One Fish, Two Fish, Red Fish, Blue Fish: Deep Learning Tracks Social Dynamics in Cichlid Fish

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The Identity Crisis

Tracking the identities of organisms accurately is critical for reliable behavioral analysis. The challenge when a species displays complex patterns of interaction and/or is not uniquely patterned is that it is difficult to distinguish among individuals when in groups. This is especially true when studying *Astatotilapia burtoni*, a highly social African cichlid fish. Though the manual scoring of behaviors is valuable, it is also time consuming, error prone, and has limitations.

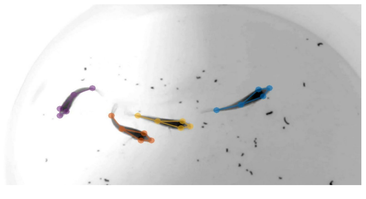
Machine learning approaches to automated tracking offer promising solutions to these limitations, enabling us to:

1. Improve scale and reliability in behavioral neuroscience research.
2. Gain deeper insight into behavior across species.
3. Reveal hidden layers of social complexity.

In an investigation of the role of group size on behavioral dynamics, we demonstrate the promise of **automated tracking** in *A. burtoni* with a deep learning framework.

Into the Deep End

- *A. burtoni* forms mixed-sex social communities and expresses highly conserved social behaviors (e.g., aggressive, territorial, affiliative behaviors).
- Group size influences developmental plasticity in juveniles and reproductive outcomes in adults.
- 32 groups of fish (8 individuals, 8 pairs, 8 triads, 8 tetrads)
- Videos recorded following group formation on Raspberry Pi 5 HQ 3MP cameras with a 6mm wide-angle lens.



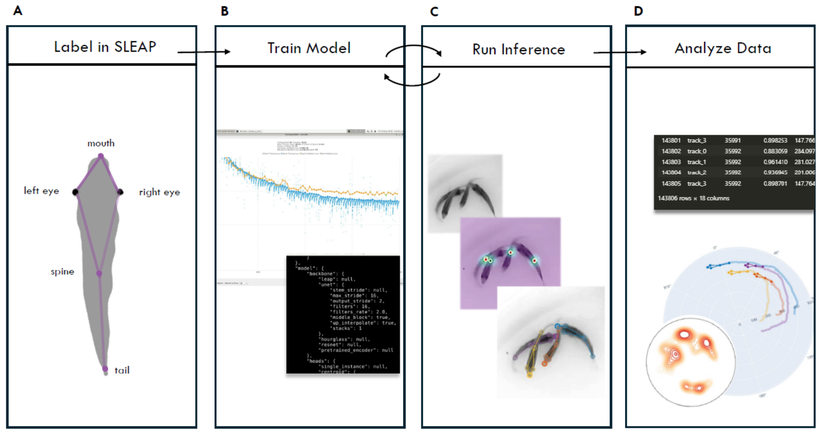
...and the Cloud

Social Leap Estimates Animal Positions (SLEAP) was installed on a spot instance Virtual Machine (VM), which acted as a cloud hosted server. The VM was configured as follows:

- Debian 11 Linux deep-learning kernel + CUDA drivers
- 4 vCPUs with 26GB RAM + Nvidia T4 GPU

In SLEAP, models are trained on representative, manually annotated video frames. Inference is run on unlabeled frames, producing coordinate locations and individual tracking data in CSV form. This file is post-processed with custom python code.

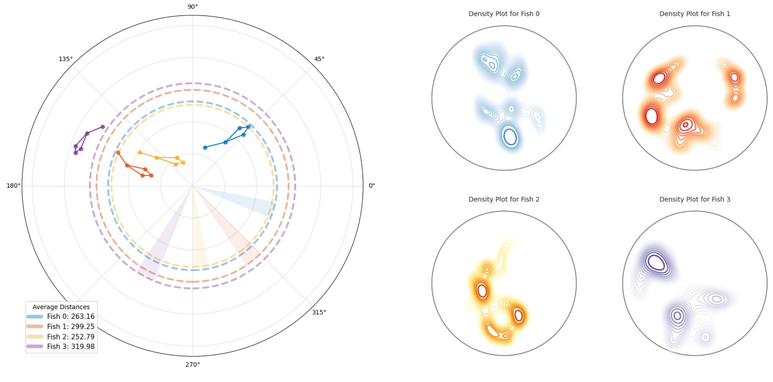
So You Think You Can Track



SLEAP was used to train a neural network and track fish identities.
To implement this, we:

1. **Labeled 1610 frames** of video to generate a training dataset.
2. **Trained models** with transfer and self-supervised learning.
3. **Ran inference** on our 32 video dataset (~1,152,000 frames).

Following inference, predictions were manually reviewed to verify accuracy in identity tracking and pose estimation.



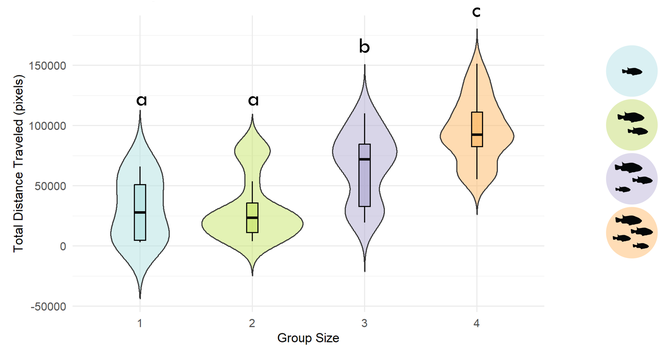
Spatial Analysis: Coordinates from SLEAP converted to polar

- Left: Reconstructed image of individual fish in a frame from coordinate data. Lines are average distances to center per fish across all frames.
- Right: Applied Kernel Density Estimation (KDE) to visualize spatial preferences within groups.

These metrics reveal variation in social proximity and space use. Fish that remain closer together may interact and/or influence each other more. Distance to the center is associated with status and stress axis function.

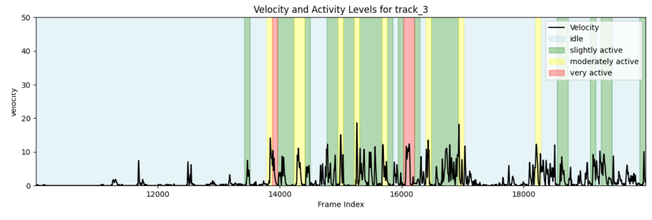
Group Size Matters

Using the full dataset (~1.15 million frames), we computed the total distances traveled by each of the 80 fish.



- **Total Distance Traveled:** Individuals in larger groups traveled significantly farther ((F(3, 76) = 26.67, p <0.001).
- **Group Consistency:** Members within the same group traveled similar distances to one another, with pairs displaying the highest intraclass correlation coefficient (ICC values for groups of 2, 3, and 4: 0.927, 0.846, 0.748 respectively).

Diving in Deeper



Future directions include:

- Further analysis of **activity** using Continuous Wavelet Transforms.
- Quantify social behaviors, such as **approaches** and **displacements.**
- Implement dynamic time warping to identify **shoaling** behavior.
- Experiment with other automated tracking frameworks, such as SAM2.
- Improve motion and occlusion analysis to identify identity swaps.

Acknowledgements

We thank the Department of Natural Sciences and the National Science Foundation (IOS-2341006) for funding to TKSL, NSF summer funding to EAM, and DNS summer funding to AY and VB. We thank the members of the Solomon-Lane Lab for the help in handling *real,* live fish.

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