Dr. Per Christensen
Pixar Animation Studios
506 Second Avenue, Suite 1100
Seattle, WA 98104, USA

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Review of Martin Sik's Ph.D. thesis.

To Charles University, Faculty of Mathematics and Physics, Department of Software and Computer Science Education:

The Metropolis algorithm is a classic technique, widely used in physical simulation. The main obstacle that prevents the use of Metropolis in professional rendering is that the convergence is unsteady and unpredictable, and visual artifacts are inconsistent in animations (temporal instability). This thesis introduces new techniques to overcome these problems, thereby making the Metropolis algorithm more useful for professional rendering in computer visualizations, animation, and visual effects.

The thesis is nicely organized, well written and clear, and has very good figures illustrating the concepts described in the text. It is rather unusual to have an appendix for each thesis chapter, but it works fine to keep the very low-level details close to the chapter where they are relevant (rather than relegating them all to one large appendix at the end of the thesis).

Chapters 2, 3, and 4 summarize previous research and standard practice in general light transport, Metropolis algorithms (Markov chain Monte Carlo), and Metropolis light transport. These chapters provide a great background and introduce the chosen terminology and notation.

Chapters 5 and 6 contain original research done by Martin. Chapter 5 improves the global exploration part of Metropolis by utilizing three mutation strategies in novel ways: replica exchange moves, tempering of reflection lobes, and equi-energy sampling. The techniques are tested on both synthetic tests (50 Gaussians in the unit plane) and light transport tests (rendering scenes with difficult diffuse-specular-diffuse light paths). This chapter also addresses practical issues such as floating-point accuracy and theoretical issues such as proving correctness.

Chapter 6 presents a novel algorithm that combines the strengths of VCM/UPS (diffuse-specular-diffuse light paths) with Metropolis's ability to detect and explore difficult light paths due to blocking geometry (complex visibility). This combination is more suitable than regular Metropolis for progressive rendering (where initial noisy images are shown to a user and iteratively improved). At the same time, this combination is also simpler than many recent extensions of Metropolis light transport. This chapter is very detailed and thorough, providing pseudo-code for the algorithm, and discussing proper MIS weights, image intensity normalization, etc. – making it possible for a reader to implement their own version of this. The best techniques are presented in a straightforward manner, but it is clear that many other combinations have been tested and failed (as discussed in section 6.C). The main test scenes are a living room, a class room, and a kitchen, all with complex light paths and visibility.

The resulting recommendations for the best combinations of techniques are relevant for use in architectural visualization and the movie industry. Among the proposed future work, the suggestions that stood out most to me were even better mutation strategies and an extension to volumes (expanding the UPBP volume rendering research that Martin has also been involved in).

After having read this thesis, I firmly believe that Martin has proven his ability to do independent research and that he has obtained very impressive new results. The quality of the research – and also the written presentation of it – is outstanding. I highly recommend this thesis (and am sad that I unfortunately will not be able to participate in the defense in person).

Questions for the defense:

1. Floating point accuracy: In formula (5.4) the second equal sign is an "approximately equal". Is that to indicate that the expressions on either side are equal except for numerical accuracy? Or does the approximation also widen the reflection lobe as shown in figure 5.24(a)? There is a discussion of numerical instability in section 5.A.1, where using the logarithm of the terms is used to reduce floating-point inaccuracy. Is that useful for formula (5.4) as well?
2. Units on graph axes: What are the units on the graph in figure 6.1? I'm guessing 1–5 minutes on the horizontal axis, but what is the magnitude of the RMS error on the vertical axis?
3. Vertex merging radii: In section 6.4 it is mentioned that the vertex merging radii are not progressively reduced (as it is usually done), but that a fixed-size radius has been chosen that is small enough to avoid numerical and visible bias. Please provide more details on how that radius was chosen?

Yours sincerely,

Per Christensen, Ph.D.