Continual Learning (CL) — Literature Review

Data Scientist Postdoc Interview — Thomas Jefferson National Accelerator Facility

September 18, 2025

Background

Continual Learning (CL) addresses *catastrophic forgetting*—when a model trained sequentially on tasks loses performance on earlier tasks. The practical goal is to balance **plasticity** (learn new tasks) with **stability** (retain prior knowledge) under constraints of time, memory, and compute.

We consider a sequence of T tasks with clear boundaries. Task τ provides data $\mathcal{D}_\tau = \{(x,y)\}_{i=1}^{n_\tau}$ drawn from distribution $p_\tau(x,y)$. A single classifier $f_\theta : \mathcal{X} \to \Delta^C$ (softmax over C classes) is updated sequentially without access to full historical datasets.

Families of Approaches

1. **Replay-based.** Maintain a small *exemplar buffer* $\mathcal{B}$ of past samples (or a generator for *generative replay*).

   - *Strengths:* Strong retention per byte; simple; works on CPU; no inference overhead.
   - *Limitations:* Memory/privacy constraints; class imbalance; careful curation needed.

2. **Regularization-based.** Constrain updates to protect prior knowledge. Examples: *Elastic Weight Consolidation* (EWC) uses Fisher-weighted penalties; *Learning without Forgetting* (LwF) uses *knowledge distillation* (KD).

   - *Strengths:* Minimal memory; no raw data storage.
   - *Limitations:* Sensitive to hyperparameters; weaker under large shifts.

3. **Architectural.** Expand capacity or route parameters per task (e.g., progressive nets, adapters, routing).

   - *Strengths:* Low forgetting via isolation.
   - *Limitations:* Parameter growth; serving complexity.

Comparison (at a glance)

Family	Retention	Memory	Serving
Replay	High	Low–Moderate	Single model
Regularization	Moderate	Very Low	Single model
Architectural	Very High	High (params)	Multi-head / routing

Key Takeaways

Replay remains the strongest baseline under realistic constraints. Hybrids such as **Replay + KD + Online EWC** provide a practical balance of accuracy, memory, and compute while mitigating catastrophic forgetting.