Workshop on Material Appearance Modeling (2013)
H. Rushmeier and R. Klein (Editors)

Grand Challenges: Material Models in Automotive

R. Schregle†, C. Denk‡, P. Slusallek§, and M. Glencross†

Abstract

Material reflectance definitions are core to high fidelity visual simulation of objects within a compelling 3D scene. In the automotive industry these are used across the entire business process: from conceptualisation of a new product range, through to the final sale. However, current state-of-the-art of material representations leave much to be desired for fast and practical deployment in the industry. Even after decades of research and development, there are no interoperable standards for material models to facilitate exchange between applications. A large discrepancy also exists between the quality of material models used (and indeed the quality at which they can be displayed) across the spectrum of use-cases within the industry.

Focussing on the needs of the Automotive Industry, in this position paper, we summarise the main issues that limit the effective use of material models. Furthermore, we outline specific solutions we believe could be investigated in order to address this problem. This paper is the result of a review conducted in conjunction with several key players in the automotive field.

Categories and Subject Descriptors (according to ACM CCS):
I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Color, shading, shadowing, and texture
I.4.1 [Computer Graphics]: Digitization and Image Capture—Reflectance

1. Introduction - The Role of Virtual Materials in the Automotive Industry

The main purpose of the automotive industry is to develop, build and sell vehicles. In the context of luxury cars, this can be in some ways much like selling a dream. Consumers can be very passionate about buying exactly the right car. Consequently 3D graphics and renderings are used across the business process in a variety of different ways. The quality and type of rendering deployed depends on use cases.

There exists several scenarios in which visually plausible material representations are required. Each of these can have very different (and often divergent) needs depending on the purpose of the final visualisation. For example, is the visualisation for conceptual design discussions, is it for testing ideas, is it for detailed design decisions, is it to develop the look and feel for a new series of car, or is it to present to a consumer? We classify the broad range of typical scenarios into two core areas: *Visual design and development* and *E-commerce and marketing applications*.

In each of these areas, the workflow commonly involves deploying a broad range of modelling and rendering tools. Each targets somewhat different goals and requirements. The tools used are quite distinct and often a combination of commercial modelling software, artist's tools, rendering products, and even in-house or customised tools, but the exchange of data between these is very limited. Consequently, current workflows result in a significant degree of redundant modelling work, and existing model assets can rarely be reused. This is particularly true in the case of material models.

Therefore, today the majority of the material modelling performed in the automotive industry involves a great deal of manual effort. This can range from completely manual creation of models [Met] (where acquisition is not feasible), semi-automated acquisition and editing, to fully automated acquisition [DHT*00, MMS*05, MHW*12, BTF, PAB]. Even in the latter case, these models are normally acquired from small reference samples and often cannot be used directly. For example, complex patterns found on some of the fabrics result in tiling artifacts [WLKT09].

Technical issues aside, material appearance in renderings is critical to the perception of the corporate brand. Every manufacturer has an image to maintain, consequently each series of car needs to conform to this. Therefore 3D mod-

† Loughborough University, Department of Computer Science
‡ BMW Group Research and Technology
§ Deutsches Forschungszentrum für Künstliche Intelligenz

DOI: 10.2312/MAM.MAM2013.001-006

Criterion	Use Case		
	Visual design & development	E-commerce & marketing	
	Interactive / offline	Realtime rendering	Print/film production
Triangle count	50–150M	10–50M	50–150M
(of which visible)	10–30M	5–10M	10–30M
Material count	50–1000	> 500	> 500
(of which visible)	50–500	> 300	10–500
Texture size	1–5Gb	1–3Gb	1–5Gb
Visual quality	Realistic / plausible / physically correct	Photorealistic / brand specific / artistic	Photorealistic / brand specific / artistic
Framerate	7–25 fps / 2 min. for global illumination @HD	15–25 fps	Offline
Output resolution	Full HD / 4k / 5× 2×2k CAVE	Full HD, 4k	A3 print @300dpi (=4962×3542)
Display device	Projection, Powerwall	LED screen, Splitwall	Print / film
Rendering	Rasterisation, raytracing, global illumination	Rasterisation	Global illumination

Table 1: *Table 1: Summary of performance criteria for various use cases in the automotive production chain.*

els for a specific series contain a palette of configuration and customisation options unique to the brand image and ambiance of the car. Usually this is conveyed through a consistent material property, notably the range of colour options, combined with the range of internal finishings available.

The processes and goals of the main business areas in which renderings are heavily used, however, vary significantly: in the design and development stage, senior management decide on the theme and ambiance for the new car series concept, which in turn defines the type of configuration bundles and the targeted look that will be ultimately offered to the consumer. On the other hand, the goal of the E-commerce and marketing department is to convince the consumer to make a decision to buy a car, which involves its personalisation, through the choice of the look and the materials used (see figure 1).

Although at opposite ends of the production chain, the key decision makers are encouraged to make an emotive decision that could not be achieved using a purely physically accurate material representation alone. Some degree of artistic freedom is required to achieve the desired fresh look to lead to a decision. We summarise some of the key characteristics of the various use cases in Table 1. In the following section we examine the implications of these in each of the defined areas and the issues this raises.

2. Key Issues and Constraints

Many challenges are still involved in realistically simulating material appearance. In the context of the automotive production chain, these can be broadly classified into the tasks of *material acquisition*, *modelling*, and *rendering*.

2.1. Acquisition Constraints

Almost all virtual materials in the automotive industry originate in the physical realm and are thus representative of materials that can be implemented in reality. Obtaining a fundamental description of a material's properties is far from trivial, particularly when reflectance measurement is involved. Key difficulties lie in the morphology of the material (i.e. its inherent structure) together with the practical issue of how to handle the sample used for measurement.

Material Morphology

Not all materials can be captured with existing reflectance measurement setups [Len05, FH09, KE09] (e.g. procedural materials, wood, carpet pile, very glossy paints [RMS*08], layered materials, etc). Furthermore, some materials may be only available as an abstract description or theoretical model based on microstructure. Virtual materials not found in nature may also be required during the design and development stage as proposals. An accurate description of these could only be obtained computationally, e.g. through virtual goniometry.

Sample Handling

It may not always be practical to send a sample material for off-site measurement; in automotive applications this can be due to commercial sensitivity or short-term availability of the sample. In the latter case shipping the sample incurs unacceptable delays, and a high resolution scan can take several hours before the sample can be returned.

The sample geometry may also not be appropriate for acquisition; ideally, samples should be planar, but this is not always the case as many automobile parts are curved by design. Some acquisition devices have been developed for non-planar samples, but these are limited to spherical or cylindrical geometry [MWL*99,MPBM03,NDM05]. A more subtle aspect of handling the sample is its physical manipulation in preparation of acquisition. In some cases, such as when the sample is on loan from a subcontractor, cutting it down to size or otherwise damaging it to accommodate the sample holder is not an option.

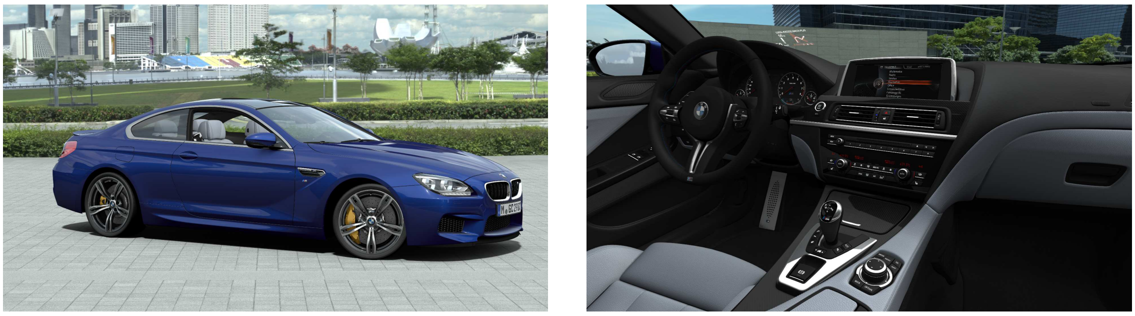

Figure 1: *Figure 1: Realtime visualisation of a personalised virtual car as presented to the prospective buyer.*

Lastly, some material representations may only be required as proposals for a preliminary design with a potential for rejection; in this case the cost/benefit factor may not warrant the overhead and expense (upwards of 2000€ depending on resolution) of a full acquisition.

2.2. Modelling Constraints

Once acquired, there are further challenges in terms of the form of the material model used and its application to geometry whose complexity varies with the use case. These modelling constraints limit the performance of the visualisation and the degree to which the material can be modified, as well as the time spent doing so.

Performance

Every use case in the production chain uses geometry of various detail levels; fine details are important for offline rendering (e.g. for high quality print), but less so for realtime rendering. Obviously there are different performance/memory tradeoffs involved depending on how the geometry is visualised, and its complexity is adapted accordingly.

It is less obvious that the same should apply for the material; fine detail (e.g. leather grain and stitches) should be readily apparent at close inspection, yet blend to a smooth appearance at greater viewing distance, at which point the material's detailed structure is computationally redundant (see figure 2.2). Current material representations do not scale to these performance requirements.

Material Editing

There has long been a lack of intuitive tools for modelling and editing materials [MG09]. This is primarily due to the broad range of available material models, but also the complexity and interaction of some of the parameters. Indeed, some parameters require an intimate understanding of the underlying representation and possibly even the material's micro/mesostructure on behalf of the user. Current material editing tools overwhelm the user and are not supportive towards achieving a desired look without considerable effort.

Furthermore, common attributes of edited materials (e.g. identical grain of differently coloured leathers) are not inherited from a base material; instead, the materials are duplicated, thus consuming extra memory.

Time Constraints

As in many industries, time constraints have to be considered when modelling a material; if the material is for a preliminary design study, the amount of allocated time will be considerably shorter than for an existing material nearing the end of the production chain and about to be exposed to the public through marketing. The complexity of the tools employed should scale to the available time to yield optimal results for each use case (e.g. with a set of predefined editing options).

2.3. Rendering Constraints

After acquisition and modelling, the final task of visualising the material introduces further challenges due to the multitude of available car configurations, types of displays, and shaders/tools used.

Wide Range of Configurations

While the design and development production stage routinely uses high performance hardware, the visualisation at the POS (point of sale) side of the chain is reduced to a lowest common denominator, implying use of more cost-effective hardware and limited internet connectivity at the dealership's expense.

The POS also has to contend with a very large number of available car models and material configurations, which are generated on-the-fly for visualisation. Given the comparatively low performance of the hardware, there is clearly a tradeoff between the desired quality and the customer's patience as he/she waits to assess the personalised car in as high a quality as possible.

Wide Range of Target Display Technologies

Each stage of the production chain employs different display technologies. These can range from high dynamic range OLED screens, CAVEs and 4K-projection systems primarily for design and development, to plasma screens, touchscreens

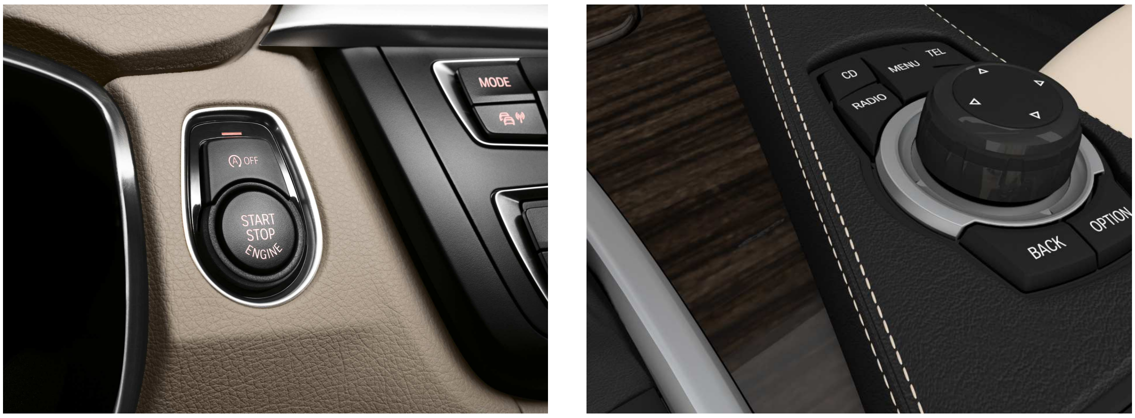

Figure 2: *Figure 2.2: Examples of leather and wood grain at close viewing.*

and tablet PCs mostly for marketing and sales. These displays are not necessarily routinely calibrated due to the high overhead involved.

This implies different target colour gamuts and dynamic ranges as well as calibration requirements [RKAJ08, YBMS05, ČWNA08]. It can therefore dramatically affect a material's appearance on the display and how it is perceived during the production chain, most importantly when design decisions are made.

Different Shader and Tool Versions

Shaders and tools used with material models evolve over time, and there is no guarantee that different versions will render a material identically. This problem is aggravated when juxtaposed with the production lifecycle of virtual car models; tools and shaders are typically updated annually, whereas the lifecycle of a virtual model can span anywhere between 1 to 10 years, precluding consistent visualisation over such a long timespan.

2.4. Issues

Having outlined the above constraints and discussed these with the automotive industry, we can hence formulate three major classes of issues which it would like to see addressed: *material editing*, *visualisation*, and *scalability*.

Editing with Artistic Enhancement

How can materials be represented that are more aesthetically pleasing in order to engender an emotive response from the prospective customer?

This would require a representation composed of a physical (e.g. measured or procedurally modelled) basis which can be artistically enhanced using intuitive tools, particularly in the marketing and sales end of the production chain. Many artists do not want to be burdened with the intricacies of material science to achieve a targeted look consistent with the car model's image (and the manufacturer's as a whole).

Multiple Visualisation Configurations

How can the multitude of software/hardware renderers and target displays used throughout the production chain guarantee a perceptually consistent appearance of a material?

It should be stressed that many decision supporting processes throughout the development chain rely on a material's appearance on a given display; any divergence in the material's perception along the chain can compromise the outcome of these processes.

Some attempts for unified shading languages have been undertaken [KRSH10], but maintaining consistency over several (mostly uncalibrated) display technologies remains a much harder problem.

Scalability to Available Resources

How can we optimise the material representation for the rendering resources available to each use case?

This would involve such adaptations as artifact free tiling for small textures (particularly for inhomogeneous materials such as wood and leather), and level of detail to only resolve fine material structure when necessary. While representations using multiresolution basis functions [WAT92, SS95] could introduce some coarse grained control for the latter, this representation precludes any intuitive editing beyond filtering and compression.

In the next section we propose how to address these issues in order to answer the above questions.

3. Future Directions

In the following we have collected a set of research topics, which we believe are important for the future and will satisfy the needs of the automotive industry for the abovementioned issues.

3.1. Level of Detail

Historically LOD has been used to adapt geometric detail to the available rendering resources. This can be applied to material representations based on perceptual metrics. The material model could be automatically adapted to the resources available for each use case without having to explicitly revise it. For example, micro/mesostructure can be disregarded beyond large viewing distances, but contributes greatly to visual realism at close range.

3.2. Layered Representation

Splitting material characteristics into layers which can be independently edited would greatly enhance a material model's usability and flexibility. At its most basic, the material colour or specularity may be adapted to the desired emotive response without affecting other model parameters. In general it is useful to adapt subsets of material properties to each use case.

For example, metallic car paint consists of an isotropic glossy lacquer covering anisotropic metal flakes with complex reflectance properties. These are distinct attributes with varying relevance depending on the use case; the metallic flakes play a much greater role in marketing and sales than in design and development as they contribute greatly to the flair exuded by the finished product, and an artist may even choose to exaggerate this effect.

3.3. Perceptually Consistent Behaviour

The salient characteristics of a material should be recognisable across the different tools, renderers and target displays used in the production chain. To this end, metrics for variance in material appearance on different renderers and target displays should be developed. If necessary, a postprocess could adapt the appearance to comply with these criteria.

3.4. Embedded Metadata

A built-in revision control system consisting of embedded metadata would be very helpful in tracking a material's modification history as it passes through the production chain. After deriving several variants for preliminary studies, it is often useful to revert to the original material for comparison.

This metadata could also contain additional, often brand-specific information, such as internal designation, categorisation (texture, colour, gloss, subsurface scattering), original manufacturer, acquisition details, current process stage, etc.

3.5. Intuitive Tools for Editing

The tools used to edit materials should exhibit predictable behaviour. Visual cues as reference would be very helpful to inform the user how to quickly achieve the desired material appearance taking into account the interaction of the various parameters. Depending on the use case and required emotive response, an indicator of physical plausibility would serve as a guide for introducing some degree of artistic liberty.

Variants of the same measured base material may be implemented as instances for reduced redundancy and memory footprint. Taking this a step further, a scene graph may be employed to hierarchically link materials to geometry. This would enable the user to instantly modify the material properties of aggregated geometry as a high-level operation.

4. Concluding Remarks

In this paper we have outlined the role of material representations in the automotive industry, and the open questions that need to be answered for the various use cases that are involved in the production of a car series. Most importantly, these include visually consistent and predictable behaviour for the various tools and renderers employed, intuitive and independent editing of layered material characteristics with version control to cater for variants and artistic enhancement, and scalable detail for adaptation to the performance requirements.

We hope that this short summary of the key issues encourages feedback and new ideas from the research community to address these issues and advance the state of the art in material representation. If helpful, researchers may be provided with sample scenes from the automotive industry, many of which by far exceed the complexity of freely available standard test scenes. The authors would be happy to address specific questions in more detail and organize the discussion in the community, when useful.

References

[BTF] BTFDBB: BTF Database Bonn and Measurement Lab. http://cg.cs.uni-bonn.de/en/projects/btfdbb/.

[ČWNA08] ČADÍK M., WIMMER M., NEUMANN L., ARTUSI A.: Evaluation of hdr tone mapping methods using essential perceptual attributes. *Computers & Graphics 32* (2008), 330–349. http://www.cgg.cvut.cz/members/cadikm/tmo/.

[DHT*00] DEBEVEC P., HAWKINS T., TCHOU C., DUIKER H.-P., SAROKIN W., SAGAR M.: Acquiring the reflectance field of a human face. In *SIGGRAPH* (2000).

[FH09] FILIP J., HAINDL M.: Bidirectional texture function modeling: A state of the art survey. *IEEE Transactions on Pattern Analysis and Machine Intelligence 31*, 11 (Nov. 2009), 1921–1940.

[KE09] KURT M., EDWARDS D.: A survey of brdf models for computer graphics. *SIGGRAPH Comput. Graph. 43*, 2 (May 2009), 4:1–4:7. http://doi.acm.org/10.1145/1629216.1629222.

[KRSH10] KARRENBERG R., RUBINSTEIN D., SLUSALLEK P., HACK S.: AnySL: Efficient and Portable Shading for Ray Tracing. In *Proceedings of the Conference on High Performance Graphics* (Aire-la-Ville, Switzerland, Switzerland, 2010), HPG '10, Eurographics Association, pp. 97–105. http://portal.acm.org/citation.cfm?id=1921479.1921495.

[Len05] LENSCH H.: Realistic materials in computer graphics, introduction, 2005. http://www.mpi-inf.mpg.de/resources/siggraph05-course-realistic-materials/download/SIG05C10-Introduction.pdf.

[Met] METASL: MetaSL Material Library. http://materials.nvidia-arc.com/.

[MG09] MENZELA N., GUTHE M.: g-brdfs: An intuitive and editable btf representation. *Computer Graphics Forum 28*, 8 (Dec. 2009), 2189–2200.

[MHW*12] MESETH J., HEMPEL S., WEIDLICH A., FYFFE G., MILLER C., CARROLL P., DEBEVEC P.: Improved linear-light-source material reflectance scanning. In *SIGGRAPH* (Aug. 2012). http://ict.usc.edu/pubs/Improved\%20Linear-Light-Source\%20Material\%20Reflectance\%20Scanning.pdf.

[MMS*05] MÜLLER G., MESETH J., SATTLER M., SARLETTE R., KLEIN R.: Acquisition, synthesis and rendering of bidirectional texture functions. *Computer Graphics Forum 24*, 1 (2005). http://cg.cs.uni-bonn.de/de/publikationen/paper-details/mueller-2005-cgf.

[MPBM03] MATUSIK W., PFISTER H., BRAND M., MCMILLAN L.: A data-driven reflectance model. In *SIGGRAPH* (2003).

[MWL*99] MARSCHNER S., WESTIN S., LAFORTUNE E., TORRANCE K., GREENBERG D.: Image-based brdf measurement including human skin. In *Eurographics Rendering Workshop* (1999).

[NDM05] NGAN A., DURAND F., MATUSIK W.: Experimental analysis of brdf models. In *Proceedings of the Eurographics Symposium on Rendering* (2005), Eurographics Association, pp. 117–226.

[PAB] pab Gonio-Photometer II. http://www.pab-opto.de/gonio-photometer/service/.

[RKAJ08] REINHARD E., KHAN E. A., AKYÜZ A. O., JOHNSON G. M.: *Color imaging: Fundamentals and Applications*. AK Peters Series. A K Peters Limited, 2008.

[RMS*08] RUMP M., MÜLLER G., SARLETTE R., KOCH D., KLEIN R.: Photo-realistic rendering of metallic car paint from image-based measurements. *Computer Graphics Forum 27*, 2 (Apr. 2008), 527–536.

[SS95] SCHRÖDER P., SWELDENS W.: Spherical wavelets: efficiently representing functions on the sphere. In *Proceedings of the 22nd annual conference on Computer graphics and interactive techniques* (New York, NY, USA, 1995), SIGGRAPH '95, ACM, pp. 161–172. http://doi.acm.org/10.1145/218380.218439.

[WAT92] WESTIN S. H., ARVO J. R., TORRANCE K. E.: Predicting reflectance functions from complex surfaces. In *Proceedings of the 19th annual conference on Computer graphics and interactive techniques* (New York, NY, USA, 1992), SIGGRAPH '92, ACM, pp. 255–264. http://doi.acm.org/10.1145/133994.134075.

[WLKT09] WEI L.-Y., LEFEBVRE S., KWATRA V., TURK G.: State of the art in example-based texture synthesis. In *Eurographics '09 State of the Art Reports* (2009).

[YBMS05] YOSHIDA A., BLANZ V., MYSZKOWSKI K., SEIDEL H.-P.: Perceptual evaluation of tone mapping operators with real-world scenes. In *SPIE 5666* (2005), vol. Human Vision and Electronic Imaging X. http://dx.doi.org/10.1117/12.587782.