

# Human-Centric Multi-Exposure Fusion: Benchmark and Bi-level Cognition Distillation Framework

## Supplementary Material

The main difficulty in exploiting EEG lies in its status as *privileged information*, which is accessible during training but unavailable at inference. To address this mismatch, we employ a Teacher–Student distillation setup in which the Teacher is guided by EEG priors whereas the Student relies solely on visual inputs, matching the deployment scenario. Standard two-stage distillation is insufficient, as a fixed Teacher often converges to EEG-dependent representations that exceed the Student’s learnable capacity. To ensure transferability, we cast the learning process as a coupled **Bi-level Optimization (BLO)** problem, where the Teacher’s lower-level objective is conditioned on the Student’s current parameters. This coupling forces the Teacher to continuously adapt its representation space to remain distillable. The Student then solves the upper-level problem by mimicking the optimal Teacher using only LDR images, producing a joint optimization procedure that tightly aligns EEG-guided supervision with the visual-only inference regime. A detailed algorithmic solution procedure is provided in Alg. 1.

---

**Algorithm 1** Training Procedure for the BLO Framework

---

**Require:** Pre-trained EEG Encoder  $\mathcal{E}_{EEG}$ .  
**Require:** Teacher  $T$  with parameters  $\theta_T$ , Student  $S$  with parameters  $\theta_S$ .  
**Require:** Hyperparameters  $\lambda_{recon}, \gamma, \beta$ .  
**Require:** Number of inner steps  $K$ , outer steps  $M$ .

- 1: **for** each training iteration **do**
- 2:   Sample a batch of LDR images  $\mathcal{I}$  and corresponding raw EEG  $E_{raw}$ .
- 3:    $E \leftarrow \mathcal{E}_{EEG}(E_{raw})$
- 4:   // Lower-level update (Train Teacher)
- 5:   Fix  $\theta_S$ .
- 6:   **for**  $k = 1$  to  $K$  **do**
- 7:      $I_F^T \leftarrow T(\mathcal{I}, E; \theta_T)$
- 8:     Compute  $L_{Lower}$  using  $L_{recon}$ .
- 9:      $\theta_T \leftarrow \theta_T - \eta_T \nabla_{\theta_T} L_{Lower}$
- 10:   **end for**
- 11:   // Upper-level update (Train Student)
- 12:   Fix  $\theta_T$ .
- 13:   **for**  $m = 1$  to  $M$  **do**
- 14:      $I_F^S \leftarrow S(\mathcal{I}; \theta_S)$
- 15:      $I_F^{T*} \leftarrow T(\mathcal{I}, E; \theta_T)$
- 16:     Compute  $L_{Upper}$  using  $L_{Distill}$  and  $L_{recon}$ .
- 17:      $\theta_S \leftarrow \theta_S - \eta_S \nabla_{\theta_S} L_{Upper}$
- 18:   **end for**
- 19: **end for**

---