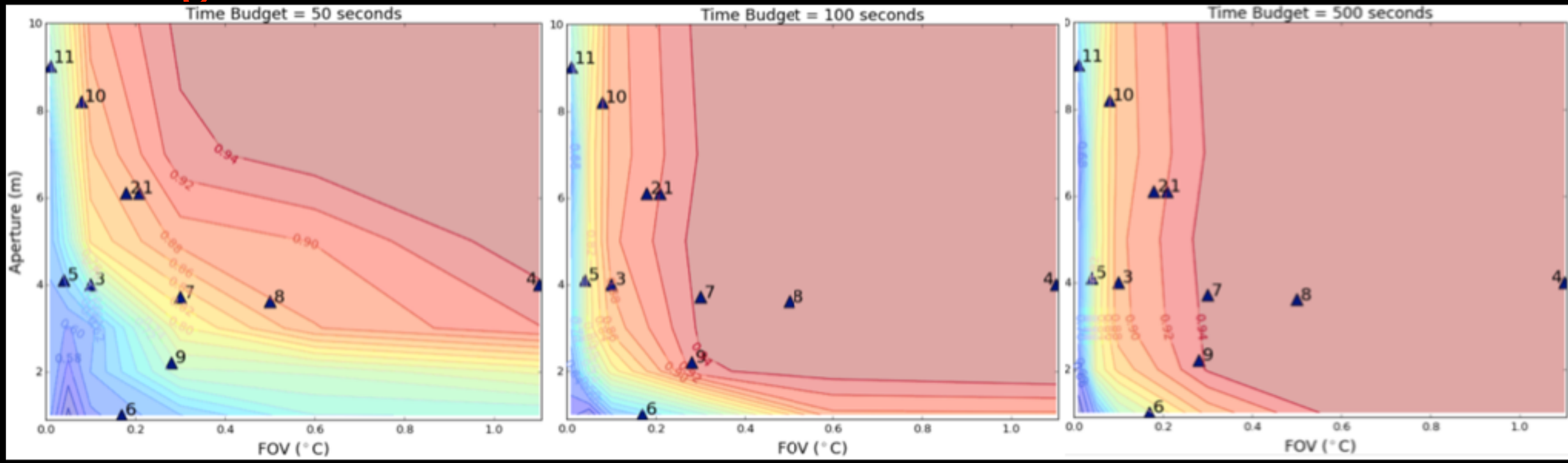
- Application of the proposed Cost-Sensitive Batch Mode Active Learning



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