Iterative Classroom Teaching

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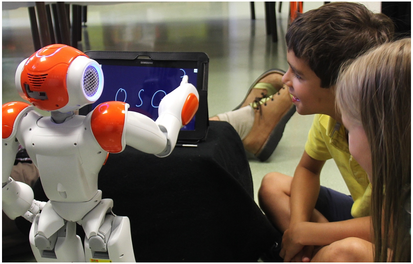
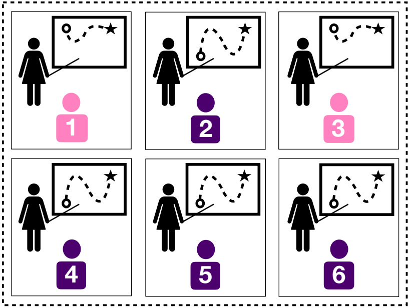
Motivation

Teaching a class of children how to write:



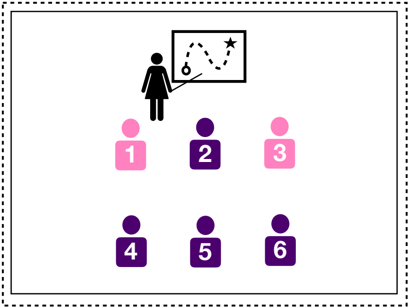
Tension Between Orchestration Cost and Students' Workload

Individual Teaching (IT)



Orchestration cost ↑
Students' workload ↓

Classroom Teaching (CT)

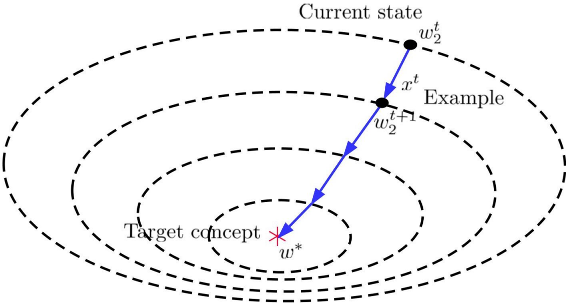


Orchestration cost ↓
Students' workload ↑

Iterative Machine Teaching[1]

Each student is characterized by:

1. Prior knowledge (initial state)
2. Learning ability



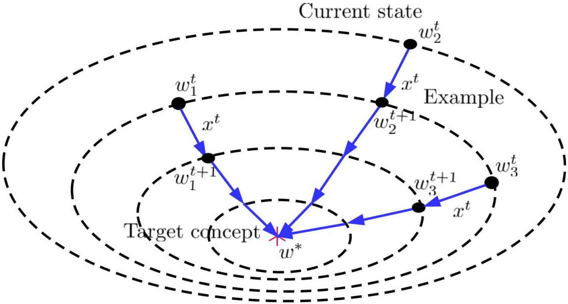
$$w^{t+1} = \texttt{Proj}_{\mathcal{W}}\left(w^t - \eta^t \frac{\partial \ell\left(\pi(w^t, x^t), y^t\right)}{\partial w^t}\right); \quad (x^t, y^t) \in \mathcal{X} \times \mathcal{Y}$$

[1] Liu, W. et al. Iterative machine teaching. ICML 2017

Stylized Model of Classroom

Diversity of the classroom depends on:

1. Prior knowledge (initial state)
2. Learning ability



$$w_j^{t+1} = \texttt{Proj}_{\mathcal{W}} \left(w_j^t - \eta_j^t \frac{\partial \ell \left(\pi(w_j^t, x^t), y^t \right)}{\partial w_j^t} \right); \quad j \in [N], (x^t, y^t) \in \mathcal{X} \times \mathcal{Y}$$

Problem

Teaching objective

The class on average converges.

$$\frac{1}{N}\sum_{i=1}^{N}\left\|w_j^T - w^*\right\|^2 \leq \epsilon \quad \text{and} \quad \left\|w_j^T - w^*\right\| \leq \epsilon, \forall j \in [N]$$

Teaching protocol

Pick examples that minimizes average distance between students' internal states and target.

$$\begin{aligned} x^t &= \arg\min_{x \in \mathcal{X}} \frac{1}{N}\sum_{j=1}^{N}\left\|w_j^t - \eta_j \frac{\partial \ell\left(\left\langle w_j^t, x\right\rangle, \langle w^*, x\rangle\right)}{\partial w_j^t} - w^*\right\|^2 \\ y^t &= \left\langle w^*, x^t\right\rangle \end{aligned}$$

Results

Reduced the orchestration cost for CT

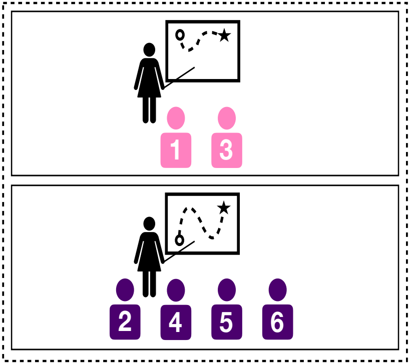
- Classroom of 1000 students, *i.e.*, $N = 1000$
- Each student is represented by a vector of size 100, *i.e.*, $d = 100$
- Orchestration cost for IT: $\mathcal{O}\left(N \log \frac{1}{\epsilon}\right)$
- Orchestration cost for CT: $\mathcal{O}\left(\min\{N, d\} \log \frac{1}{\epsilon}\right)$

Orchestration cost: learning ability vs prior knowledge

Finer partitions for slower learners:

$$\{[\eta_{\text{min}}, 2\eta_{\text{min}}), [2\eta_{\text{min}}, 4\eta_{\text{min}}), \ldots, [2^m\eta_{\text{min}}, 2\eta_{\text{max}})\}\text{, where } m = \left\lfloor \log_2 \frac{\eta_{\text{max}}}{\eta_{\text{min}}} \right\rfloor$$

Classroom Teaching with Partitioning (CTwP)



k Number of groups

$T(k)$ Orchestration cost

$S(k)$ Students' average cost

λ Tradeoff parameter

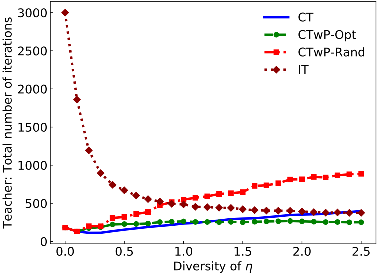
$$\boxed{\text{cost}(k) = T(k) + \lambda S(k)}$$

Homogenous partitioning based on:

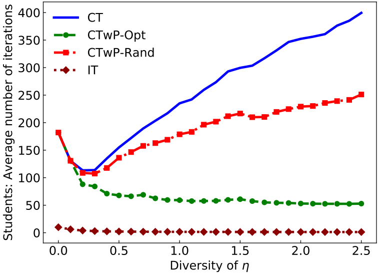
1. Learning ability: Finer partitions for slower learners.
2. Prior knowledge: Via pre-quiz or by demographics.

Experiments - Simulations

Diversity impacts the number of iterations (both students' and teacher's)



(a) Convergence from teacher's perspective



(b) Convergence from students' perspective

Legend:

CT: Classroom teaching

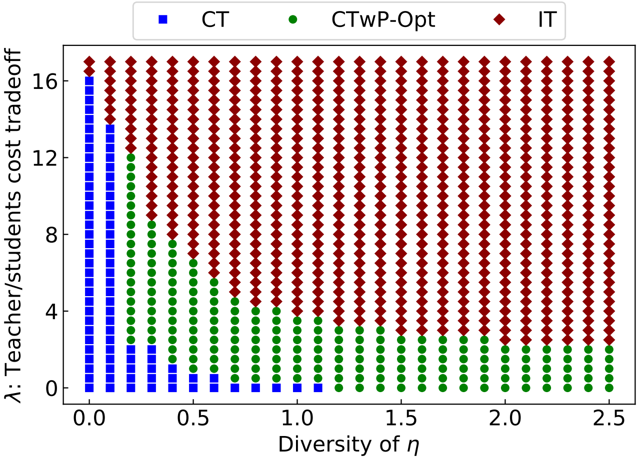
CTwP-Opt: CT with optimal partitioning,

CTwP-Rand: CT with random partitioning,

IT: Inidivdual teaching

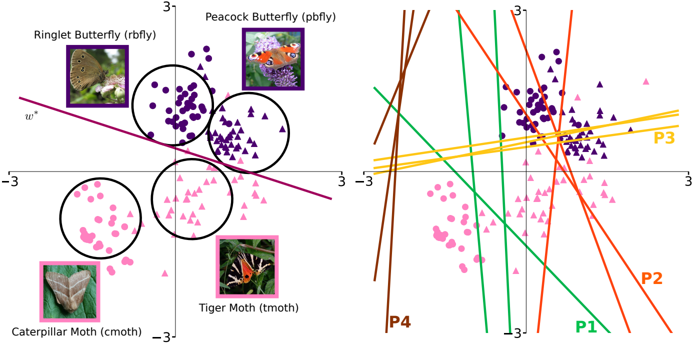
Experiments - Simulations

Tradeoff between teacher's and students' workload.



Experiments - Real World

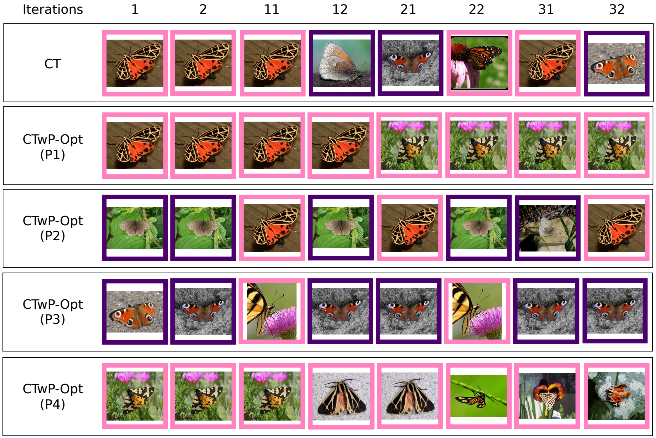
Embeddings of the dataset and target concept.



(a) Initial dataset   (b) Initial learners

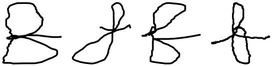
Experiments - Real World

Training examples selected by the teacher in a class with 4 types of students.

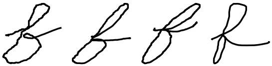


Teaching How to Write

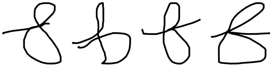
Shaky and distorted handwriting:



Shaky and rotated handwriting:

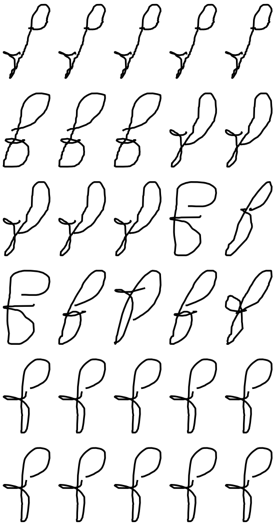


Rotated and distorted handwriting:



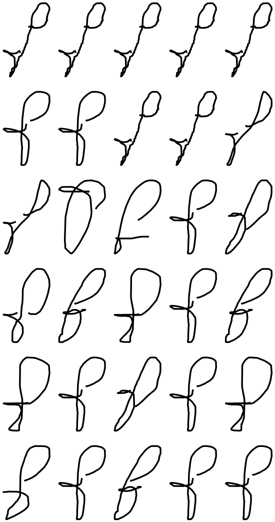
Teaching How to Write

Teaching examples for shaky and rotated handwriting:



Teaching How to Write

Teaching examples for distorted, rotated, and shaky handwriting:



Conclusions

- Trade-off between orchestratrion cost and students' workload
- Learning ability matters more than prior knowledge
- A natural homogeneous partitioning strategy based on learning ability