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Illustrative Particle Visualization of 4D MRI Blood-Flow Data

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Introduction

Cardiovascular morphology is significantly influenced by the unsteady behavior of flowing blood. Insight into the hemodynamics promises valuable diagnostic information for various cardiovascular diseases (CVD). At present, diagnosis and prognosis of CVD is primarily based on morphological information, possibly enriched by cine information. In the near future, blood-flow dynamics might become a vital source of information.
Blood-flow information can be measured non-invasively. For our work, we depend on 4D phase-contrast magnetic resonance imaging (PC-MRI) for the acquisition blood-flow velocity information. This technique provides quantitative 3D-cine velocity fields of the blood-flow for a full cardiac cycle (figure 1).

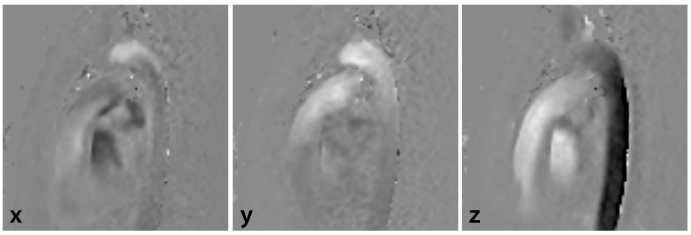

Figure 1: Slice of 4D PC-MRI flow data at one instant of the heartbeat.

Methods & Results

Building on previous work [1], we were inspired by illustrative techniques, typically found in cartoons [2]. In detail, we extend common sphere or integral line renderings. Our approach enhances perception of speed and direction within the blood-flow field (figure 2).

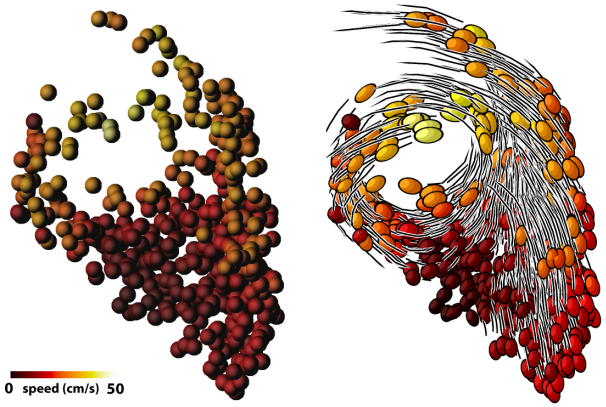

Figure 2: Comparison between imposter spheres and our illustrative particles, using imposter ellipsoids and speed lines with halos

First, spheres are deformed to ellipsoids, conveying speed and direction of the blood-flow velocity. This technique is applied in comics, and mimics the behavior of a ball in high-speed motion.
Second, the perception of direction is enhanced by means of speed lines, capturing the particle trajectory. We apply two lines per particle, similar to comics depicting motion. Whenever speed-lines are parallel, the particle fully resides within the flow field. Otherwise, the particle probably dwells near the vessel wall. The speed lines are reversed pathline-traces, rendered as tapered line strips with halos for additional depth perception [3].

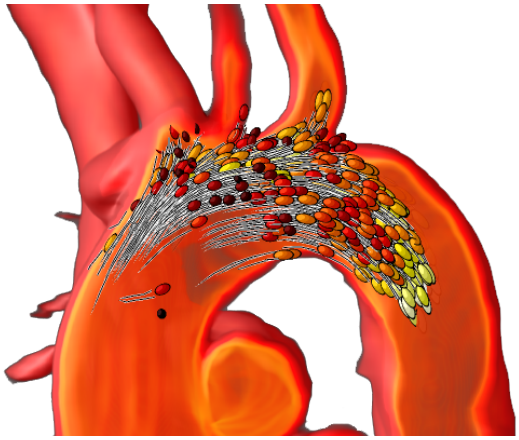

Figure 3: Illustrative particles with volume rendered context

Discussion

The combination of ellipsoids and speed lines captures local speed and direction of the blood-flow. Color coding of speed information is superfluous, saving color information to convey more elaborate flow characteristics, such as vorticity or particle residence time. Figure 3 depicts the illustrative particles in context of the anatomy. Our particle system is implemented using modern consumer graphics hardware. Integration of particles is performed on the graphics hardware using a Runge-Kutta 4 integration scheme.

References

[1] R.F.P. van Pelt, J.O. Bescos, M. Breeuwer, R.E. Clough, M.E. Gröller, B. ter Haar Romenij, and A. Vilanova. Exploration of 4D MRI blood-flow using stylistic visualization. *IEEE TVCG* **16(6)**, 1339–1347 (2010).
[2] A. Joshi and P. Rheingans. Illustration-inspired techniques for visualizing time-varying data. *IEEE Vis*, 679–686 (2005).
[3] M. H. Everts, H. Bekker, J. B. Roerdink, and T. Isenberg. Depth-dependent halos: Illustrative rendering of dense line data. *IEEE TVCG* **15(6)**, 1299–1306 (2009).