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Dynamics by Hybrid Combination of Photorealistic and Non-Photorealistic Rendering Styles

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Abstract

In order to extend the set of classic presentation variables, we present the use of hybrid rendering styles combining photorealistic (PR) and non-photorealistic (NPR) techniques. Hybrid images cannot simply be generated by combining classic PR rendering with the addition of NPR line styles. Instead, different combinations of photorealism and non-photorealism are applied to different parts of the scene simultaneously. Dynamic presentations are created by a smooth blending between the different styles used. Two blending approaches are presented: use of the α-channel and modification of objects' emissive color. Any parameterization of these blending techniques are supported by an analysis of perceptional constraints leading to the definition of a dynamics stimulus window. Possible application scenarios are presented for a technical as well as a medical model.

1. Introduction

The history of computer graphics is marked by the aim to create photorealistic renditions. Thereby, the main research goal is to get as close to a photograph or a video as possible. Photorealism in this context generally makes use of the Phong illumination model and either Gauroud or Phong shading with possible additions or enhancements.[1]

The use of photorealism has the advantage of an representation of rendered objects that appears to be true to the original. However, for a visualization goal of presenting some—possibly complex—context information, the availability of a variety of detail information does not necessarily increase the communication bandwidth. In order to focus on objects of interest in a scene, these can be aggregated and simplified visually. This directly leads to non-photorealistic representations. To be precise, the set of non-photorealistic images includes all renditions that are not photorealistically illuminated.

This way, non-photorealism extends the set of classic presentation variables as presented by Noik [Noi94]. So far, these included shape, position, and materials. In order to extend this set even further, some work was done to evaluate the potential of motion as an presentation dimension of its own [Bar97, Bar01, JS01]. We pick up the work presented by Jesse and Isenberg combining more than one rendering style in the same image and even enhance traditionally produced photorealistic images with non-photorealistic styles [JI03]. Using this idea of hybrid rendering styles, we extend the approach of employing motion as expression dimension and denote the *changes* of simultaneously used rendering styles as *dynamics*.

As an example for a line-based NPR technique, we employ a stylized silhouette rendering. This implies that the line stylization and rendering happens after the model has been rendered because a correct z-buffer is necessary for the hidden line removal of the silhouette. In addition, the described techniques are implemented using Open Inventor, a scene graph-based rendering toolkit. The scene graph architecture also has implications on the blending techniques.

The remaining parts of this paper are organized as follows: Section 2 presents related work on non-photorealistic rendering and their combination with classical rendering styles. The perception of dynamics and concluding temporal limitations of dynamic

1 In this paper, we consider local illumination models only. Some argue that real photorealism can only be achieved by using global illumination models such as raytracing and radiosity.

presentations are subject of Section 3. For this purpose, the definition of a *dynamics stimulus window* is introduced. Two alternative techniques for dynamic transitions from photorealism to non-photorealism are introduced and discussed in Section 4. A presentation of the scene graph oriented implementation follows in Section 5. In order to outline practical applicability of the presented ideas, Section 6 covers two application scenarios. Finally, the paper is summarized and ongoing research tasks are discussed.

2. Related Work

In recent years, non-photorealistic rendering (NPR) has received a great deal of attention. Two books have been published which give a comprehensive overview about the subject [GG01, SS02]. However, the group of non-photorealistic rendering styles are typically considered to be separated from photorealistic styles. Only little attempt has been made to combine the two into individual renditions in a systematic way.

Saito and Takahashi were the first to add non-photorealistic elements such as silhouettes to photorealistically shaded objects in order to create more expressive renditions [ST90]. Gooch et al. combine an adapted photorealistic shading with non-photorealistic elements such as silhouettes to create a non-photorealistic lighting model [GGSC98]. Their main application domain is the automatic technical illustration. In [GSG+99], Gooch et al. explore techniques to speed up the computation of the lighting model in order to allow for interactive technical illustration. Although both create a somewhat hybrid style, they apply it coherently to the whole scene. I. e., the rendering itself only uses this one style. It is, thus, not hybrid in the sense of this work.

In contrast, Masuch and Strothotte combine different styles in one image [MS01]. They use a photorealistic rendering or photographic image as a background and add a non-photorealistically rendered object as foreground in order to visualize the uncertainty and the degree of trust in the reconstruction of ancient architecture. When using a photo, naturally they only produce still images (see also Strothotte et al. [SPM+99]). However, when including the NPR renditions into the photorealistic background, they are able to create real-time animations. On the other hand, they are not able to make a continuous transition from the photorealistic style to non-photorealism or vice versa.

Ritter et al. use additional silhouettes for semi-transparent objects in interactive medical illustrations to increase the user's ability to recognize these objects [RSHS03].

Halper et al. present an interface for easy combination of various different rendering styles [HSS02]. Being conceived as a tool for designers to assemble and experiment with renditions it makes it easy to come up with new combinations of styles including the possibility to create hybrid renditions.

A different kind of hybrid animation is used in movies such as "Who Framed Roger Rabbit" (1988) or "Space Jam" (1996). In this type of movies, real footage is combined with hand-drawn cartoon characters. Johnston improves the appearance of the cartoon characters by creating toon renditions using the light positions from the real scene [Joh02]. When combining it with real video footage, the more coherent $2\frac{1}{2}$D look of the character with correct highlights is achieved by estimating normals from the hand-drawn silhouette using a set of heuristics.

Jesse and Isenberg describe a hybrid rendering system which combines non-photorealistic styles with regular photorealistic shading techniques [JI03]. In order to provide for a maximum of rendering and application flexibility, the use of each rendering style is controlled either interactively or by a script based scene description. The overall script structure as well as a specific application example is presented by Jesse in [Jes03].

3. Dynamics Stimulus Window

Dynamics span a broad range of presentation techniques: from simple color blinking to sophisticated motion patterns. Changes in rendering styles of hybrid presentations—as subject of this work—are considered to be dynamic as well. Without putting them into any specific order with regard to each other, all the individual techniques are therefore respective subsets of dynamics. As motion is part of this collection, dynamic presentations in general promise to share at least some of its expressive power. However, in order to avoid cognitive overload, dynamics require some temporal constraints.

In order to assure the perception of different stimuli as a unit, they are to be presented to the user within a "stimulus window" of $20 - 40\,ms$. Thus, events are *not* perceived to happen separately and consecutively unless they are separated by at least this interval. This minimum event separation time span is also referred to as *inter-stimulus-interval* [HS61, Pöp97, vSWP96]. Further support for this specification of an interval separating perceived events is provided by an evaluation by Kanabus et al. [KSRP02]: The minimal temporal interval enclosing the perception of a correct distinction of two acoustic or visual events exceeds $40\,ms$. This number is based on a 75% quota[1] of correct answers of all test persons. This directly leads to the conclusion that a frame rate of not necessarily more than $25\,fps$ suffices to produce an impression of smooth dynamics, such as changes in rendering style.

The maximum possible time frame allowing the perception of an event as being unique and separated from others varies between two and three seconds [Pöp94]. Pöppel [Pöp97, p. 58] references a set of studies supporting this [Elb91, Pöp71, Pöp78]. In case a visual event exceeds this limit, it is likely not to be perceived as an individual unit by the user. Whereas some visual perception parameters (such as color) depend on cultural influences, the temporal limits for event perception do not [GF95, SEEP87]. Furthermore, the aforementioned time spans are pre-semantic, that is, independent of the concrete task at hand [Pöp97, p. 59]. Therefore, the transition between two distinct rendering styles is best presented in a time frame ranging from $40\,ms$ to three seconds. In the following, we refer to this time span as the *dynamics stimulus window*.

1 A quota of 75% is deemed as the boundary between the denomination of *correct* and *approximative* results in such user studies [TMMJ98].

4. Transition Between PR and NPR

NPR techniques can roughly be divided into surface shading techniques and line-oriented methods. In addition, combinations of both are possible. Usually, both variants of NPR techniques can be used individually, e. g., a cartoon shading can be used as well as just displaying the visible silhouettes of a model. However, when combining NPR techniques with photorealistically rendered models this does not necessarily hold anymore. For example, using a photorealistically shaded model and only displaying one object of the model using silhouettes can be very confusing since the rest of the model is visible through the silhouette lines (see Figure 4.1). Thus, in cases where line-based NPR techniques are used, it is usually advisable to combine these techniques with some kind of surface shading, either photorealistic or non-photorealistic (see Figure 4.2).

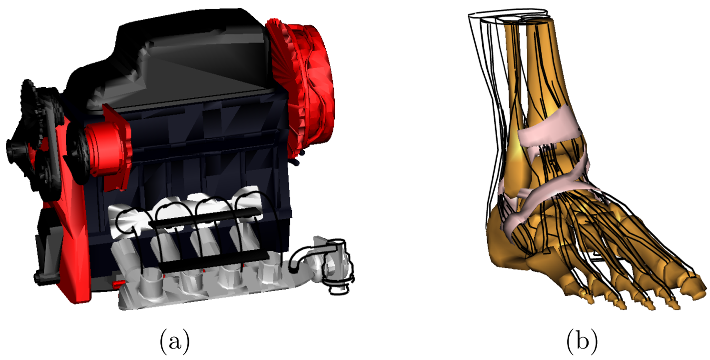
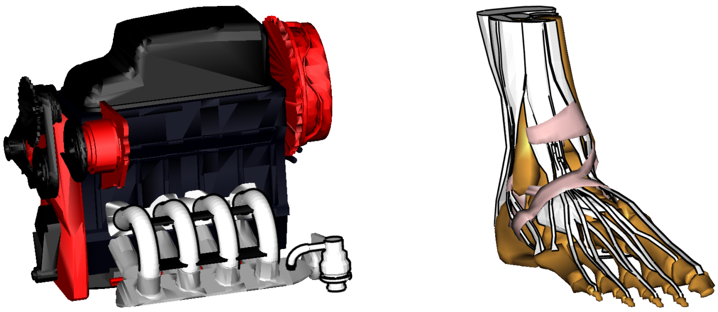


Figure 4.1.: When the shading of an object is exchanged with a line-based NPR technique, the photorealistically rendered remainder of the model is seen in the background, which is very distracting for many applications.

For a smooth transition between the regular photorealistic shading of an object's surface to non-photorealistic shading, one style has to be continuously de-emphasized while the other style is successively emphasized. Typically, this type of transition is achieved by using α-blending. This method will be discussed in Section 4.1. An alternative way to create the background shading for line-based NPR styles as mentioned above will be introduced in Section 4.2.



(a) (b)

Figure 4.2.: Using a shading to enhance the appearance of the line-based NPR style. In contrast to Figure 4.1, hidden surfaces do not shine through the non-photorealistically rendered parts of the models.

4.1. α-Blending

An intuitive implementation of a transition between different rendering styles produces renditions of both styles and uses the α-channel for blending. That is, transparency is used in order to allow for the perception of different object representations and their respective rendering styles. Besides the use of classical illumination models for photorealistic rendering, this allows for a transition to various NPR-shadings of a model, such as gray-scale or Gooch shading [GGSC98].

(a) Normal. (b) Sorted.

Figure 4.3.: Problems with sorting when using α-blending.

Different kinds of blending can be used with regard to the order of rendering for all objects. When using a *normal* blending order, all objects are rendered as they are represented in the geometric model. An alternative is *delayed* blending which cares about opaque objects first and renders transparent objects afterwards. By using *sorted* blending, all opaque and transparent objects are rendered in an order depending on their respective distance from the camera's position.

This is illustrated by Figure 4.3. Normal blending is used in 4.3(a). Clearly visible is a partial occlusion of the cube by the sphere, caused by an unfortunate ordering of both objects in the geometric scene description. On the contrary, the correct ordering of the sphere with regard to the cylinder causes the latter to stay completely visible throughout the transparent sphere. Figure 4.3(b) shows the same scene as rendered

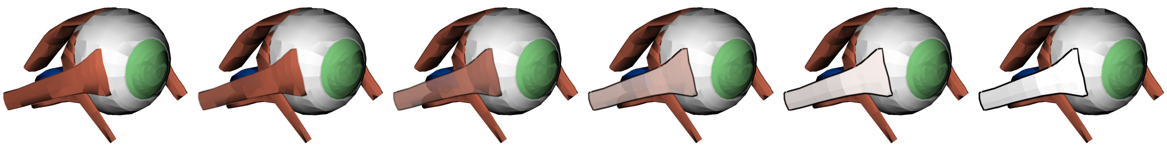


Figure 4.4.: Snapshots from an animation created by blending from a realistic rendition to a non-realistic rendition regarding a part of the model. For this purpose, α-blending is used. Note the *see through effect* in the third and forth image causing faces hidden by the blended object to shine through for some period of time during the animation.

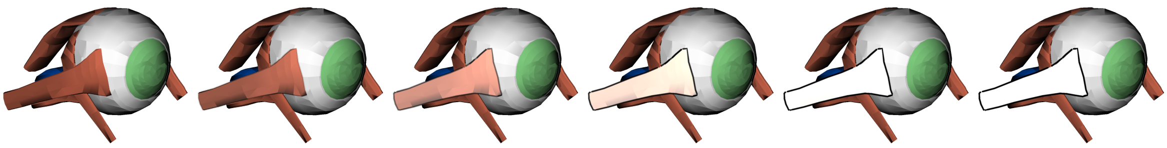


Figure 4.5.: Snapshots from an animation created by changing the emissive color RGB values of a nerve continually from 0.0 to 1.0. Note that no shading artifacts are visible for this specific nerve and that the *see through effect* from Figure 4.4 is avoided.

with sorted blending. That is, all objects are handled according to their distance from the camera. As a result, the sphere appears transparent to both remaining objects.

This directly leads to the *seeing through problem* in α-blending: As one object is rendered in two different styles, these styles visually interact with each other by being visible through their respective transparent counterpart. This effect is well visible in the third and forth image of Figure 4.4 which shows a series of snapshots from an animation created by blending an eye's nerve continuously from a realistic rendering style to silhouette line style by steady adjustments to the α-channel. A naïve approach to avoid the (unwanted) see through effect is to render the NPR shading non-transparently first, followed by an opaque rendering of the realistic shading style. The latter is then continuously made more transparent until it is completely blended out. This guarantees a smooth transition from a realistic rendering style to a non-realistic style that fits nicely into the temporal presentation window as given by the inter-stimulus-interval and the maximum stimulus interval of a single event as presented earlier.

However, this approach is challenged by the problem that the size of non-photorealistically rendered objects usually extends the size of its respective realistic counterparts slightly.[1] This especially holds for the case of silhouette lines shaped as waves, but is valid for other line shapes as well. As an alternative, the stencil buffer might be used in order to render the face content in an opaque manner early on and blend in the face border. As of now, we just accept the see through problem as a rendering artifact.

Another challenge when dealing with the simultaneous rendering of two different styles for the same object is in possible flickering caused by "triangle fights". As triangles in both styles are located at approximately the same depth with regard to the camera

1 Think of stylistic silhouette renditions, for example.

viewpoint, they appear to flicker because of limited z-buffer resolution. At some angles, one of of two respective triangles appears to be closer to the viewer, at other angles the other triangle does. In order to avoid this visually unpleasing effect, the triangles need to be layered accordingly. This is achieved by using OpenGL's polygon offset for defining how to offset specific triangles with respect to others.

4.2. Emissive Color Method

An alternative to modifying the α-channel of a material is in adjusting the emissive color of objects in a scene. In order to blend from one style to another, the RGB values of the color are continuously changed from 0.0 to 1.0. A vector of $(0.0, 0.0, 0.0)$ does not influence the color representation of an object's material at all. A color triple of 1.0 values results in the object being rendered completely white. By incrementally selecting appropriate steps in between, blending from a realistic rendering style to a non-realistic style can be achieved. Similarly to α-blending, the remaining part of the scene is not influenced, as all modifications are local and no light source is touched. Figure 4.5 shows a series of snapshots taken from an animation created by increasing the RGB values of an eye's nerve from 0.0 to 1.0.

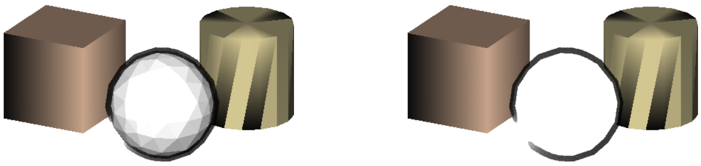
In order to achieve the effect of white lines on black background, the RGB values are reduced to the range $(-1.0, -1.0, -1.0)$. This way an effect of the illumination model is used that is not possible in physics. The objects "suck in" the light from regular shading. To get an even better appearance, the background of the rendition can be changed to black as well.

Depending on the choice of colors to be used as RGB values, two visual metaphors can be created: the effect of sketching with a pencil on a white sheet of paper or the effect of using chalk on a blackboard. Only black and white pen colors are to be used in case a rendition without any shading artifacts is to be achieved. Using alternative colors not only results in shading still being represented but in the visual metaphors being less perceivable.

An effect of modifying the emissive color of an object in order to blend from one style to another is in completely covering the affected faces. This holds especially for large RGB values $(1.0 - \epsilon)$. On one hand, this explains why shading artifacts are avoided. Furthermore, only a single shading technique is used and no transition between two shadings and transparency made necessary. On the other hand, this prevents other NPR shading techniques—such as Gooch shading [GGSC98]—from being usable simultaneously.

4.3. Comparison

Figure 4.6 presents two snapshots of the same scene. One object in the scene is rendered with a silhouette line shape whereas the remaining objects in the scene are rendered with a photorealistic style. Figure 4.6(a) represents the use of α-blending for this purpose and the result of changing the emissive color is shown in Figure 4.6(b), respectively.



(a) α-blending a shading.

(b) Manipulating the emissive color.

Figure 4.6.: Comparison of both methods for generating hybrid renditions. In both cases, the silhouette in form of a line stroke is combined with a background.

As can clearly be seen, the shading artifacts are still visible in the left image, that is for α-blending. Even though flat shading is used in this specific case in order to illustrate the effect, it holds for advanced shading techniques as well. Besides avoiding the shading effect, Figure 4.6(b) expresses the *pen on paper* metaphor.

Both blending techniques are capable of fulfilling the requirements according to cognitive limitations as expressed by the dynamics stimulus window from Section 3. Stepping over the lower window boundary is automatically ensured as each individual rendering style already fulfills this requirement. Therefore, any combination of multiple styles does not fall below the lower temporal boundary. In order to guarantee not to extend the dynamic stimulus window's upper limit as well, any style changes need to be parameterized accordingly. For the worst case of very complex scenes and low rendering bandwidth, a transition from one rendering style to another can be presented in as les as two steps—one for each end of the blending pipeline. However, both presented blending techniques are designed to provide for smooth transitions between different styles within the complete range of the dynamic stimulus window.

The use of more than just one shading technique is only possible with α-blending. This requires two rendering passes of the scene, though: once using a classic photorealistic style and once for the desired NPR style. The resulting drawback in rendering time is at least partially compensated by α-blending often being implemented directly in graphics hardware. Due to the visual metaphors achieved by the emissive color technique, its rendering results appear more artistic. This allows for the perception of an extended degree of abstraction compared to α-blending.

5. Implementation of the Scene Graph Integration

The dynamic use of hybrid rendering styles is implemented by using a scene graph API. For that purpose, a visualization toolkit named OpenNPAR is being developed on top of Open Inventor. Figure 5.1 shows the general scene graph layout for rendering of non-photorealistic images using OpenNPAR.

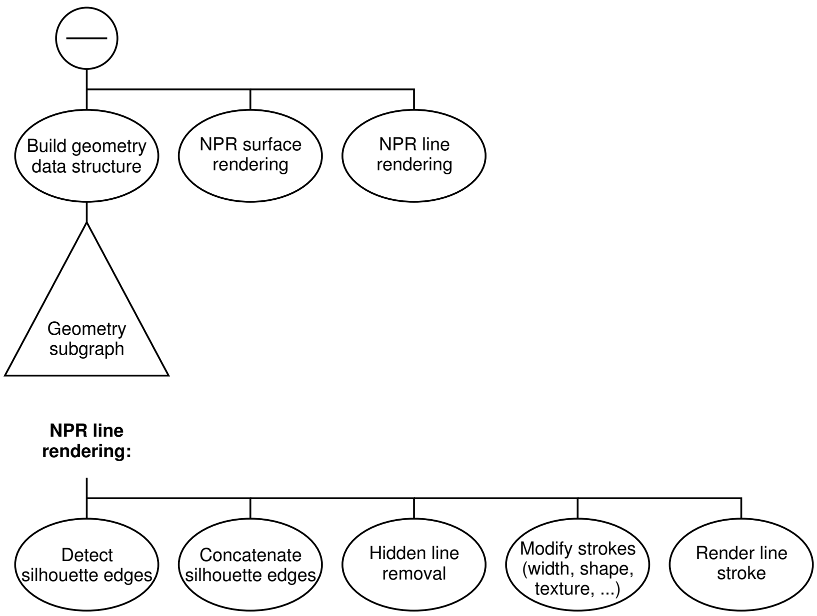


Figure 5.1.: General scene graph composition for visualizing in a non-photorealistic style using OpenNPAR.

The basis for using any NPR style in this system is a photorealistic rendition of the scene. In order to apply an OpenNPAR rendering style, the scene graph is to be prepared accordingly. To allow for fast edge lookup, a data structure can be used here that provides local neighbourhood information for individual edges and their affected faces. Baumgart presents the *WingedEdge* data structure as meeting this criteria [Bau75]. The preparation process furthermore adds a material node for each scene object in case it does not yet exist. This node is not explicitly contained in the figure but is part of the geometry subgraph and holds responsible for blending styles as discussed in the previous section.

The *NPR line rendering* subgraph represents the stylization pipeline allowing for a variety of styles to be used. For stylized silhouettes as presented here, the silhouette edges need to be detected first. After concatenating the edges appropriately, hidden lines are removed. This is followed by a parameterization of stroke styles. Finally, the strokes can be rendered.

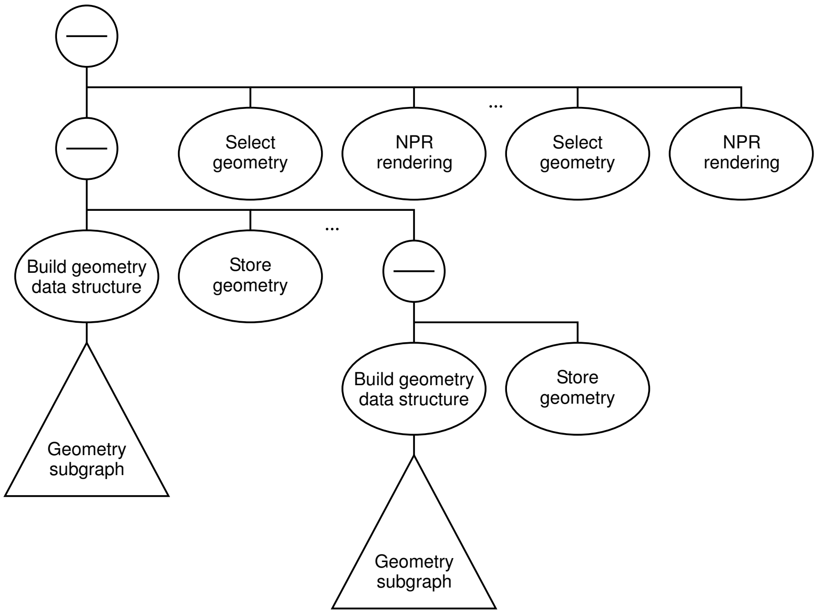


Figure 5.2.: Scene graph extended to allow for multiple styles being used simultaneously as well as to apply a style to parts of the scene only.

In order to employ more than a single NPR style in a scene, the scene graph from Figure 5.1 is extended as presented in Figure 5.2. The geometry subgraph is devided into a number of subgraphs, for each of which a separate *WingedEdge* data structure is constructed. This enables us to store geometry data for all respective objects in the scene. Thereby, the scene graph layout is designed such that hierarchical object handling is possible. This ensures a maximum of flexibility with regard to apply individual styles to either whole objects or parts of an object that belong together.

For each rendering style, a separate style pipeline is to be put into the scene graph. The set of geometry data nodes is referenced by separate selection nodes. These map a style onto its respective object or object hierarchy. Parameterization of the individual styles remains as described above, but is now independent from each other.

6. Application Scenarios

The main question addressed by the presented rendering system is how to communicate information effectively by simultaneous use of multiple rendering styles. A visualization supporting this task was explicitly cited as one of the grand challenges for NPR by David Salesin's keynote at the 2^{nd} NPAR symposium [Sal02]. The generality of the system provides for a broad range of possible applications. As the previous section pointed out, the underlying base model is a geometric scene description. This can either be pre-modelled or generated (semi-) automatically. While this enables applications in the broad field of information visualization such as the example presented by Jesse [Jes03], we now concentrate on the use of predefined geometric models. Section 6.1 presents the use of hybrid rendering styles for illustration purposes in a technical model whereas the use of the same techniques in a medical object is subject of Section 6.2.

6.1. Presentation of technical objects

The construction and maintenance life cycle for engineering models spans a broad area of activities. This includes the refinement of the model or parts thereof during the *detailed design phase* [FS94]. As an example, the model of an engine is used here. In order to examine the utilization of individual engine elements, the design engineer is supported by visual feedback for the status of current items of interest.

Figure 6.1 shows a series of snapshots from an animation presenting the utilization of the engine model. The current item of interest is its cooling system. Four tubes combine to this system and are supported by a cooling aggregate. The snapshots express the consecutive usage of all individual tubes with a smooth transition from one tube to the next. The work load of the small extra tube connected to the cooling aggregate is emphasized incrementally while going through the main tubes. The trained design engineer is now in charge of interpreting the scenario in order to decide on a potential lack of capacity for the bandwidth of this connection tube.

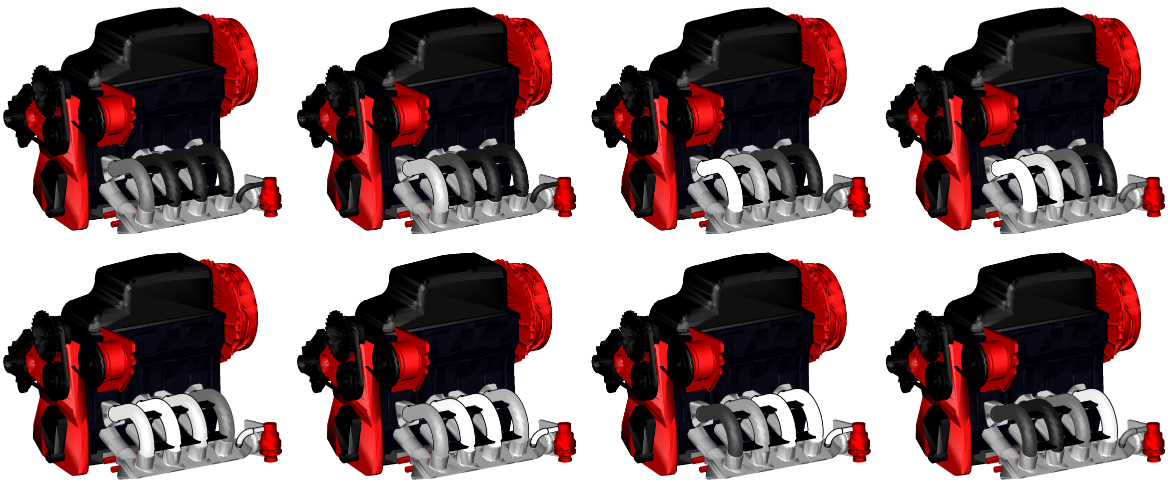


Figure 6.1.: Snapshots of an engine model. The tubes of the engine's cooling system are gradually emphasized by being rendered in a line shaped silhouette style. The style changes reflect the possible utilization of the single tubes and their interplay with the cooling aggregate located ad the bottom right side.

6.2. Examination of anatomical objects

A typical goal in medical studies is in teaching students anatomical context of specific body parts. As stated by Ritter et al. [RPDS00], a good way to approach this goal is in active exploration and examination of a geometric model of the object in question.

A series of snapshots for the example of a foot presentation is shown in Figure 6.2. Therein, dynamic changes of hybrid rendering style are used to communicate the spatial relationship of phalangis—the bones of the toes. Beginning at a cuneiform bone, a silhouette line rendering is used in order to gradually emphasize the individual bones forming a toe and associated bones. Precisely, the order of bones as pointed out in the figure is: *Os cuneiformie I*, *Os metatarsale I*, *Phalanx proximalis I*, and *Phalanx distalis I*.

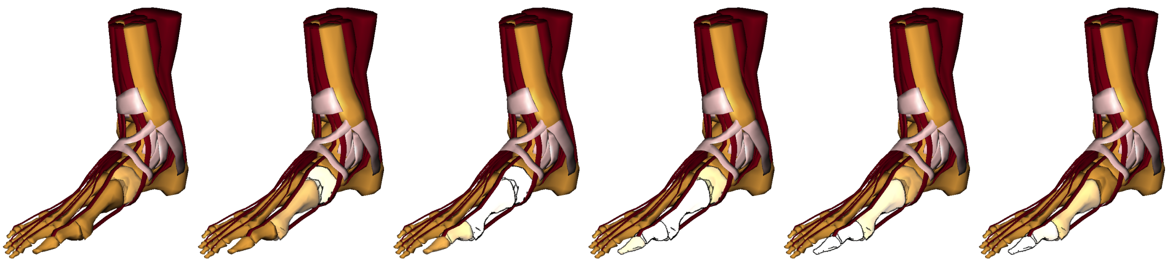


Figure 6.2.: Snapshots of an animation pointing out specific parts of an anatomical example. *Os cuneiformie I*, *Os metatarsale I*, *Phalanx proximalis I*, and *Phalanx distalis I* are emphasized in order to visualize their functionality.

This animation can be run cyclical at varying speeds. Now, a sophisticated learning environment could possibly provide multiple parameterizations of the animation cycle to the students. By spanning the whole spectrum of the presented stimulus intervals and analyzing the learning effect on the students, studies about respectively modified learning curves can be derived.

7. Summary and Conclusion

The presented work shows the construction of hybrid presentations by a combined use of photorealistic and non-photorealistic rendering techniques. It has been shown that individual rendering styles cannot only be employed for the whole scene but also for disjoint parts of a scene. Thereby, multiple styles can even be used simultaneously. Dynamics are created by blending different rendering styles. For this purpose, two blending techniques are presented in detail including supportive remarks on their implementation.

As discussed, each of the blending techniques described in Section 4 has its advantages and disadvantages. In order to provide for a coherent color representation for emissive color blending, a combined use of both blending techniques sounds promising. Thereby, α-blending could be used for the first half or $\frac{2}{3}$ of a complete blending cycle. This would be followed by emissive color adjustments up until the final rendering style is reached. A smart decision of the switch point might help to solve the see through problem as well, as the influence of the rendered faces as caused by the increasing emissive color values would prevent hidden objects from shining through. In order to solve this see through problem for an exclusive use of α-blending, using the stencil buffer as discussed remains to be evaluated.

Acknowledgements

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