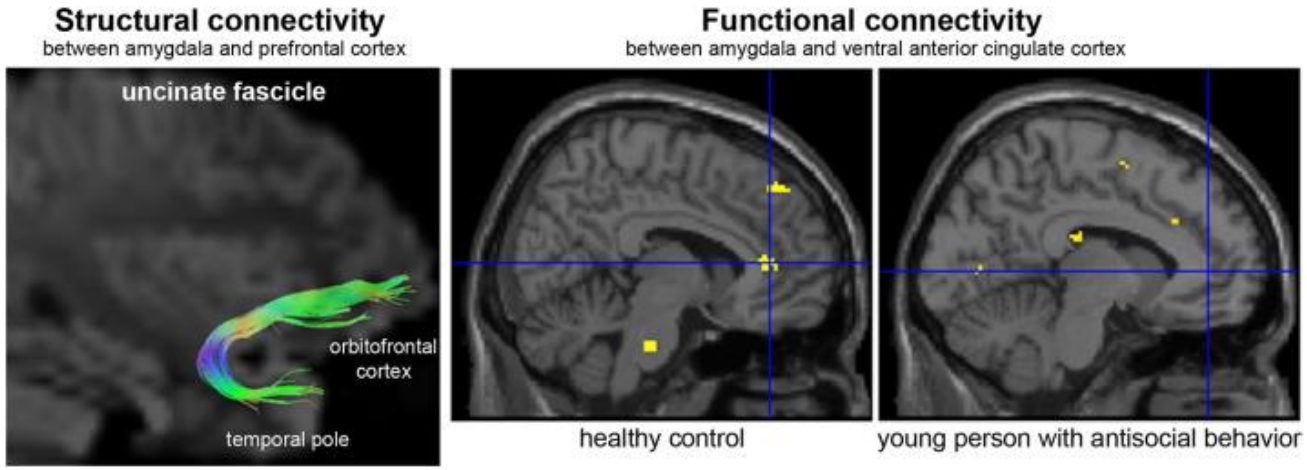
Applying Predictive Neural Networks to Model Free-swimming Zebrafish Movement in 3D Space

Oscar Low

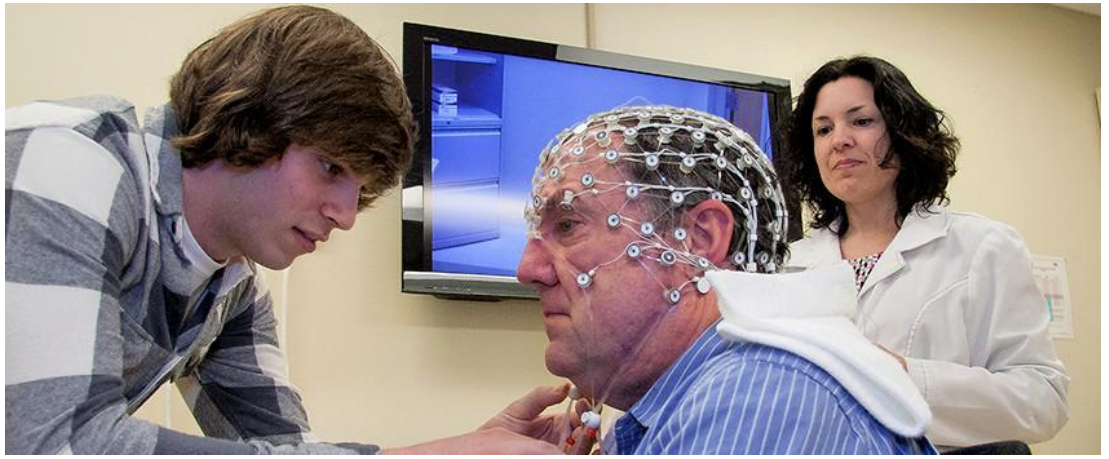
UnERD 2025

Non-Design Bioengineering

Behavioural Neuroscience



Cupaioli et al., 2021 [8]

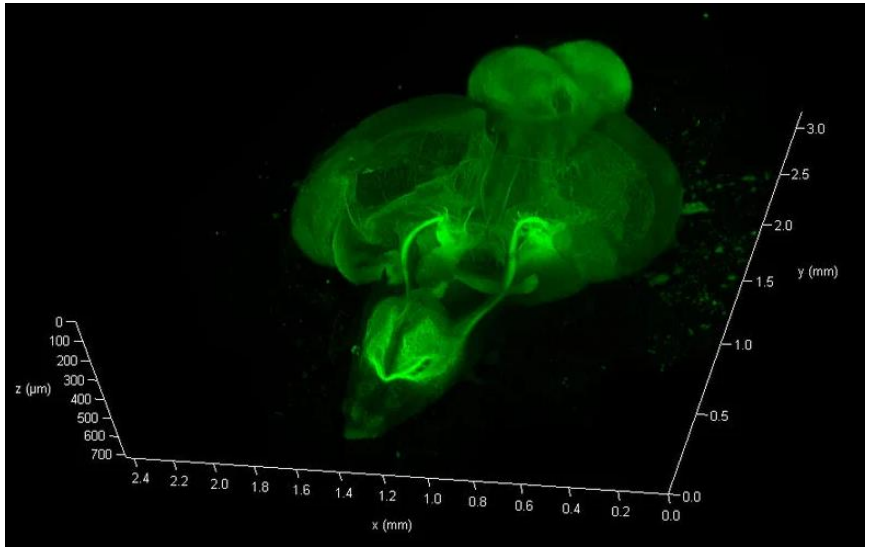


Stockton University [9]

Zebrafish in Behavioural Neuroscience

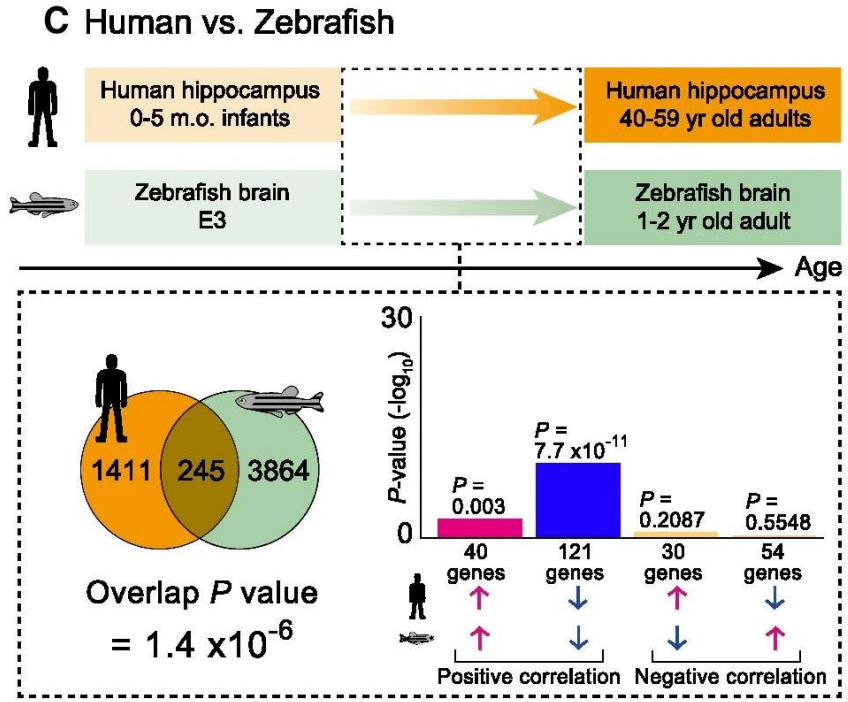
Zebrafish in Behavioural Neuroscience

Brain Imaging



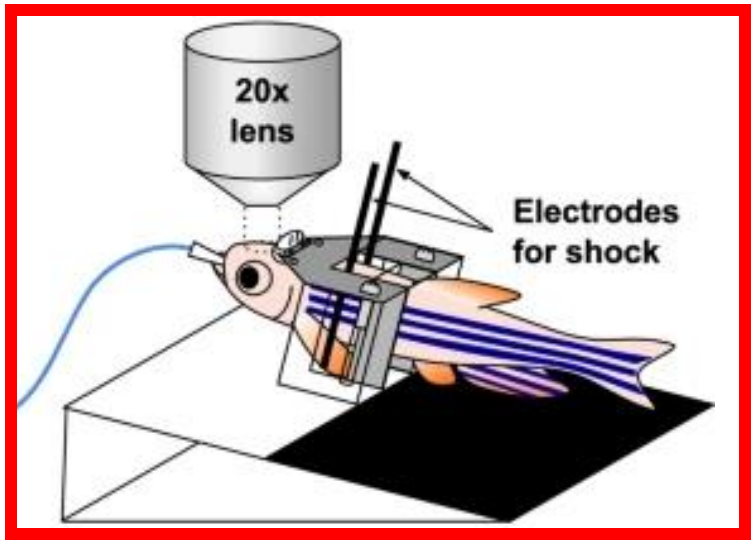
Eric Clark, ECW [10]

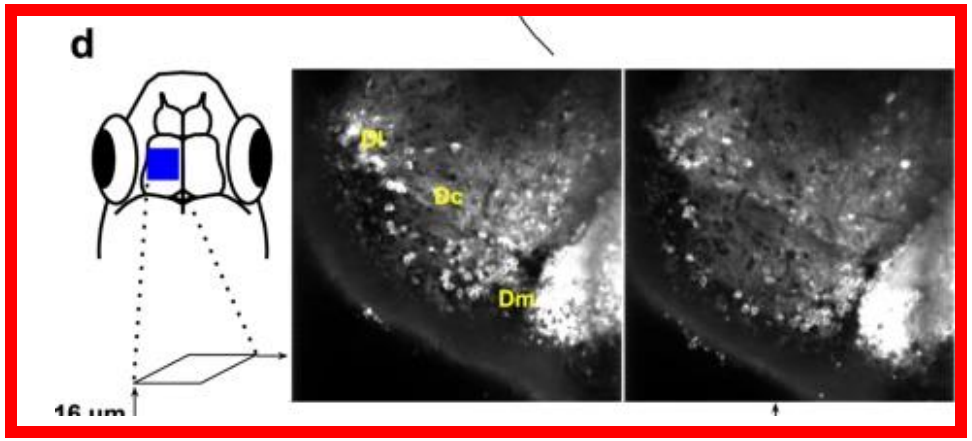
Genome & Organ Similarities

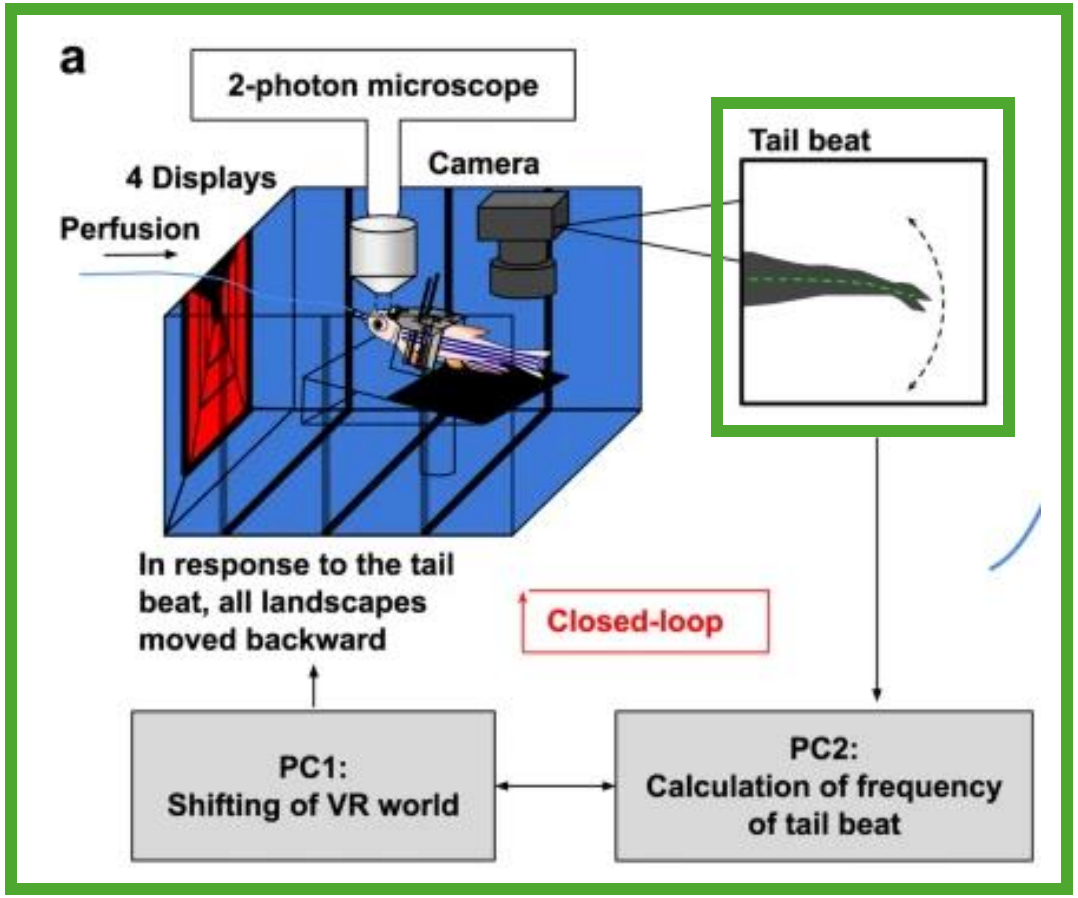


Nakajima et al., 2021 [11]

Zebrafish Virtual Reality (VR) Setups

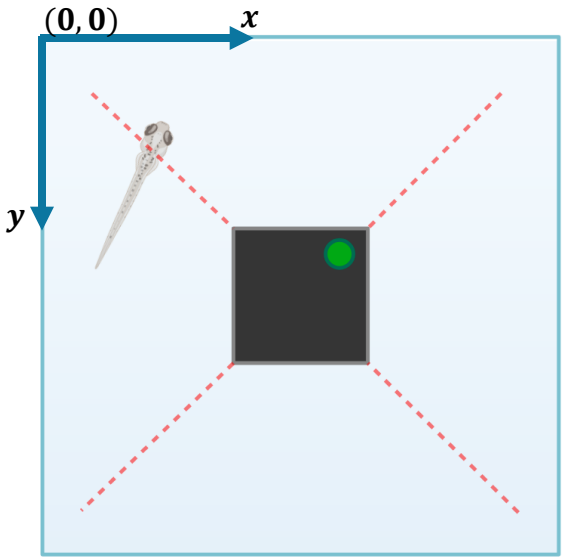




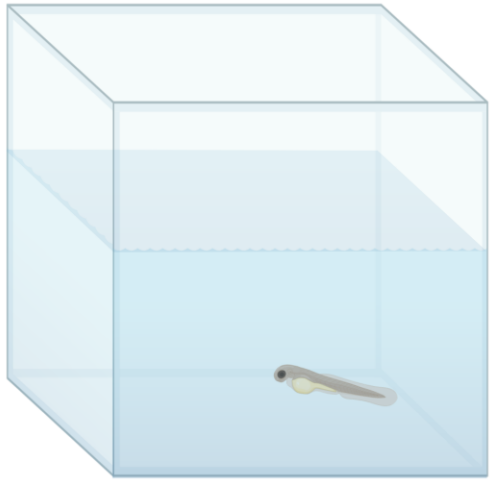


Torigoe et al., 2021 [12]

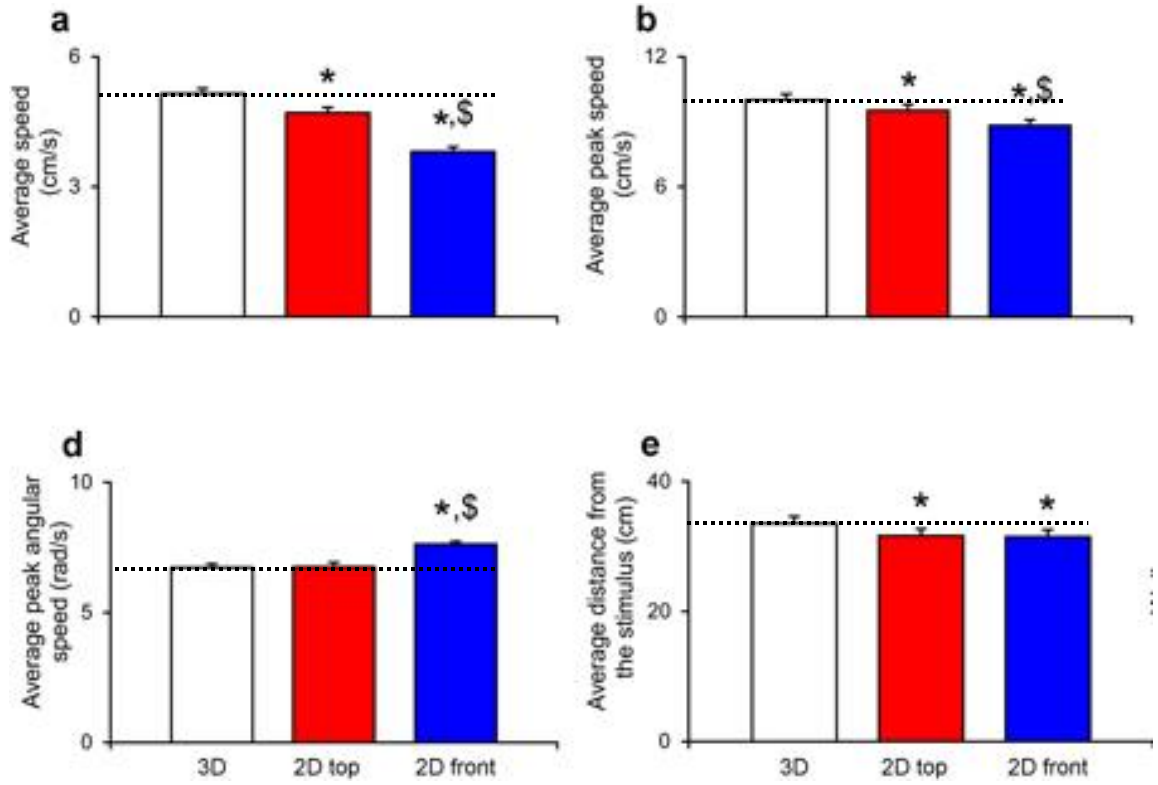
Zebrafish setups lack information in 2D



What the camera sees

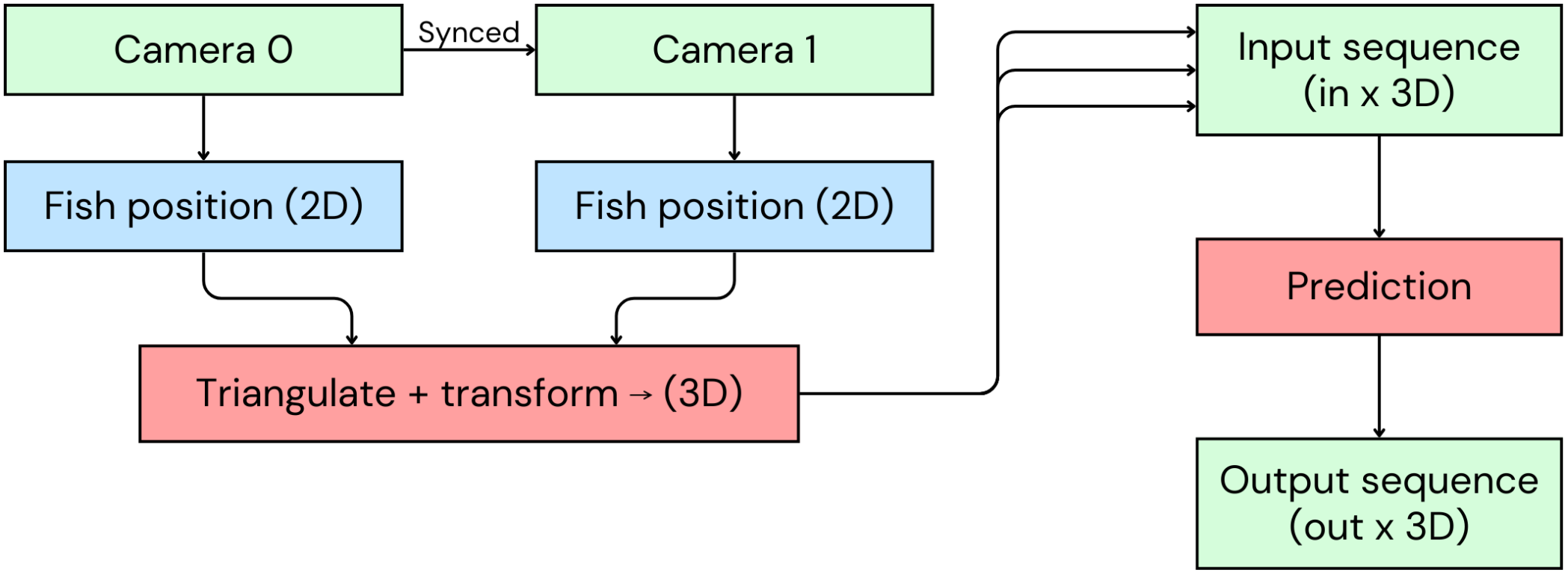


What we see

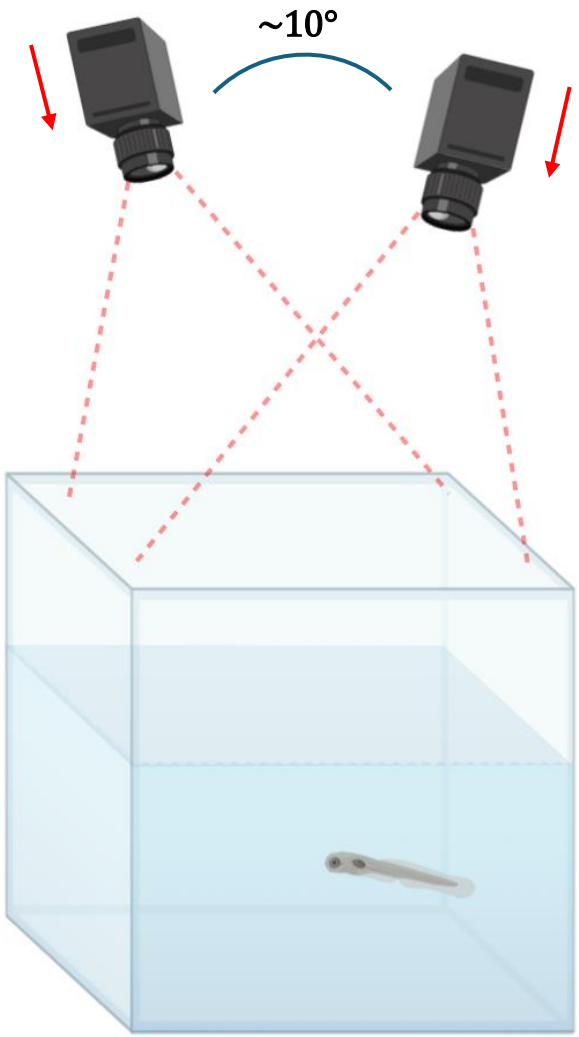


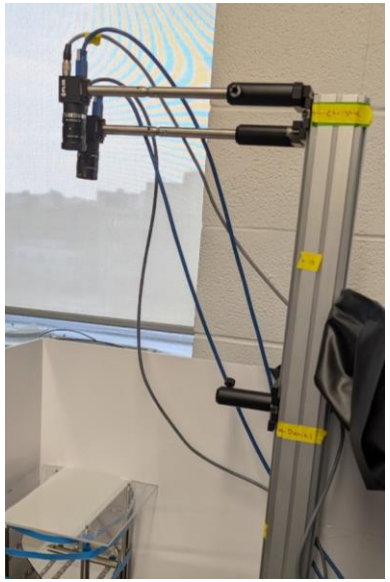
Macri et al., 2017 [6]

Prediction pipeline for 3D locomotion of free-swimming zebrafish in real-time

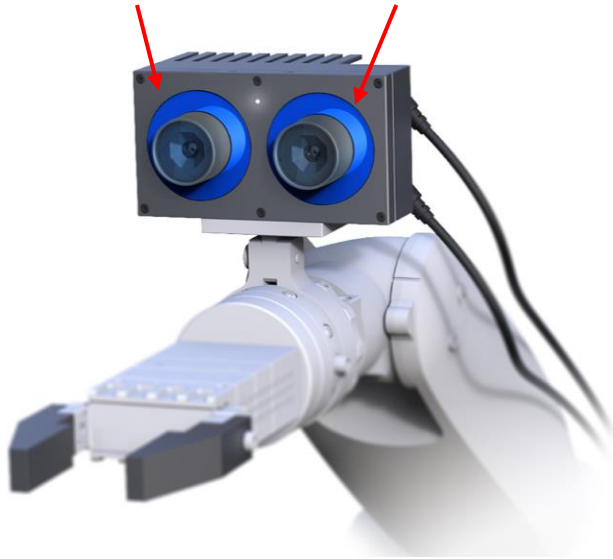


Two 2D positions

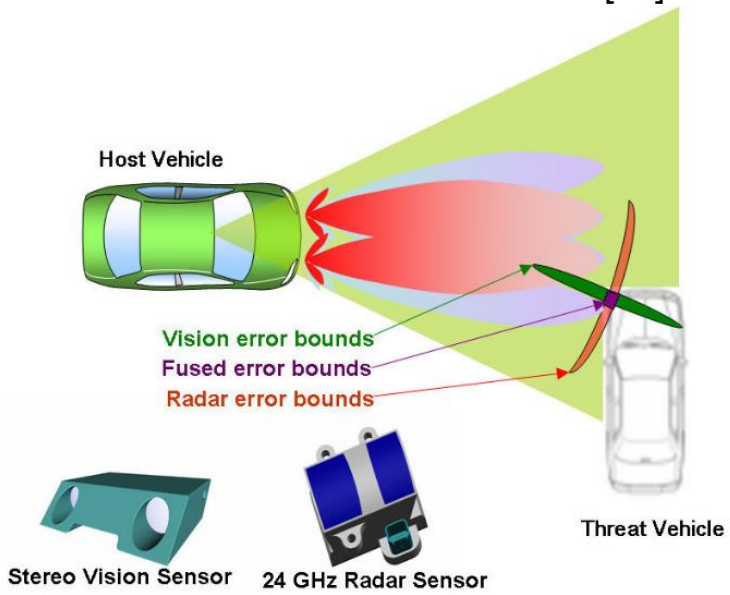




Stereo camera systems

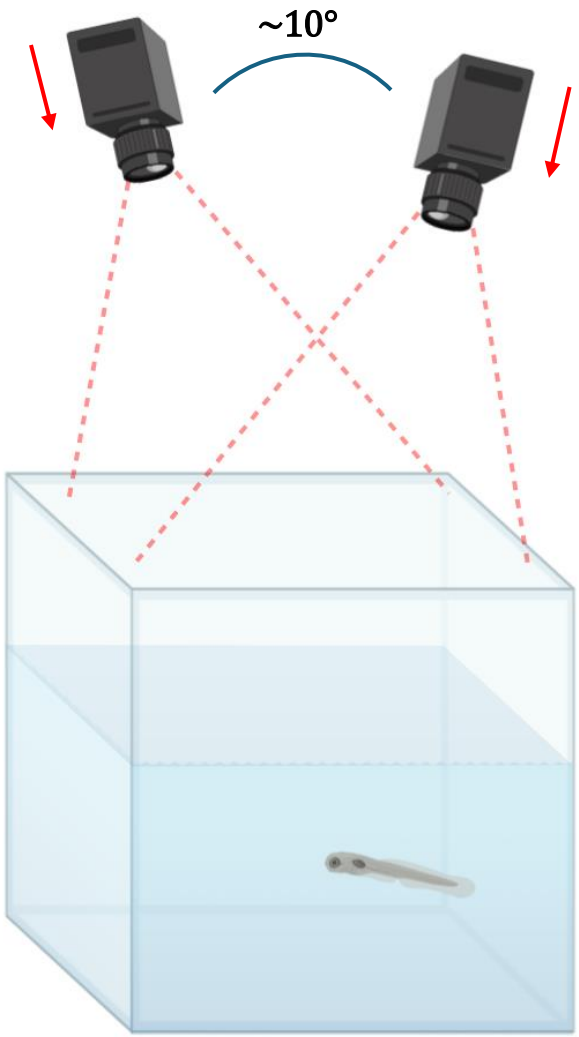


Basler AG [14]



Wu et al., 2008 [13]

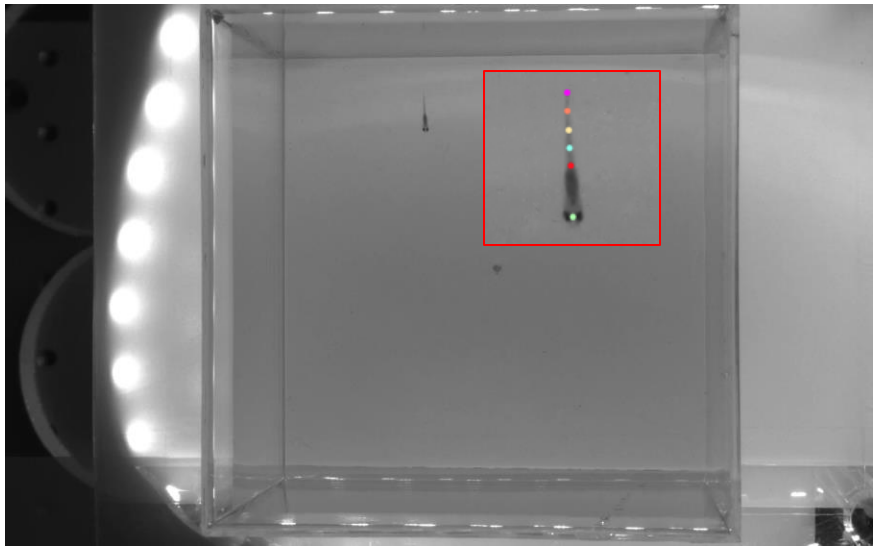
Two 2D positions



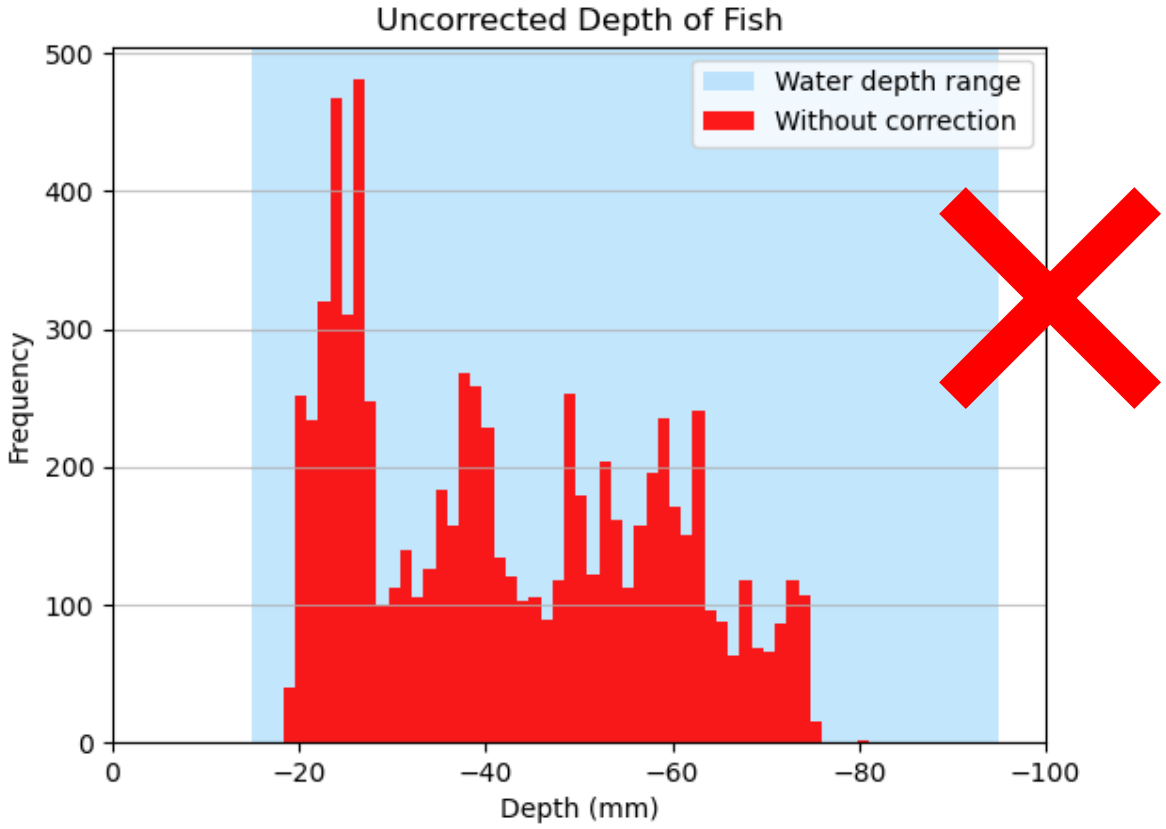
Camera 1

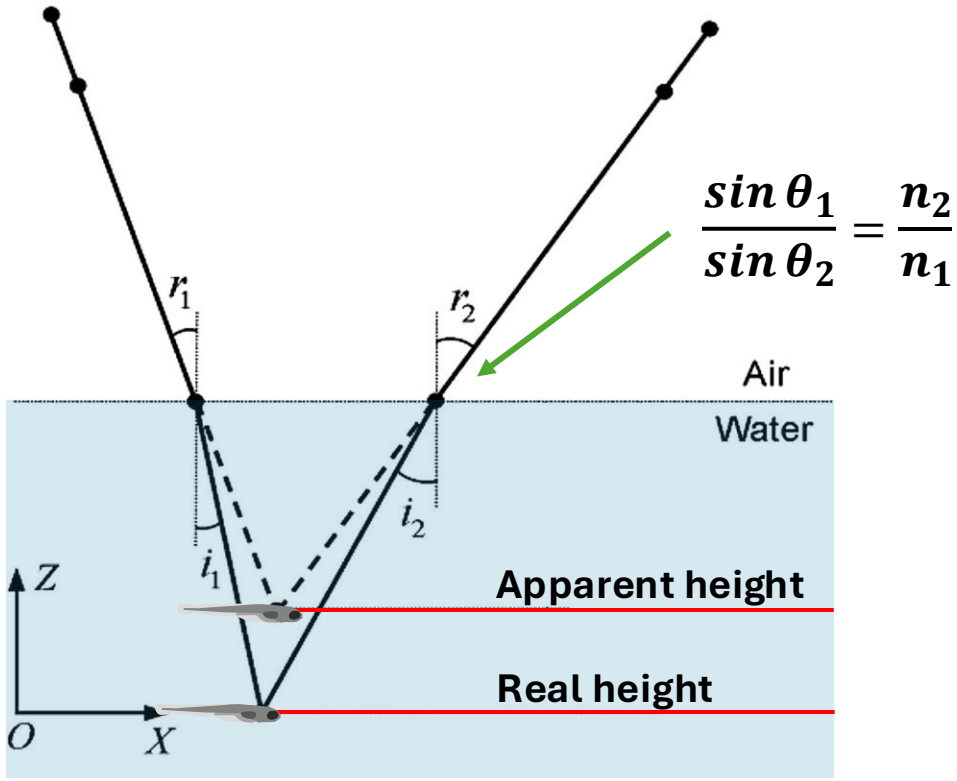
Camera 2

Jocher, Qiu, & Chaurasia [16]



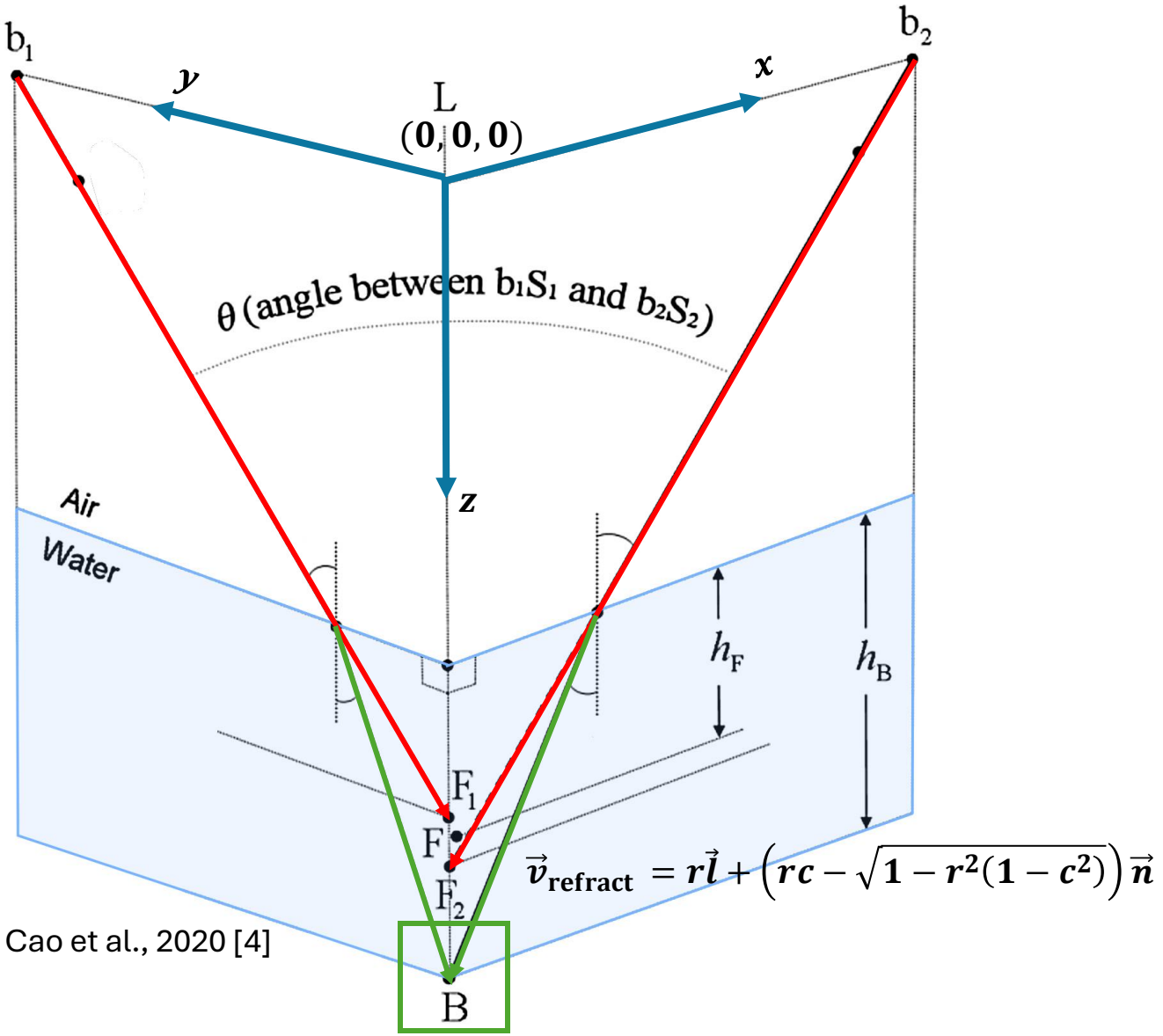
Refraction introduces depth error





Cao et al., 2020 [4]

Correcting for refraction



Cao et al., 2020 [4]

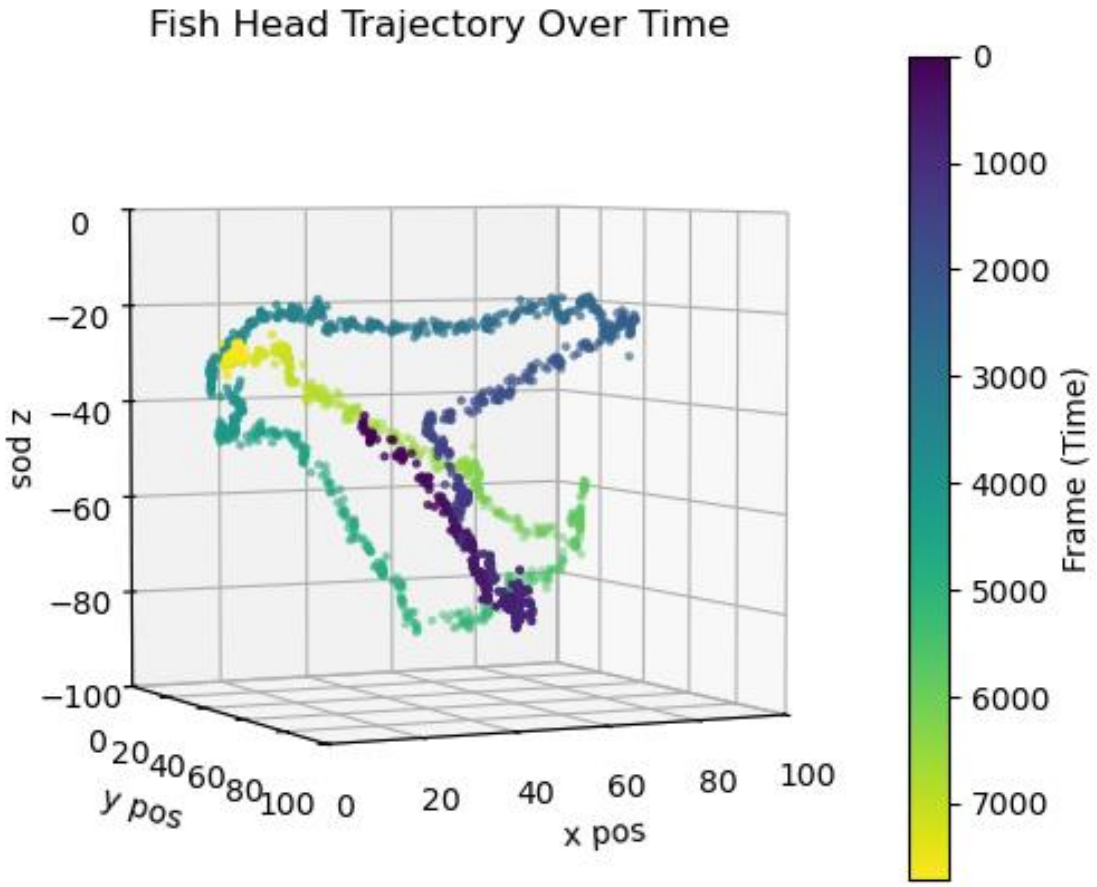
Project 3D rays from 2D positions

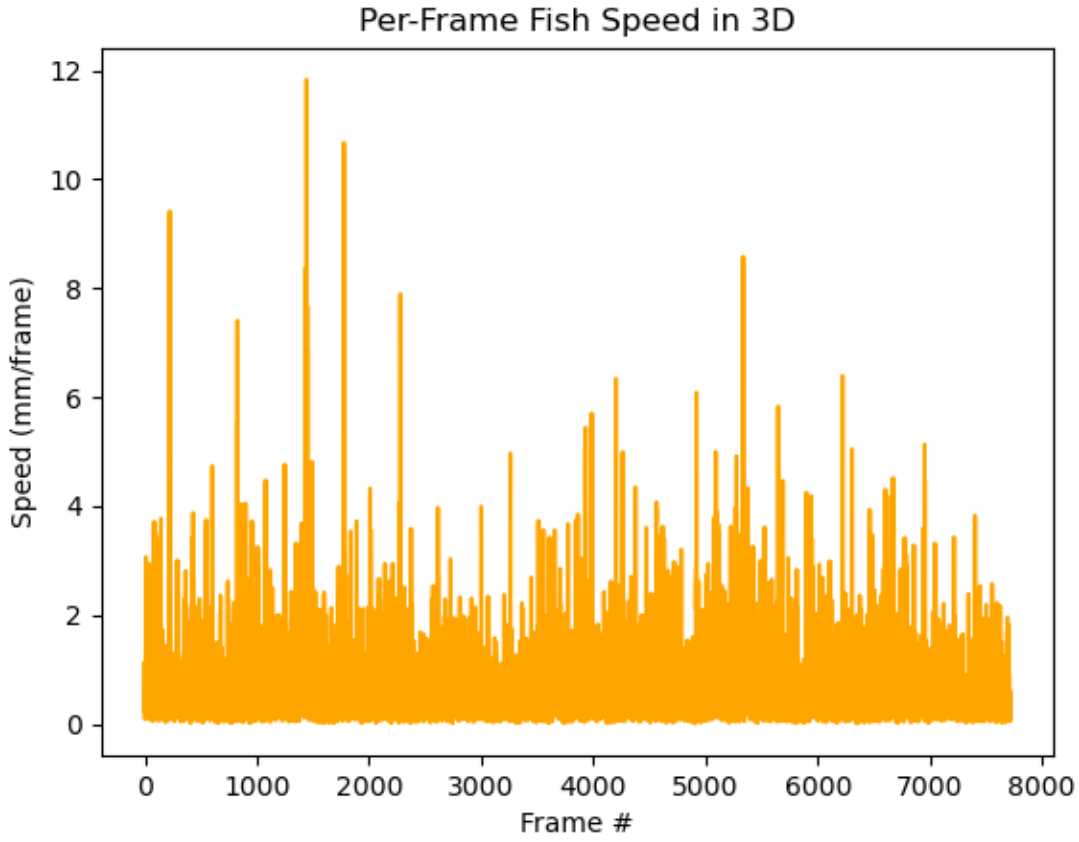
Refract rays w.r.t. water parameters

Find closest intersection of rays as the 3D position

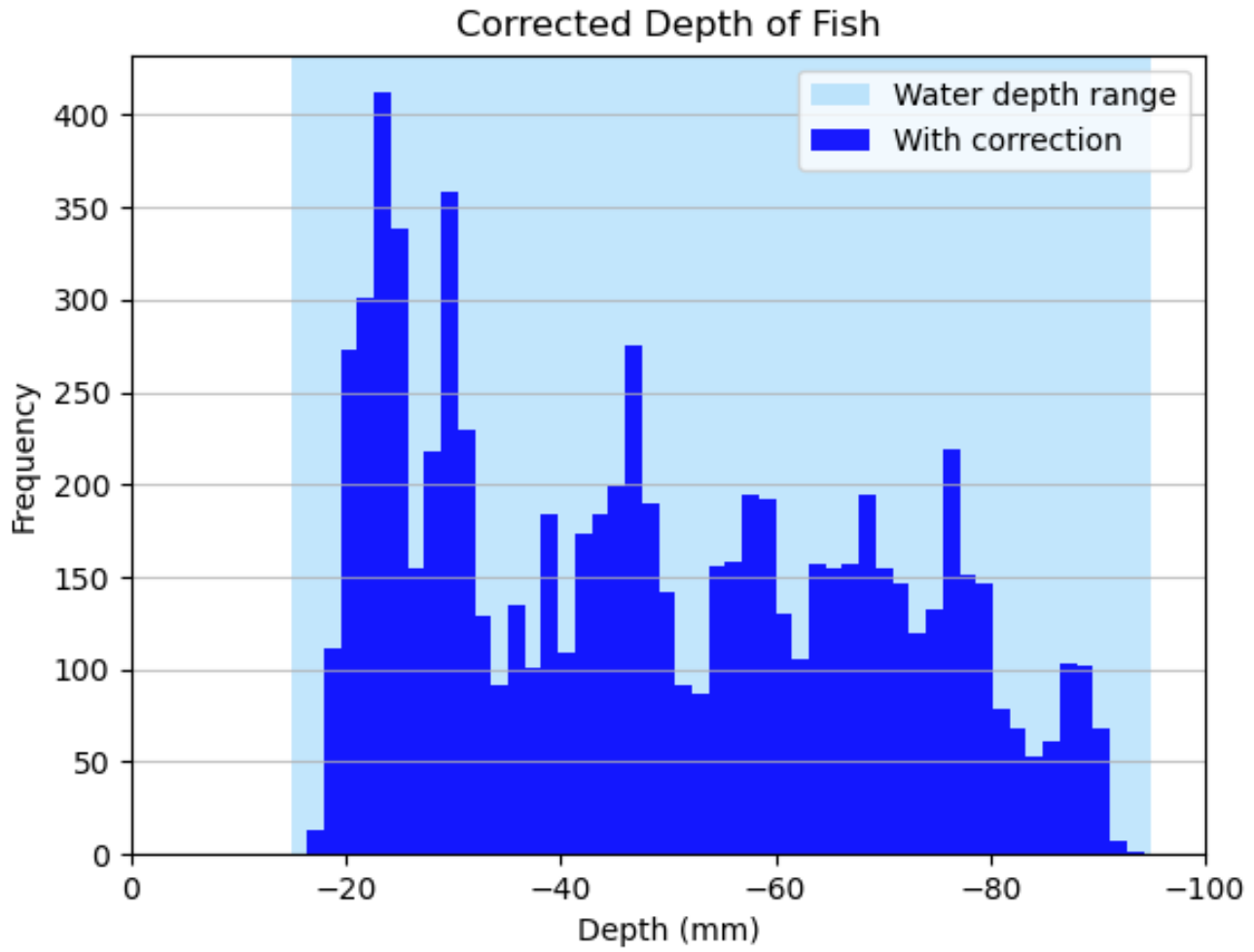
Normalize results to axes of enclosure

Triangulating current 3D position

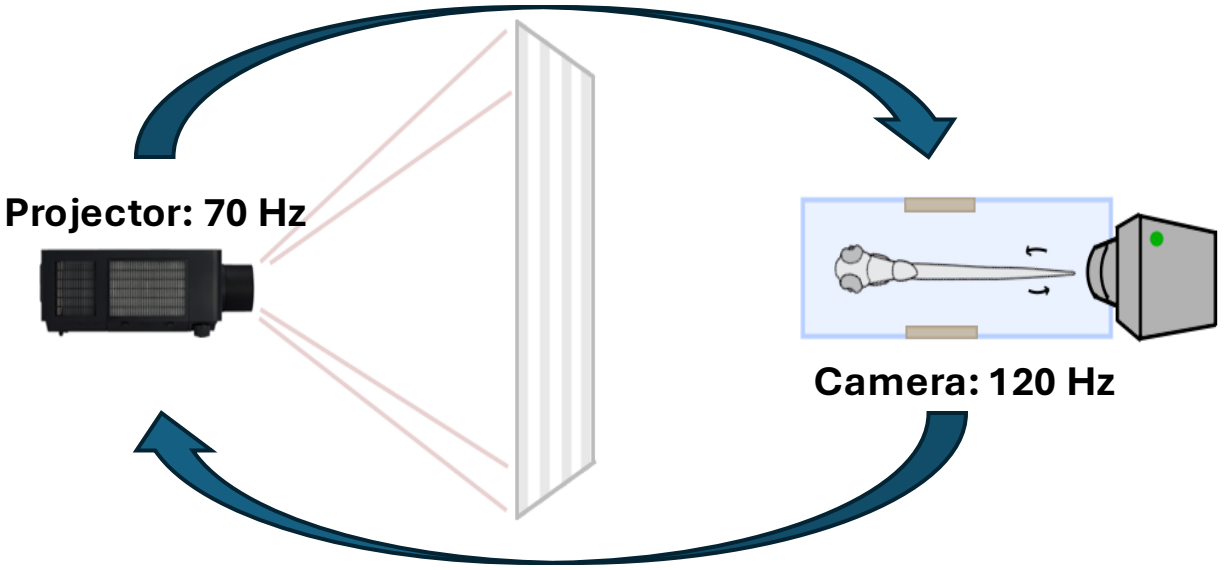




Triangulating current 3D position



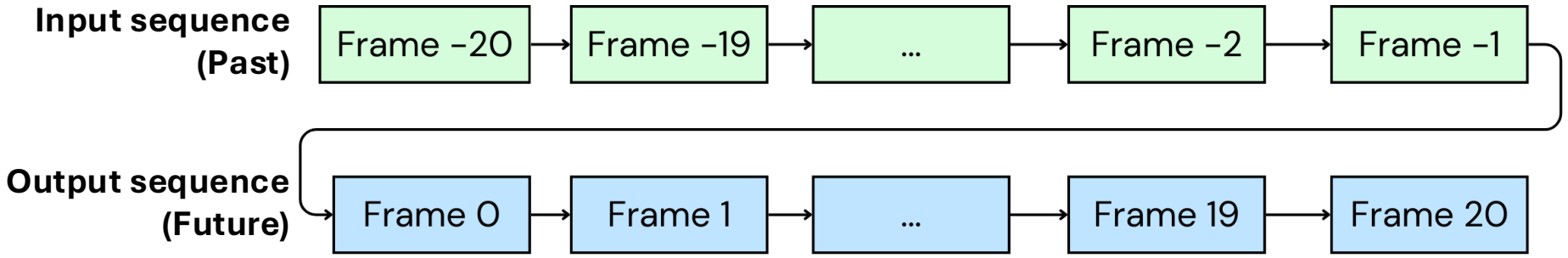
Predicting future 3D positions



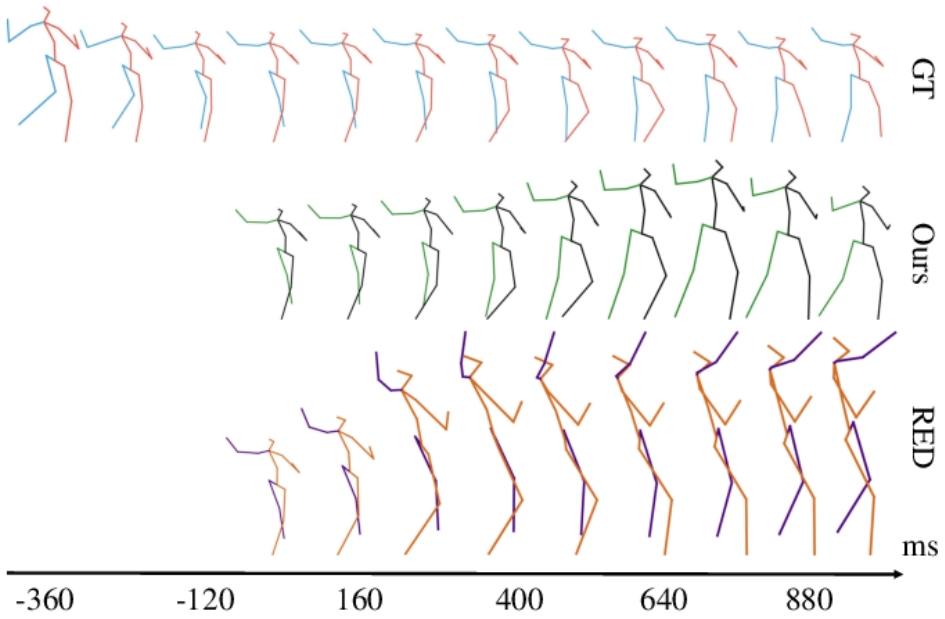
Speed	> 100 Hz
Accuracy	< 5 mm error
Latency	< 5 ms

Predicting future 3D positions

“One-shot” approach

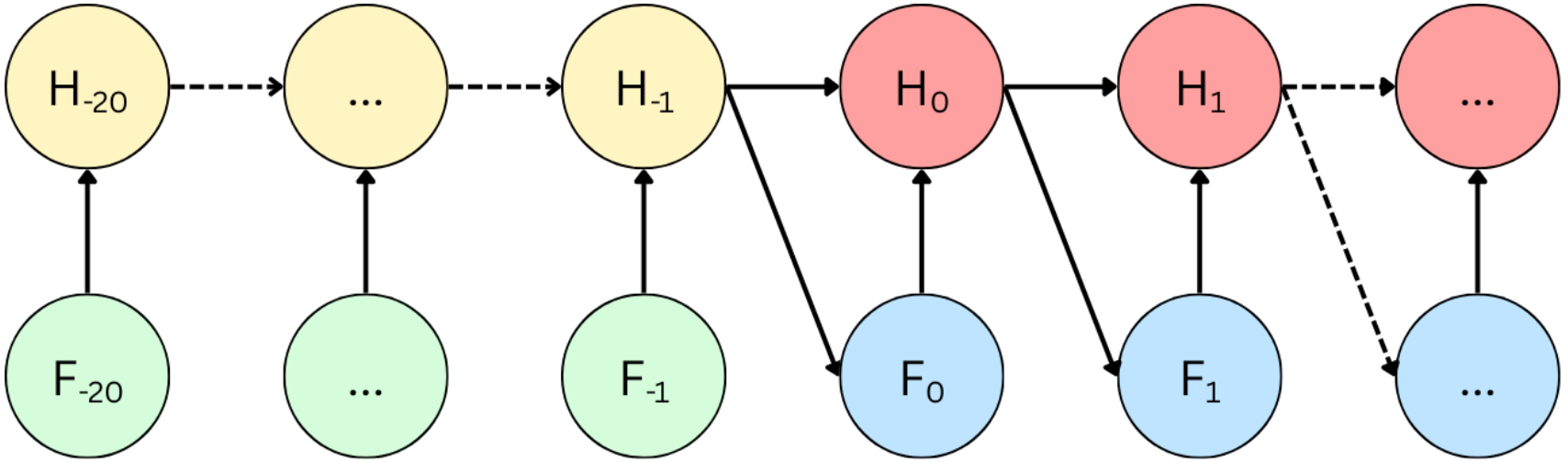


Human pose prediction



Marchellus & Park, 2022 [5]

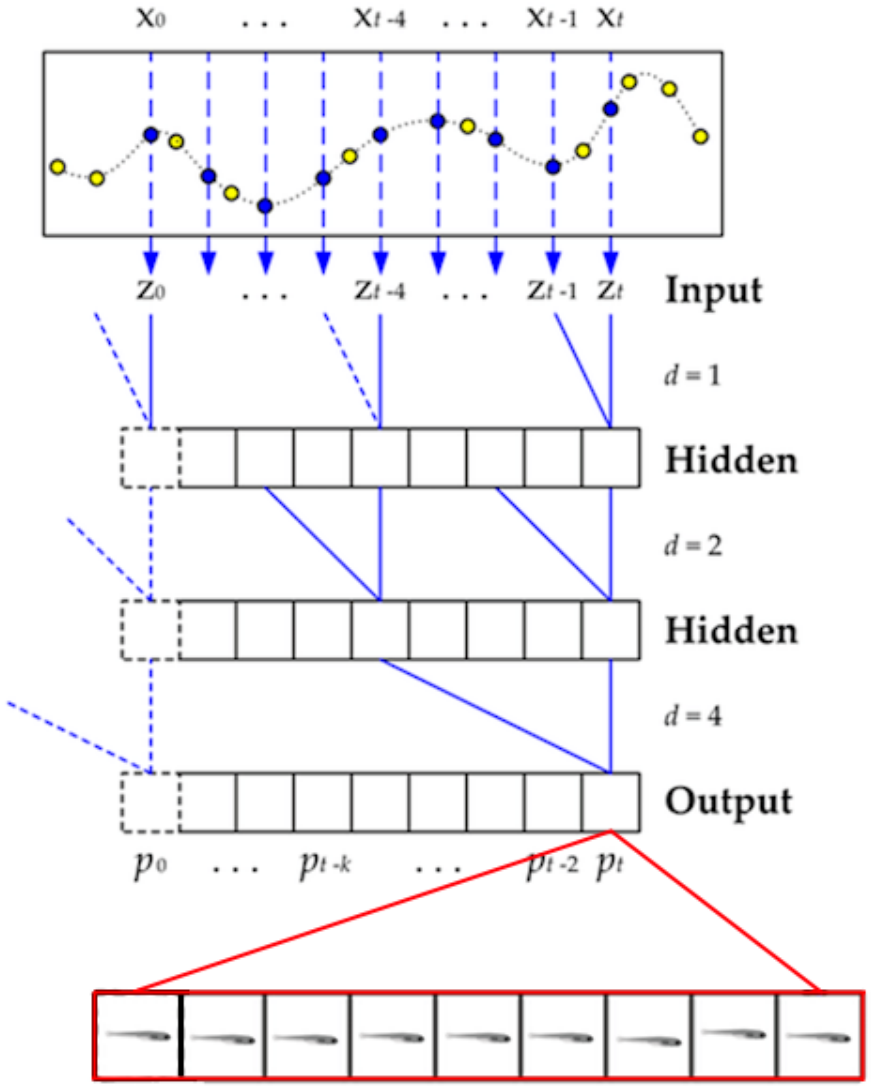
LSTMs (Long short-term memory)



- “Recurrent” – takes in one frame at a time
- Proven to work in past experiments with zebrafish

  (Yi et al., 2006)

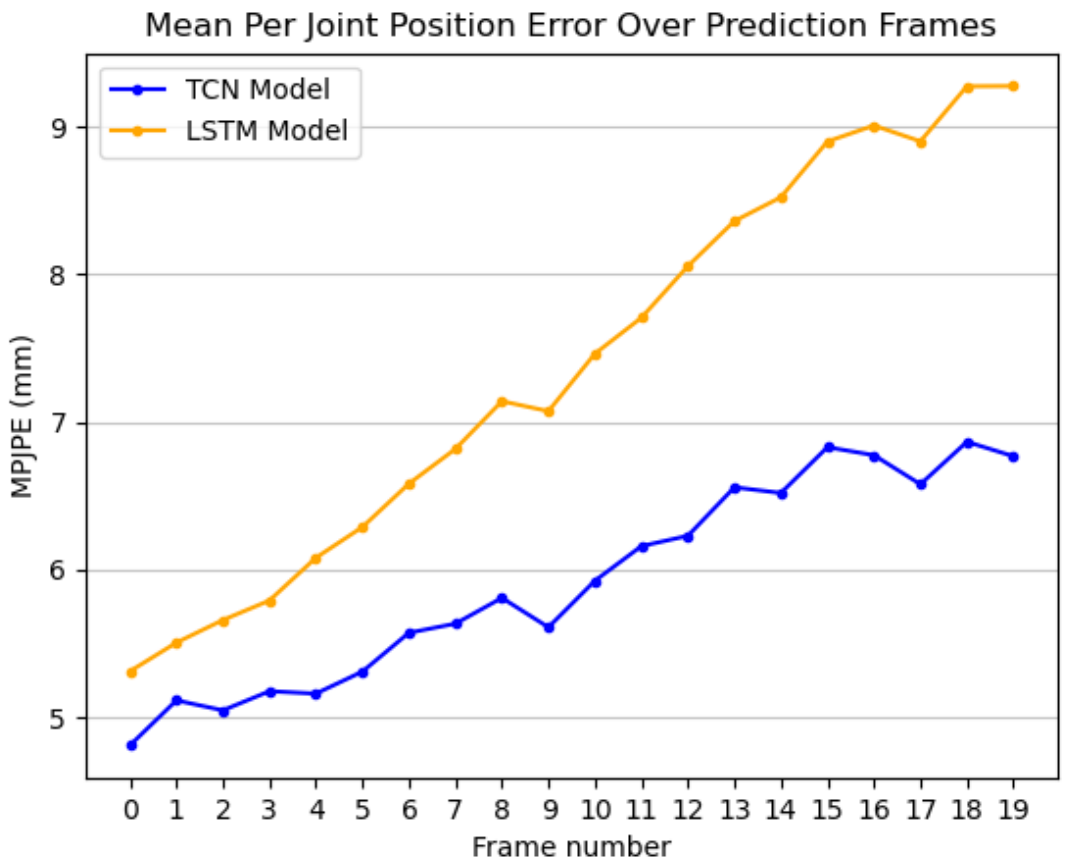
TCNs (Temporal Convolutional Networks)

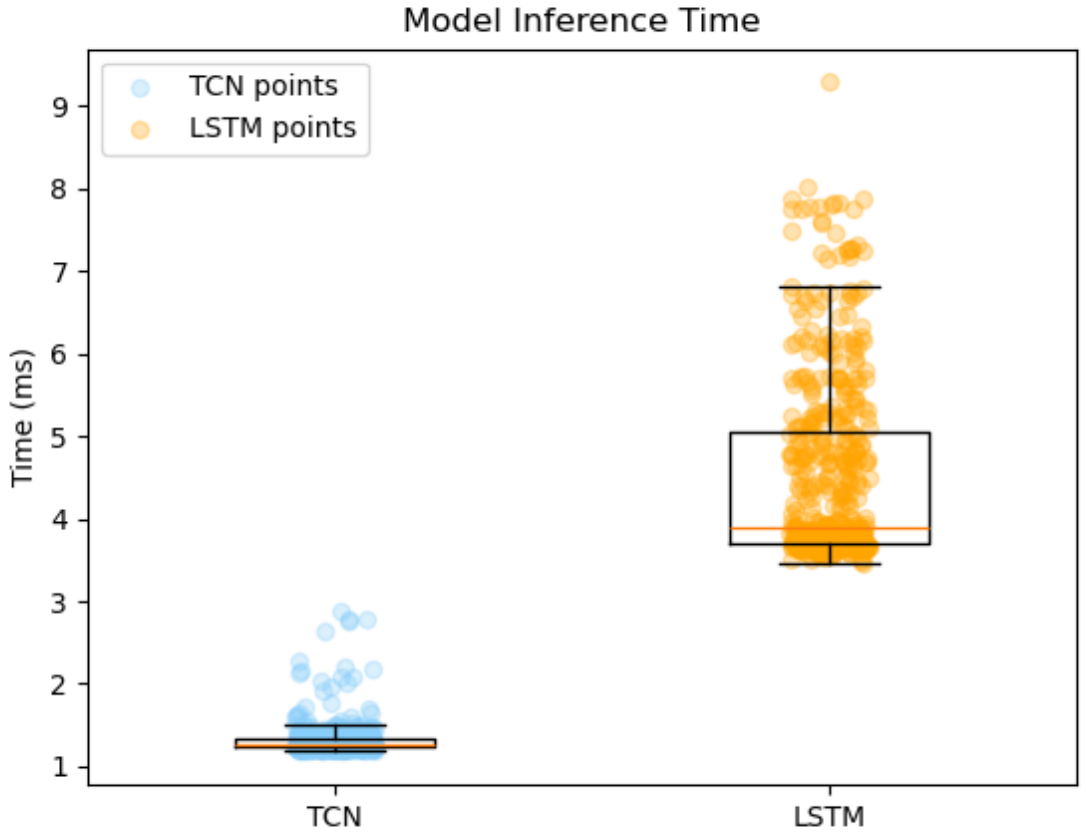


Moor et al., 2019

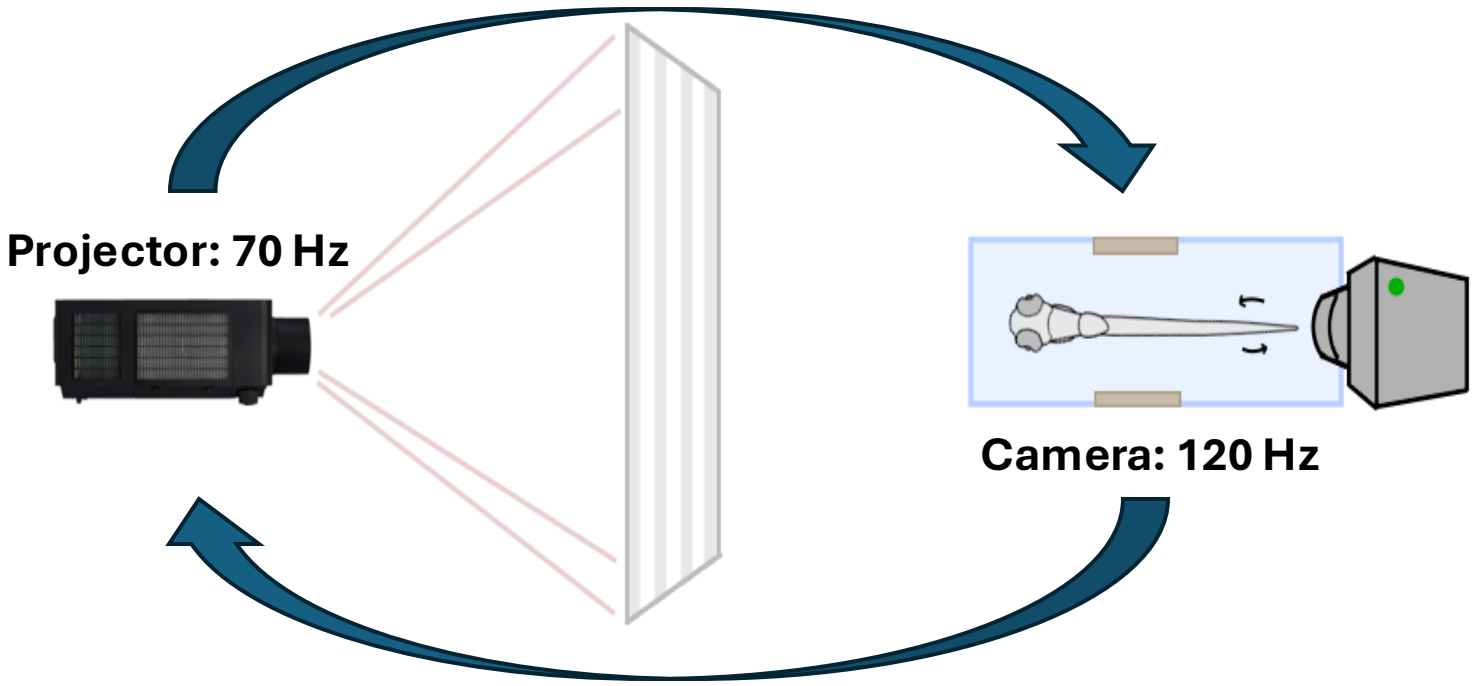
- "Parallel" – processes entire input sequence at once
- Not done before with fish

TCNs perform better in accuracy and latency





TCNs in a VR context

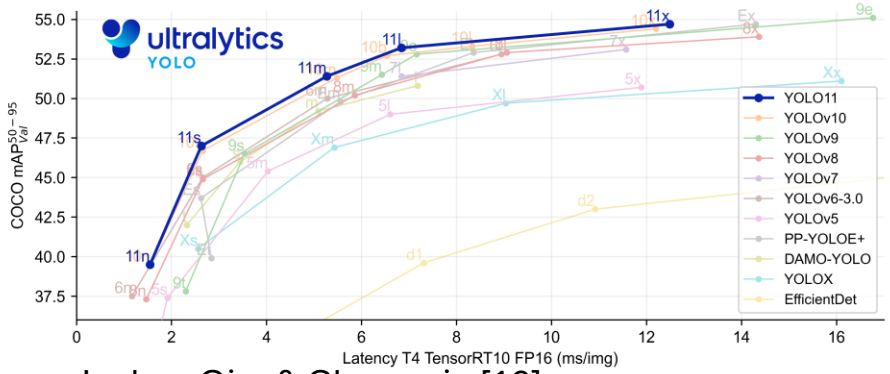


Speed: 120 Hz ✓

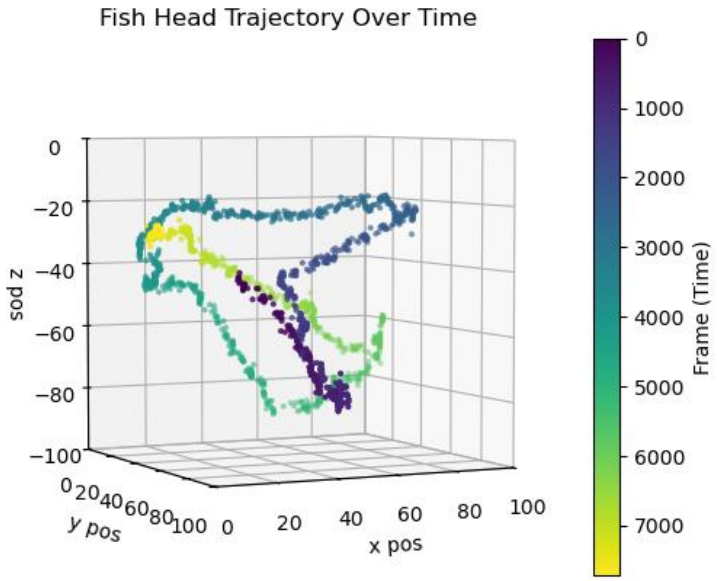
Accuracy: < 5 mm ✓

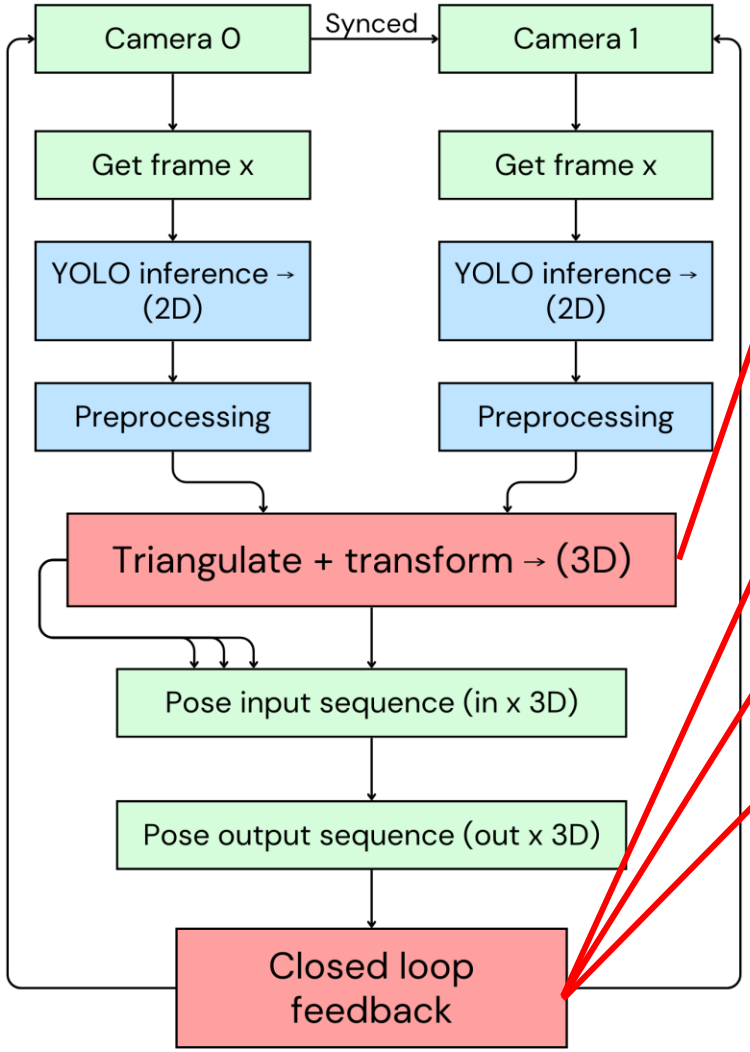
Latency: ~ 3 ms ✓

Future Work & Applications



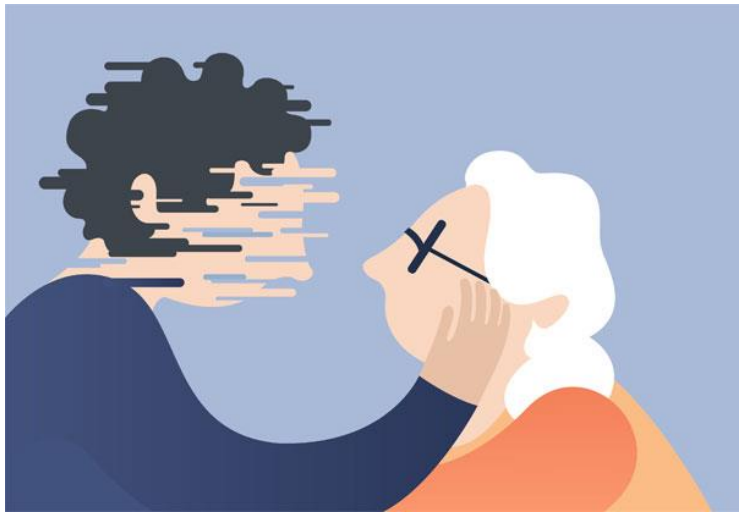
Jocher, Qiu, & Chaurasia [16]

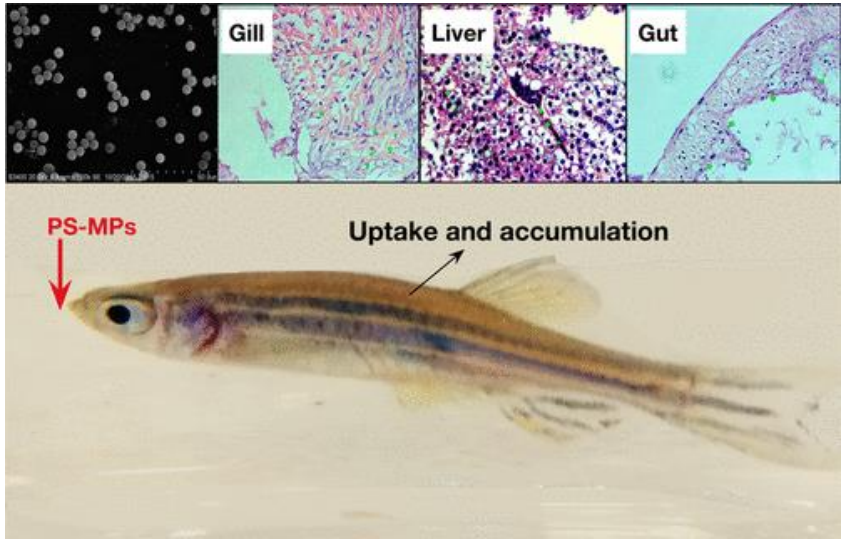




- Increase accuracy for free-swimming tasks
- Update VR visual feed
- Catching fish by predicting trajectory
- Multi-fish tracking

From predicting zebrafish to predicting human disease

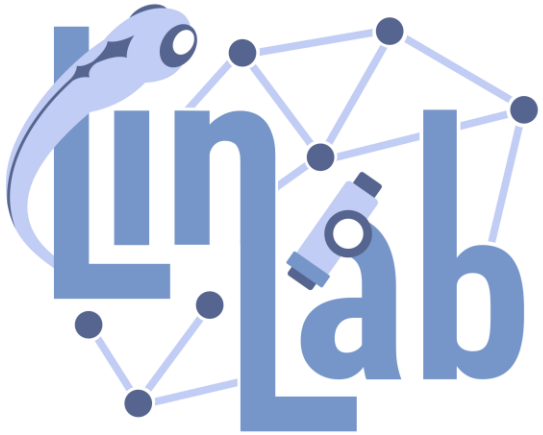




Lu et al., 2016 [15]

Thank you to everyone at Lin Lab!

- Prof. Lin
- Christine Tang
- Yapeng Zhuang
- Pauline Shen
- Habibe Ucpunar
- Frank Fu
- Yuqian Ma
- Cameron Parro
- And everyone!



Q&A

Bibliography

[1] A. V. Kalueff, A. M. Stewart, and R. Gerlai, “Zebrafish as an emerging model for studying complex brain disorders,” Trends in Pharmacological Sciences, vol. 35, no. 2, pp. 63–75, Feb. 2014, doi: https://doi.org/10.1016/j.tips.2013.12.002.
[2] T. Islam, M. Torigoe, Y. Tanimoto, and H. Okamoto, “Adult zebrafish can learn Morris water maze-like tasks in a two-dimensional virtual reality system,” Cell Reports Methods, vol. 4, no. 10, p. 100863, Oct. 2024, doi: https://doi.org/10.1016/j.crmeth.2024.100863.
[3] M. Pedersen, S. Bengtson, R. Gade, N. Madsen, and T. B. Moeslund, “Camera Calibration for Underwater 3D Reconstruction Based on Ray Tracing Using Snell’s Law,” CVF Conference on Computer Vision and Pattern Recognition Workshops, Dec. 2018, doi: https://doi.org/10.1109/cvprw.2018.00190.
[4] B. Cao, R. Deng, and S. Zhu, “Universal algorithm for water depth refraction correction in through-water stereo remote sensing,” International Journal of Applied Earth Observation and Geoinformation, vol. 91, p. 102108, Sep. 2020, doi: https://doi.org/10.1016/j.jag.2020.102108.
[5] M. Marchellus and I. K. Park, “Deep Learning for 3D Human Motion Prediction: State-of-the-Art and Future Trends,” IEEE Access, vol. 10, pp. 35919–35931, 2022, doi: https://doi.org/10.1109/access.2022.3163269.
[6] S. Macrì, D. Neri, T. Ruberto, V. Mwaffo, S. Butail, and M. Porfiri, “Three-dimensional scoring of zebrafish behavior unveils biological phenomena hidden by two-dimensional analyses,” Scientific Reports, vol. 7, no. 1, May 2017, doi: https://doi.org/10.1038/s41598-017-01990-z.
[7] A. Ravan, R. Feng, M. Gruebele, and Y. R. Chemla, “Rapid automated 3-D pose estimation of larval zebrafish using a physical model-trained neural network,” PLOS Computational Biology, vol. 19, no. 10, pp. e1011566–e1011566, Oct. 2023, doi: https://doi.org/10.1371/journal.pcbi.1011566.
[8] F. A. Cupaioli, F. A. Zucca, C. Caporale, K.-P. Lesch, L. Passamonti, and L. Zecca, “The neurobiology of human aggressive behavior: Neuroimaging, genetic, and neurochemical aspects,” Progress in Neuro-Psychopharmacology and Biological Psychiatry, vol. 106, p. 110059, Aug. 2020, doi: https://doi.org/10.1016/j.pnpbp.2020.110059.

Bibliography

[9] “Behavioral Neuroscience Minor - School of Social and Behavioral Sciences | Stockton University,” Stockton.edu, 2025. https://www.stockton.edu/social-behavioral-sciences/behavioral-neuroscience.html (accessed Aug. 20, 2025).
[10] R. E. Robinson and R. T. Borlinghaus, “Zebrafish Brain - Whole Organ Imaging at High Resolution,” Leica-microsystems.com, Apr. 08, 2019. https://www.leica-microsystems.com/science-lab/life-science/zebrafish-brain-whole-organ-imaging-at-high-resolution/ (accessed Aug. 20, 2025).
[11] R. Nakajima, H. Hagihara, and T. Miyakawa, “Similarities of developmental gene expression changes in the brain between human and experimental animals: rhesus monkey, mouse, Zebrafish, and Drosophila,” Molecular Brain, vol. 14, no. 1, Sep. 2021, doi: https://doi.org/10.1186/s13041-021-00840-4.
[12] M. Torigoe et al., “Zebrafish capable of generating future state prediction error show improved active avoidance behavior in virtual reality,” Nature Communications, vol. 12, no. 1, Sep. 2021, doi: https://doi.org/10.1038/s41467-021-26010-7.
[13]S. Wu, S. W. Decker, P. Chang, T. Camus, and Jayan Eledath, “Collision Sensing by Stereo Vision and Radar Sensor Fusion,” IEEE Transactions on Intelligent Transportation Systems, vol. 10, no. 4, pp. 606–614, Dec. 2009, doi: https://doi.org/10.1109/tits.2009.2032769.
[14] “Basler Stereo visard,” Baslerweb.com, 2025. https://www.baslerweb.com/en/cameras/basler-stereo-camera/stereo-visard/ (accessed Aug. 20, 2025).
[15] Y. Lu et al., “Uptake and Accumulation of Polystyrene Microplastics in Zebrafish (Danio rerio) and Toxic Effects in Liver,” Environmental Science & Technology, vol. 50, no. 7, pp. 4054–4060, Mar. 2016.
[16] Jocher, G., Qiu, J., & Chaurasia, A. Ultralytics YOLO (Version 8.0.0) [Computer software]. https://github.com/ultralytics/ultralytics (2023)