

High-performance neural population dynamics modeling enabled by scalable computational infrastructure

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Summary

Advances in neural interface technology are facilitating parallel, high-dimensional time series measurements of the brain in action. A powerful strategy for analyzing these measurements is to apply unsupervised learning techniques to uncover lower-dimensional latent dynamics that explain much of the variance in the high-dimensional measurements ([Cunningham & Yu, 2014](#); [Golub et al., 2018](#); [Vyas et al., 2020](#)). Latent factor analysis via dynamical systems (LFADS) ([Pandarinath et al., 2018](#)) provides a deep learning approach for extracting estimates of these latent dynamics from neural population data. The recently developed AutoLFADS framework ([Keshtkaran et al., 2021](#)) extends LFADS by using Population Based Training (PBT) ([Jaderberg et al., 2017](#)) to effectively and scalably tune model hyperparameters, a critical step for accurate modeling of neural population data. As hyperparameter sweeps are one of the most computationally demanding processes in model development, these workflows should be deployed in a computationally efficient and cost effective manner given the compute resources available (e.g. local, institutionally-supported, or commercial computing clusters). The initial implementation of AutoLFADS used the Ray library ([Moritz et al., 2018](#)) to enable support for specific local and commercial cloud workflows. We extend this support, by providing additional options for training AutoLFADS models using local clusters in a container-native approach (e.g. docker, podman), unmanaged compute clusters leveraging Ray, and managed compute clusters leveraging KubeFlow and Kubernetes orchestration.

As the neurosciences increasingly employ deep learning based models that require compute intensive hyperparameter optimization ([Keshtkaran & Pandarinath, 2019](#); [Willett et al., 2021](#); [Yu et al., 2021](#)), standardization and dissemination of computational methods becomes increasingly challenging. Although this work specifically provides an implementation using AutoLFADS, the tooling provided demonstrates strategies for employing computation at scale while facilitating dissemination and reproducibility.

Statement of need

Machine learning models enable neuroscience researchers to uncover new insights regarding the neural basis of perception, cognition, and behavior ([Vu et al., 2018](#)). However, models are often developed with hyperparameters tuned for a specific dataset, despite their intended generality. Application to new datasets requires computationally intensive hyperparameter searches for model tuning. Given the diversity of data across tasks, species, neural interface technologies, and brain regions, hyperparameter tuning is common and presents a significant barrier to evaluation and adoption of new algorithms. With the maturation of “AutoML”

hyperparameter exploration libraries (HyperOpt, SkOpt, Ray), it is now easier to effectively search an extensive hyperparameter space. Solutions like KubeFlow (Smith et al., 2018) additionally enable scaling on managed clusters and provide near codeless workflows for the entire machine learning lifecycle from data ingest and initial algorithm evaluation to model training and tuning. Using these tools, we empower researchers with multiple deployment strategies for leveraging AutoLFADS on local compute, on ad-hoc or unmanaged compute, and on managed or cloud compute Figure 1.

Solutions

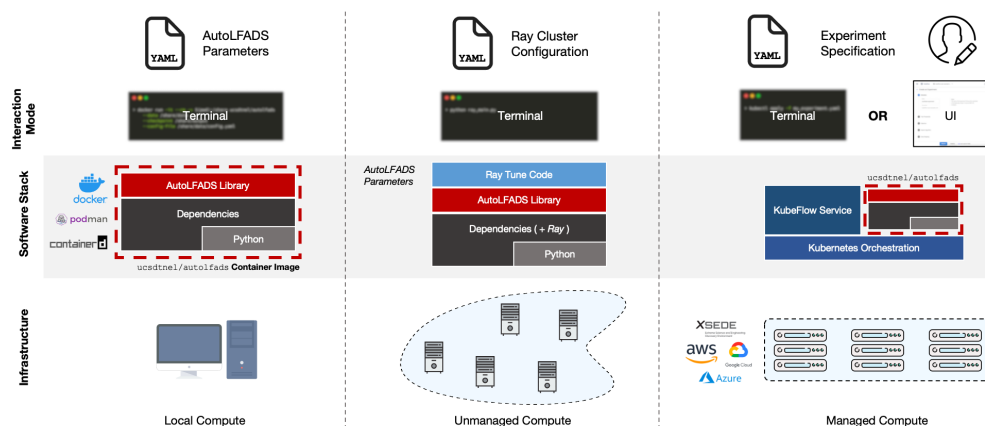


Figure 1: Solutions for running AutoLFADS on various compute infrastructures. (Left) This column depicts a local workflow: users leverage a container image that bundles all the AutoLFADS software dependencies and provides an endpoint directly to the LFADS package. Container images are run with a supported container runtime (e.g. docker, podman, containerd). Users can interact with this workflow by providing YAML model configuration files and command line (CLI) arguments. (Middle) This column depicts a scalable solution using Ray: users start a Ray cluster by specifying the configuration (network location and authentication) as a YAML file. They install AutoLFADS locally or in a virtual environment, update YAML model configurations and hyperparameter sweep scripts, and then run the experiment code. (Right) This column depicts a scalable solution using KubeFlow: users provide an experiment specification that includes model configuration and hyperparameter sweep specifications either as a YAML file or using a code-less UI-based workflow. After experiment submission, the KubeFlow service spawns workers across the cluster that use the same container images as the local workflow.

When training models on a novel dataset, it is often helpful to probe hyperparameters and investigate model performance locally prior to conducting a more exhaustive, automated hyperparameter search. This need can be met by installing the LFADS package locally or in a virtual environment. Isolating the workflow from local computational environments, we provide a pair of reference container images targeting CPU and GPU architectures. This allows users to treat the bundled algorithm as a portable executable where they simply provide the input neural data and desired LFADS model configuration. This approach eliminates the need for users to configure their environments with compatible interpreters and dependencies. Instead, the user installs a container runtime engine (e.g. docker, podman), which are generally well-supported cross-platform tools, to run the image based solution. In addition to streamlining configuration, this approach enables reproducibility as the software environment employed for computation is

62 fully defined and version controlled.

63 Scaling initial investigations may involve evaluating data on internal lab resources, which may
 64 comprise a set of loosely connected compute devices. In such a heterogeneous environment, we
 65 leverage Ray to efficiently create processing jobs. In this approach Ray spawns a set of workers
 66 on compute nodes that the primary spawner is then able to send jobs to. This approach
 67 requires users to provide a mapping of machine locations (e.g. IP, hostname) and access
 68 credentials. It provides useful flexibility beyond single node local compute, but requires users to
 69 manage compute cluster configuration details. Ray can also be deployed in managed compute
 70 environments, but similarly requires users to have knowledge of the underlying compute
 71 infrastructure configuration defined by the managed environment. In short, the Ray based
 72 solution requires researchers to specifically target, and potentially modify, compute cluster
 73 configuration.

74 To more effectively leverage large scale compute in managed infrastructure, we use KubeFlow
 75 which is a comprehensive machine learning solution designed to be operated as a service on top of
 76 Kubernetes based orchestration. It enables code-less workflows and provides a rich set of tooling
 77 around development (e.g. notebooks, algorithm exploration) and automation (e.g. Pipelines)
 78 that reduces research iteration time. In contrast to Ray, configuration requirements are
 79 algorithm focused and are generally agnostic to the lower level details related to compute cluster
 80 configuration. With this solution, Kubernetes manages the underlying compute resource pool
 81 and is able to efficiently schedule compute jobs. Within KubeFlow, we leverage Katib ([George
 82 et al., 2020](#)) – KubeFlow’s “AutoML” framework – to efficiently explore the hyperparameter
 83 space and specify individual sweeps. As KubeFlow is an industry-grade tool, many cloud
 84 providers offer KubeFlow as a service or provide supported pathways for deploying a KubeFlow
 85 cluster, facilitating replication and compute resource scaling.

86 Evaluation

87 A core innovation of AutoLFADS is the integration of PBT for hyperparameter exploration.
 88 As the underlying job scheduler and PBT implementation are unique in KubeFlow, we used
 89 the MC Maze dataset ([Churchland, 2021](#)) from the Neural Latents Benchmark ([Pei et al.,
 90 2021](#)) to train and evaluate two AutoLFADS models. One model was trained with the Ray
 91 solution and the other with the KubeFlow solution using matching PBT hyperparameters and
 92 model configurations to ensure that models of comparable quality can be learned across both
 93 solutions. A comprehensive description of the AutoLFADS algorithm and results applying
 94 the algorithm to neural data using Ray can be found in Keshtkaran et al. ([2021](#)). We
 95 demonstrate similar converged model performances on metrics relevant to the quality of
 96 inferred firing rates (see table below) ([Pei et al., 2021](#)). In [Figure 3](#), inferred firing rates
 97 from the KubeFlow trained AutoLFADS model are shown along with conventional firing rate
 98 estimation strategies. Qualitatively, these example inferences are similar to those described
 99 in Keshtkaran et al. ([2021](#)), showing similar consistency across trials and resemblance to
 100 peristimulus time histogram PSTHs. In [Figure 2](#), we plot the hyperparameter and associated
 101 loss values for the KubeFlow based implementation of AutoLFADS to provide a visualization of
 102 the PBT based optimization process on these data. These results demonstrate that although
 103 PBT is stochastic, both the original Ray and novel KubeFlow implementations are converging
 104 to stable, comparable solutions.

Table 1: AutoLFADS Performance. An evaluation of AutoLFADS performance on Ray and KubeFlow. Test trial performance comparison on four neurally relevant metrics for evaluating latent variable models: co-smoothing on held-out neurons (co-bps), hand trajectory decoding on held-out neurons (vel R2), match to peri-stimulus time histogram (PSTH) on held-out neurons (psth R2), forward prediction on held-in neurons (fp-bps). The trained models converge with less than 5% difference between the frameworks on the above metrics. The percent difference is calculated with respect to the Ray framework.

Framework	co-bps (↑)	vel R2 (↑)	psth R2 (↑)	fp-bps (↑)
Ray	0.3364	0.9097	0.6360	0.2349
KubeFlow	0.35103	0.9099	0.6339	0.2405
Percent difference	+4.35	+0.03	-0.33	+2.38

Hyperparameter Evolution

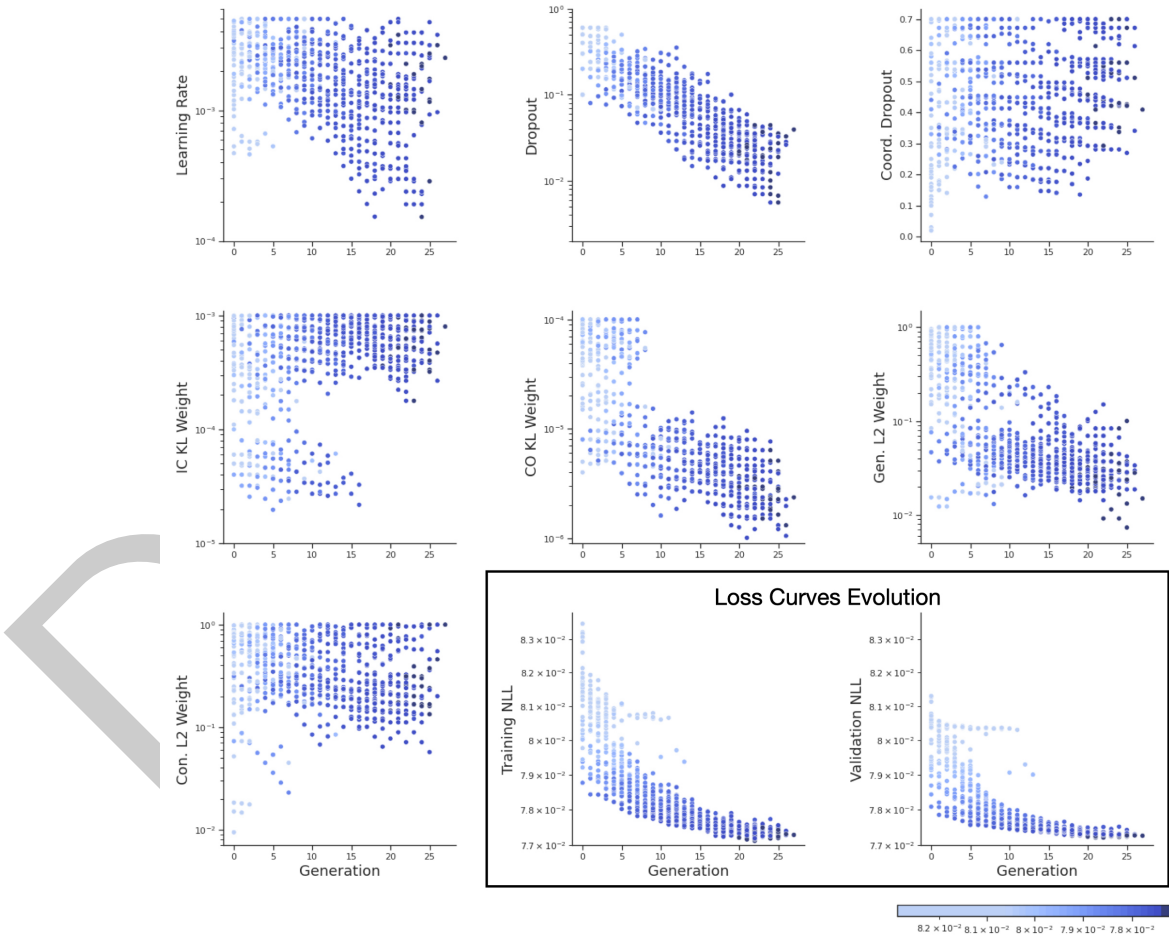


Figure 2: Evolution of loss curves and hyperparameters for AutoLFADS using KubeFlow. Each point represents each individual training trial. Points are colored by the exponentially-smoothed negative log-likelihood (NLL) loss at the end of each generation.

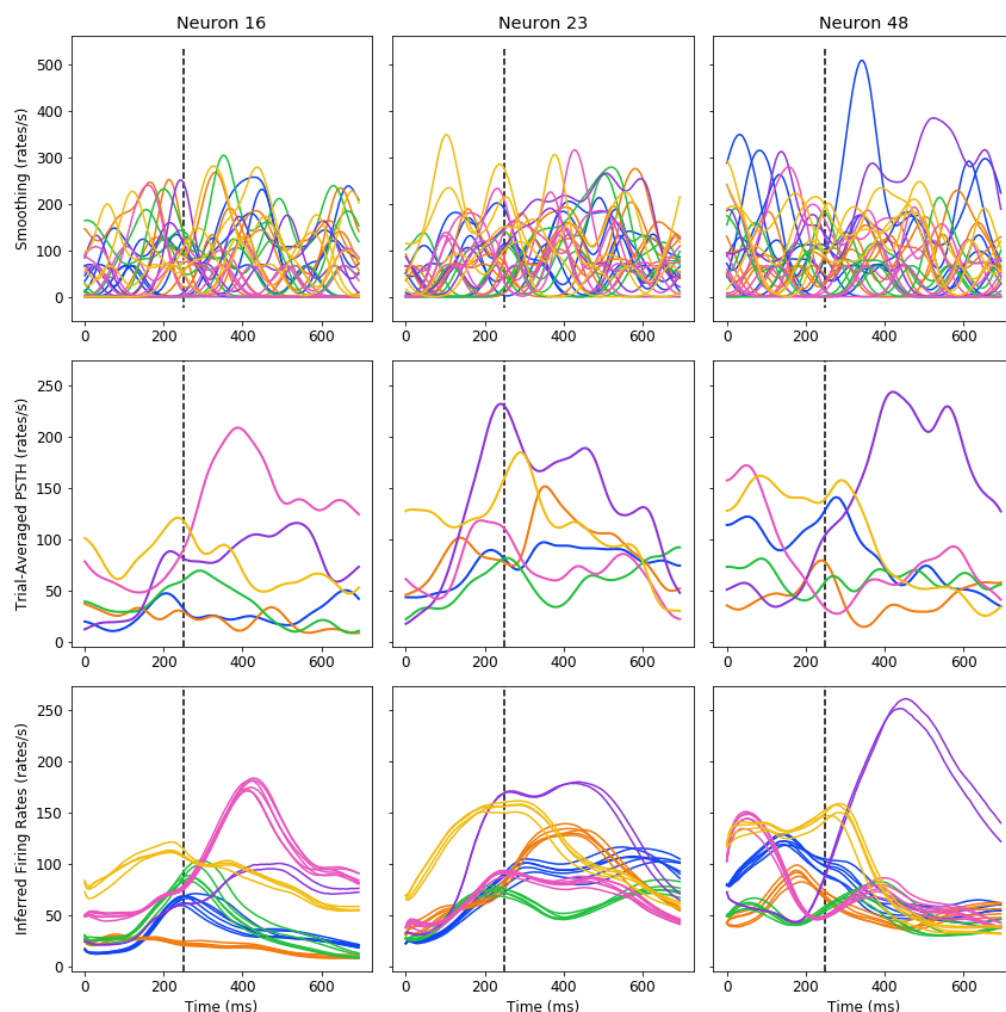


Figure 3: AutoLFADS inferred firing rates, relative to conventional estimation strategies, aligned to movement onset time (dashed vertical line at 250ms) for 3 example neurons (columns) and 6 example conditions (colors; out of 108 conditions). Smoothed spike rates calculated with a Gaussian kernel, 50 ms st.dev. (top), trial-averaged peristimulus time histogram (PSTH) (middle), and inferred firing rates of AutoLFADS on KubeFlow (bottom). The smoothed spikes and inferred firing rates are shown for corresponding trials in the validation set (trial count range from 2 to 6 per condition, shown as individual traces for each trial), while the PSTHs are calculated for all trials (trial counts range from 19 to 24 per condition, one trace per condition). In addition, the PSTHs are calculated based on the averaged spikes smoothed with a 70 ms st.dev Gaussian kernel, which corresponds to the definition of PSTHs used for the evaluation metric PSTH R2 (Table 1). In all subfigures, the inferred rates are calculated with a time resolution of 5ms.

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