Title: MALPOLON: A Framework for Deep Species Distribution Modeling

arXiv ID: 2409.18102v1

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Summary: This paper describes a deep-SDM framework, MALPOLON. Written in Python and built upon the PyTorch library, this framework aims to facilitate training and inferences of deep species distribution models (deep-SDM) and sharing for users with only general Python language skills (e.g., modeling ecologists) who are interested in testing deep learning approaches to build new SDMs. More advanced users can also benefit from the framework's modularity to run more specific experiments by overriding existing classes while taking advantage of press-button examples to train neural networks on multiple classification tasks using custom or provided raw and pre-processed datasets. The framework is open-sourced on GitHub and PyPi along with extensive documentation and examples of use in various scenarios. MALPOLON offers straightforward installation, YAML-based configuration, parallel computing, multi-GPU utilization, baseline and foundational models for benchmarking, and extensive tutorials/documentation, aiming to enhance accessibility and performance scalability for ecologists and researchers.

Title: EfficientCrackNet: A Lightweight Model for Crack Segmentation

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Summary: Crack detection, particularly from pavement images, presents a formidable challenge in the domain of computer vision due to several inherent complexities such as intensity inhomogeneity, intricate topologies, low contrast, and noisy backgrounds. Automated crack detection is crucial for maintaining the

structural integrity of essential infrastructures, including buildings, pavements, and bridges. Existing lightweight methods often face challenges including computational inefficiency, complex crack patterns, and difficult backgrounds, leading to inaccurate detection and impracticality for real-world applications. To address these limitations, we propose EfficientCrackNet, a lightweight hybrid model combining Convolutional Neural Networks (CNNs) and transformers for precise crack segmentation. EfficientCrackNet integrates depthwise separable convolutions (DSC) layers and MobileViT block to capture both global and local features. The model employs an Edge Extraction Method (EEM) and for efficient crack edge detection without pretraining, and Ultra-Lightweight Subspace Attention Module (ULSAM) to enhance feature extraction. Extensive experiments on three benchmark datasets Crack500, DeepCrack, and GAPs384 demonstrate that EfficientCrackNet achieves superior performance compared to existing lightweight models, while requiring only 0.26M parameters, and 0.483 FLOPs (G). The proposed model offers an optimal balance between accuracy and computational efficiency, outperforming state-of-the-art lightweight models, and providing a robust and adaptable solution for real-world crack segmentation.

Title: A Sim-to-Real Vision-based Lane Keeping System for a 1:10-scale Autonomous Vehicle

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Summary: In recent years, several competitions have highlighted the need to investigate vision-based solutions to address scenarios with functional insufficiencies in perception, world modeling and localization. This article

presents the Vision-based Lane Keeping System (VbLKS) developed by the
DEI-Unipd Team within the context of the Bosch Future Mobility Challenge 2022.
The main contribution lies in a Simulation-to-Reality (Sim2Real) GPS-denied
VbLKS for a 1:10-scale autonomous vehicle. In this VbLKS, the input to a
tailored Pure Pursuit (PP) based control strategy, namely the Lookahead Heading
Error (LHE), is estimated at a constant lookahead distance employing a
Convolutional Neural Network (CNN). A training strategy for a compact CNN is
proposed, emphasizing data generation and augmentation on simulated camera
images from a 3D Gazebo simulator, and enabling real-time operation on
low-level hardware. A tailored PP-based lateral controller equipped with a
derivative action and a PP-based velocity reference generation are implemented.
Tuning ranges are established through a systematic time-delay stability
analysis. Validation in a representative controlled laboratory setting is
provided.

Title: Mobility in Age-Based Gossip Networks

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Summary: We consider a gossiping network where a source forwards updates to a set of
n gossiping nodes that are placed in an arbitrary graph structure and gossip
with their neighbors. In this paper, we analyze how mobility of nodes affects
the freshness of nodes in the gossiping network. To model mobility, we let
nodes randomly exchange positions with other nodes in the network. The position
of the node determines how the node interacts with the rest of the network. In
order to quantify information freshness, we use the version age of information
metric. We use the stochastic hybrid system (SHS) framework to derive recursive

equations to find the version age for a set of positions in the network in terms of the version ages of sets of positions that are one larger or of the same size. We use these recursive equations to find an upper bound for the average version age of a node in two example networks. We show that mobility can decrease the version age of nodes in a disconnected network from linear scaling in n to at most square root scaling and even to constant scaling in some cases. We perform numerical simulations to analyze how mobility affects the version age of different positions in the network and also show that the upper bounds obtained for the example networks are tight.

Title: A 2-approximation algorithm for the softwired parsimony problem on binary, tree-child phylogenetic networks

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Summary: Finding the most parsimonious tree inside a phylogenetic network with respect to a given character is an NP-hard combinatorial optimization problem that for many network topologies is essentially inapproximable. In contrast, if the network is a rooted tree, then Fitch's well-known algorithm calculates an optimal parsimony score for that character in polynomial time. Drawing inspiration from this we here introduce a new extension of Fitch's algorithm which runs in polynomial time and ensures an approximation factor of 2 on binary, tree-child phylogenetic networks, a popular topologically-restricted subclass of phylogenetic networks in the literature. Specifically, we show that Fitch's algorithm can be seen as a primal-dual algorithm, how it can be extended to binary, tree-child networks and that the approximation guarantee of this extension is tight. These results for a classic problem in phylogenetics

strengthens the link between polyhedral methods and phylogenetics and can aid

in the study of other related optimization problems on phylogenetic networks.

Title: Prediction of the Infrared Absorbance Intensities and Frequencies of Hydrocarbons:A Message Passing Neural Network Approach

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Summary: Accurately and efficiently predicting the infrared (IR) spectra of a molecule can provide insights into the structure-properties relationships of molecular species, which has led to a proliferation of machine learning tools designed for this purpose. However, earlier studies have focused primarily on obtaining normalized IR spectra, which limits their potential for a comprehensive analysis of molecular behavior in the IR range. For instance, to fully understand and predict the optical properties, such as the transparency characteristics, it is necessary to predict the molar absorptivity IR spectra instead. Here, we propose a graph-based communicative message passing neural network (CMPNN) algorithm that can predict both the peak positions and absolute intensities corresponding to density functional theory (DFT) calculated molar absorptivities in the IR domain. By modifying existing spectral loss functions, we show that our method is able to predict with DFT-accuracy level the IR molar absorptivities of a series of hydrocarbons containing up to ten carbon atoms and apply the model to a set of larger molecules. We also compare the predicted spectra with those generated by the direct message passing neural network (DMPNN). The results suggest that both algorithms demonstrate similar predictive capabilities for hydrocarbons, indicating that either model could be effectively used in future research on spectral prediction for such systems.

Title: Optimal Protocols for Continual Learning via Statistical Physics and Control Theory

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Summary: Artificial neural networks often struggle with catastrophic forgetting when learning multiple tasks sequentially, as training on new tasks degrades the performance on previously learned ones. Recent theoretical work has addressed this issue by analysing learning curves in synthetic frameworks under predefined training protocols. However, these protocols relied on heuristics and lacked a solid theoretical foundation assessing their optimality. In this paper, we fill this gap combining exact equations for training dynamics, derived using statistical physics techniques, with optimal control methods. We apply this approach to teacher-student models for continual learning and multi-task problems, obtaining a theory for task-selection protocols maximising performance while minimising forgetting. Our theoretical analysis offers non-trivial yet interpretable strategies for mitigating catastrophic forgetting, shedding light on how optimal learning protocols can modulate established effects, such as the influence of task similarity on forgetting. Finally, we validate our theoretical findings on real-world data.

Title: LightAvatar: Efficient Head Avatar as Dynamic Neural Light Field

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Summary: Recent works have shown that neural radiance fields (NeRFs) on top of parametric models have reached SOTA quality to build photorealistic head avatars from a monocular video. However, one major limitation of the NeRF-based avatars is the slow rendering speed due to the dense point sampling of NeRF, preventing them from broader utility on resource-constrained devices. We introduce LightAvatar, the first head avatar model based on neural light fields (NeLFs). LightAvatar renders an image from 3DMM parameters and a camera pose via a single network forward pass, without using mesh or volume rendering. The proposed approach, while being conceptually appealing, poses a significant challenge towards real-time efficiency and training stability. To resolve them, we introduce dedicated network designs to obtain proper representations for the NeLF model and maintain a low FLOPs budget. Meanwhile, we tap into a distillation-based training strategy that uses a pretrained avatar model as teacher to synthesize abundant pseudo data for training. A warping field network is introduced to correct the fitting error in the real data so that the model can learn better. Extensive experiments suggest that our method can achieve new SOTA image quality quantitatively or qualitatively, while being significantly faster than the counterparts, reporting 174.1 FPS (512x512 resolution) on a consumer-grade GPU (RTX3090) with no customized optimization.

Title: MARS: Multi-radio Architecture with Radio Selection using Decision Trees
  for emerging mesoscale CPS/IoT applications

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Summary: IoT is rapidly growing from small-scale apps to large-scale apps. Small-scale apps employ short-range radios like Zigbee,BLE while large-scale apps employ long-range radios like LoRa,NB-IoT. The other upcoming category of apps like

P2P energy-trade in smart homes are termed mesoscale IoT apps. There are no specialized radios for these apps. They either use short/long-range radios. To close this gap, we explored mesoscale apps using the COTS IoT radios available. Our qualitative analysis identifies Zigbee and LoRa as potential candidates. Our quantitative analysis on single and multi-hop topologies showed that Zigbee and LoRa achieve competitive throughput at a distance of 500-1200m from the gateway. A fundamental finding of these analyses is that a multi-radio system that can efficiently switch between Zigbee and LoRa performs better than the single-radio systems. However, instantaneously selecting and switching to a high-throughput radio during transmission is not trivial because of the erratic link quality dynamics. To address this issue, we developed MARS, that uses path quality metrics to instantaneously select the high-throughput radio during transmission. However, realizing MARS on resource-constrained end devices entails the challenge of obtaining instantaneous path-quality metrics. Traditional path quality estimation is not instantaneous due to propagation and queuing delays. We overcome this challenge by showing that collecting local path metrics as input to our decision trees provides sufficient information to instantaneously identify the high-throughput radio. The radio selector of MARS is powered by TAO-CART trees. The evaluation of MARS on a large-scale mesh topology at two different locations shows that MARS can efficiently identify and switch to the high-throughput radio during transmission, leading to an average throughput gain of 48.2% and 49.79% over its competitors.

Title: FlowBench: A Large Scale Benchmark for Flow Simulation over Complex Geometries

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Summary: Simulating fluid flow around arbitrary shapes is key to solving various engineering problems. However, simulating flow physics across complex geometries remains numerically challenging and computationally resource-intensive, particularly when using conventional PDE solvers. Machine learning methods offer attractive opportunities to create fast and adaptable PDE solvers. However, benchmark datasets to measure the performance of such methods are scarce, especially for flow physics across complex geometries. We introduce FlowBench, a dataset for neural simulators with over 10K samples, which is currently larger than any publicly available flow physics dataset. FlowBench contains flow simulation data across complex geometries (\textit{parametric vs. non-parametric}), spanning a range of flow conditions (\textit{Reynolds number and Grashoff number}), capturing a diverse array of flow phenomena (\textit{steady vs. transient; forced vs. free convection}), and for both 2D and 3D. FlowBench contains over 10K data samples, with each sample the outcome of a fully resolved, direct numerical simulation using a well-validated simulator framework designed for modeling transport phenomena in complex geometries. For each sample, we include velocity, pressure, and temperature field data at 3 different resolutions and several summary statistics features of engineering relevance (such as coefficients of lift and drag, and Nusselt numbers). %Additionally, we include masks and signed distance fields for each shape. We envision that FlowBench will enable evaluating the interplay between complex geometry, coupled flow phenomena, and data sufficiency on the performance of current, and future, neural PDE solvers. We enumerate several evaluation metrics to help rank order the performance of neural PDE solvers. We benchmark the performance of several baseline methods including FNO, CNO, WNO, and DeepONet.