Exercise 1: Optical Flow

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I. Introduction

In this exercise, we implemented and compared two optical flow estimation methods: the Lucas-Kanade [1] method and the Horn-Schunck [2] method. We evaluated their performance on rotated random noise images and extended the analysis to additional image pairs. Furthermore, we explored the reliability of the Lucas-Kanade method by integrating a confidence measure based on the Harris response. We also analyzed the impact of key parameters on both methods, measured their execution times, and investigated possible optimizations, such as using Lucas-Kanade output to initialize Horn-Schunck for improved efficiency.

II. Experiments

We tested both the Lucas-Kanade and Horn-Schunck optical flow methods on rotated random noise images. For all tests, the images were grayscaled and Gaussian-smoothed with a $\sigma = 1.5$. The Gaussian derivative had $\sigma = 1$, the temporal derivative was the difference between the second and first image, and an $\epsilon = 0.1$ was used in Lucas-Kanade to avoid division by zero.

The optical flow field in Figures 1 and 2 (bottom-right) is small near the center and large at the edges of the image since pixels near the edges move much more than center pixels during rotation.

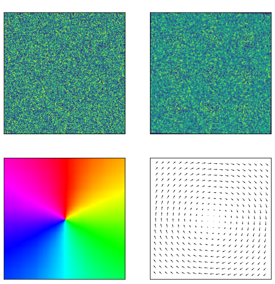

Figure 1. Optical flow results using the Lucas-Kanade method on a rotated random noise image (neighborhood size = 100).

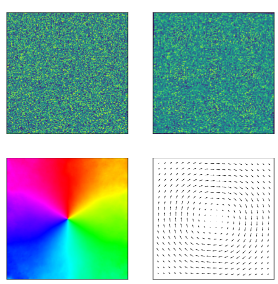

Figure 2. Optical flow results using the Horn-Schunck method on a rotated random noise image (1000 iterations, $\lambda = 20$).

Then, we applied them to different frames from TV shows and movies to analyze their performance.

Figures 3, 4, and 5 demonstrate that the Lucas-Kanade method (middle row) captures larger, more prominent movements but tends to miss finer details. In contrast, the Horn-Schunck method (bottom row) provides a more detailed and accurate estimation of motion—such as slight facial movements in Figure 3, the forward movement of the main actor in Figure 4, and the motion of the right bird toward the left bird in Figure 5. However, this increased sensitivity also results in more noise in the output.

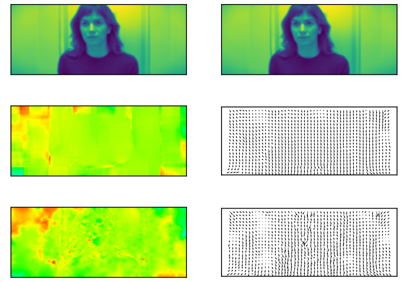

Figure 3. Optical flow results on two frames from *Severance* (2022). Parameters: Lucas-Kanade (neighborhood size = 50), Horn-Schunck (1000 iterations, $\lambda = 100$).

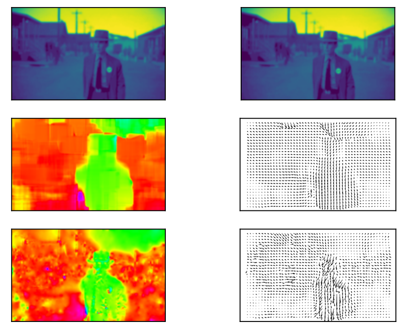

Figure 4. Optical flow results on two frames from *Oppenheimer* (2023). Parameters: Lucas-Kanade (neighborhood size = 50), Horn-Schunck (1000 iterations, $\lambda = 500$).

Lucas-Kanade flow cannot be reliably estimated in regions where the image gradient is weak or ambiguous—specifically, when the eigenvalues of the structure tensor are too small or have a large ratio, indicating poor feature localization. To address this, we introduced a simple improvement by incorporating the Harris corner response to filter out unreliable flow estimates.

Figure 6 shows that certain regions were masked out in the final flow output (right image), removing areas where reliable estimation was not possible. These include mostly background regions and parts of the actor that remained relatively still between frames.

We then investigated how key parameters influence optical flow estimation: the neighborhood size for Lucas-Kanade, and the number of iterations and the smoothness parameter λ for Horn-Schunck.

Figure 7 shows that increasing the neighborhood size in Lucas-Kanade reduces detail and noise, while emphasizing larger, more coherent motion. In Figure 8, increasing the number of iterations in Horn-Schunck leads to a more stable flow with reduced noise and smoother vectors. Finally, Figure 9 illustrates that increasing λ further smooths the flow field, suppressing fine details but enhancing overall coherence in the motion estimation.

Lastly, we measured and compared the execution times of the Lucas-Kanade method, the original Horn-Schunck method, and a sped-up Horn-Schunck variant that was initialized with the output of Lucas-Kanade, all running on an Apple M1 Pro chip.

Table I shows the time measurements. Lucas-Kanade is the fastest, as it computes flow locally and requires fewer

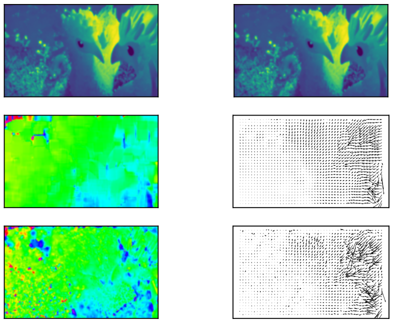

Figure 5. Optical flow results on two frames from *Flow* (2024). Parameters: Lucas-Kanade (neighborhood size = 30), Horn-Schunck (1000 iterations, $\lambda = 200$).

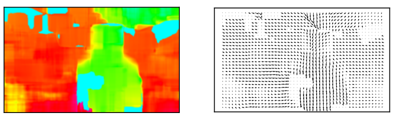

Figure 6. Optical flow results from the same two frames from *Oppenheimer*, where unreliable optical flow was masked out, with the same neighborhood size as before.

operations. In contrast, Horn-Schunck is slower due to its global iterative nature. The sped-up version is slightly faster than standard Horn-Schunck because it starts from an already reasonable flow estimate, reducing the number of effective updates needed. However, the speed gain is relatively minor; a more efficient acceleration technique, such as early stopping or multi-resolution pyramids, would be needed for a significant improvement. In Figure 10, we can see that this method builds on the Lucas-Kanade result and refines it, adding detail and smoothing while preserving the overall structure.

Table I
Time measurements for the same two frames from *Oppenheimer* using the parameters from Figure 4, including a third measurement for the sped-up Horn-Schunck method.

Lucas-Kanade [s]	Horn-Schunck [s]	Sped Up Horn-Schunck [s]
2.62	8.17	7.80

III. Conclusion

Both Lucas-Kanade and Horn-Schunck methods can produce reliable optical flow results when the motion is smooth and the image has enough texture. Lucas-Kanade works well for larger, clearer movements, while Horn-Schunck is better at capturing subtle details. However, both methods have limitations—like struggling with large displacements or low-texture areas—and there's always a trade-off between accuracy, noise, and speed.

References

[1] B. D. Lucas and T. Kanade, "An iterative image registration technique with an application to stereo vision," in *Proceedings of the 7th International Joint Conference on Artificial Intelligence - Volume 2*, ser. IJCAI'81. San Francisco, CA, USA: Morgan Kaufmann Publishers Inc., 1981, p. 674–679.

[2] B. K. Horn and B. G. Schunck, "Determining optical flow," *Artificial Intelligence*, vol. 17, no. 1, pp. 185–203, 1981. [Online]. Available: https://www.sciencedirect.com/science/article/pii/0004370281900242

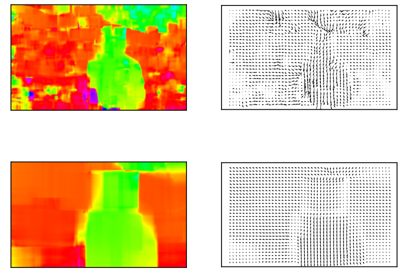

Figure 7. Optical flow results from the same two frames from *Oppenheimer*, comparing Lucas-Kanade flow with neighborhood sizes of 25 and 100.

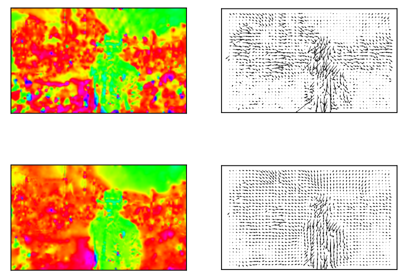

Figure 8. Optical flow results from the same two frames from *Oppenheimer*, showing Horn-Schunck flow with 100 and 1000 iterations ($\lambda = 200$).

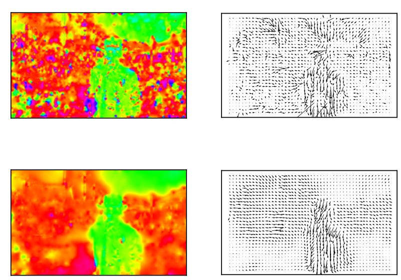

Figure 9. Optical flow results from the same two frames from *Oppenheimer*, showing Horn-Schunck flow with $\lambda = 10$ and $\lambda = 1000$ (1000 iterations for both).

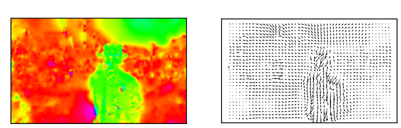

Figure 10. Optical flow results from the same two frames from *Oppenheimer*, using the sped-up Horn-Schunck method.