EG UK Theory and Practice of Computer Graphics (2009)
Wen Tang, John Collomosse (Editors)

Influencing User Attention Using Real-Time Stylised Rendering

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Abstract

In this paper, we present a series of experiments that were conducted to further understand how using adaptive levels of artistic abstraction within an interactive 3D scene can influence user gaze behaviour. We found that when an object was placed in the center of stylised focus, users took significantly less time to complete a search and recognition task in comparison to normal renderings or when the target object was heavily abstracted i.e. stylistically out-of-focus. We also compared a number of different abstraction techniques and found that some abstraction styles consistently lead to faster search times than others. Finally we performed experiments using an eye-tracker to show that our real-time abstraction techniques can successfully draw user attention to specific objects within an interactive scene. We believe that our experimental framework will be useful in the future for comparing the effectiveness of different non-photorealistic styles in influencing a user's perception of a scene.

1. Introduction

Whilst a number of non-photorealistic rendering (NPR) techniques have been proposed to improve the effectiveness of images in conveying informational content and drawing user attention to important objects in an image, there has been a limited amount of work done to objectively evaluate and compare different proposed stylisations. In particular, there is little work that deals with the issue of comparing interactive real-time NPR styles. With the wide range of available stylisations, each with their respective objectives and side-effects, measurable indicators of the effectiveness of NPR styles are vital in optimising the perceptual fidelity of interactive NPR systems.

Our motivation is to use varying non-photorealistic stylization levels within an interactive scene to affect a user's gaze behaviour and scene exploration. We employ a system for creating real-time abstracted NPR of scenes based on previous work described in [RD08]. Figure 1 shows an example scene rendered using our adaptive abstraction method. While it has been shown that computationally expensive NPR techniques can influence user gaze behaviour in static images we intend to show that real-time NPR techniques can also have the same effect, both on single images and in interactive scenes. This would allow NPR to be used as a tool for affecting user gaze and scene exploration within an interactive application. Determining the effectiveness of various types of non-photorealistic abstractions should enable us to develop the most efficient NPR techniques for increasing the saliency of important scene objects.

Figure 1: *Example of an interactive scene using real-time NPR techniques containing multiple levels of abstraction.*

Five sets of experiments were conducted to investigate the effect of multi-level abstraction on a user's perception of a scene. Three experiments analysed what effect various NPR techniques could have on a timed search task. The fi-

DOI: 10.2312/LocalChapterEvents/TPCG/TPCG09/173-180

nal two experiments used eye-tracking data to investigate whether NPR techniques had a major effect on gaze behaviour. The results of the experiments show conclusively that: (a) stylised abstraction can improve visual search times of users, (b) stylisation can be used to effectively draw user gaze to intended objects in a scene and (c) certain stylisations consistently perform better than others. The experimental framework presented in this paper can be applied to evaluating the effectiveness of other NPR techniques in drawing attention.

2. Background

NPR is a class of rendering which places emphasis on stylisation and efficient communication over the traditional goal of simply producing increasingly lifelike images. A vast body of work exists which deals with producing NPR images for specific applications or simulating specific artistic styles in computer imagery. A full discussion of these techniques is beyond the scope of this paper so we refer the reader instead to [GG01] and [SS02], which provide extensive surveys on the area. We focus our discussion in this section on the works most relevant to gaze direction and evaluation of NPR imagery.

Although a number of NPR techniques are motivated purely by aesthetics, a fundamental premise for most NPR styles has been to improve the effectiveness of images in conveying information. Artists and proponents of NPR exploit well known perceptual mechanisms to provide informational cues to the viewer. Examples of these are descriptive lines and brushstrokes to enhance silhouettes and contours, and abstractions to texture and fill areas, which are designed to remove extraneous detail. Given the abundance of stylisation choices, it is important to have measurable indicators of quality for evaluating and comparing the effectiveness of different abstraction styles. Isenberg et al. [IFH*03] present an observational study to examine user's understanding and assessment of hand-drawn pen-and-ink illustrations of objects in comparison with NP renderings of the same 3D objects. Their results showed that people perceive differences between those two types of illustration but that those that look computer-generated are still highly valued as scientific illustrations. Halper et al. [HMH*03] investigate the relationship between NPR and psychology and find that there is much promise for using NPR to influence user judgement. Gooch et al. [GRG04] demonstrate the effectiveness of NPR images in communicating information effectively. They used psychophysical studies to assess accuracy and speed in recognition and learning tasks relating to human faces and found that illustrations of faces were learned twice as fast as normal photographs.

Santella and DeCarlo [SD02a] use eye tracking data to guide automatic painterly abstraction to create what they refer to as *meaningful abstraction* of images. Visually salient parts of an image are determined with the use of an eye-tracker before the appropriate abstraction is performed using brushstrokes of various sizes depending on the importance of different points. In [SD02b] a similar approach is employed in order to obtain importance data, used in transforming photographs into line-drawing style images with bold lines and large regions of constant colour. Eye-tracking experiments confirmed in [SD04] that these techniques were effective at focussing a user's interest on particular parts of an image.

Cole et al [CDF*06] describe a technique for directing gaze with *stylised focus*, and validate their results using an eye-tracker to gauge if user fixations are guided by their method. The experiments are performed on still images rendered by the system and achieve interactive rates (3-5 fps). While the goals of Cole et al. are similar to those of this paper, the rendering system employed here achieves real-time frame rates (20-25 fps). Also the continuous effect on user's gaze in animations is investigated in this paper and therefore the possibilities for real-time abstraction filters in interactive applications are shown.

More recent works have demonstrated that real-time interactive NPR is also possible, although some compromises have to be made in choosing abstracted rendering techniques for lines and fills that are fast enough to run in real-time and that exhibit reasonable frame-to-frame coherency. Winnemöller et al [WOG06] use image-based abstraction techniques, accelerated on the GPU to deliver real-time abstraction of video input. In previous work [RD08] we employed a hybrid technique to generate multi-level abstractions of 3D textured urban scenes with the goal of creating stylised focus on different parts of the rendered image. An automated saliency metric, proposed by [IKN98], was used to demonstrate that such a system has the potential to affect a user's visual search behaviour while exploring the scene. However, this metric is based on a low-level model of visual interest and, although it strongly indicates that salient points may be affected by the technique, further evidence is required to show that gaze behavior can be directed by such a system as intended in a practical scenario.

Outside of the NPR literature, related work has been done by Sundstedt et al, who propose utilizing eye tracking, as part of the computer game design cycle to predict fixation behavior of players [SSWR08] and McNamara et al who show how search task performance can be influenced by using subtle gaze direction [MBG08].

Further studies are clearly required in order to evaluate the effectiveness of NPR in animated scenes and in particular real-time interactive animations. Furthermore, we believe that measurable indicators of effectiveness, obtained through high-level task-based studies, should be incorporated in the design process to ensure that interactive NPR applications achieve their intended objective of increasing the effectiveness of interactive imagery.

Figure 2: *(a) Example frame from experiment one where focus is on the target sphere (Filter 1), (b) Example frame from experiment one where stylised focus is on some other random sphere (Filter 4), (c) The range of possible target sphere appearances shown to users before all experiments*

3. Rendering Styles

This section details the real-time rendering stylisations we employed in our experiments. Although techniques to create generic real-time adaptive NPR are worthy of note, our major contribution in this paper is a comparitive study of types of stylisation across interactive NPR scenes. Thus we provide only a brief overview of the rendering techniques themselves, although we provide relevant information so that the system and the experiments may be replicated by the reader.

To ensure real-time performance and reliable abstraction results without style specific data such as procedural NPR textures, we employ a system based on the approach described in [RD08] which uses image space stylisation coupled with object space segmentation. The technique, requires only generic 3D models with standard textures and, accelerated on the GPU, performs adaptive abstraction in real-time. Although there are aesthetically and functionally more superior stylisation techniques available in the state-of-the-art, what was required in these experiment is a representative sample of specific classes of stylisations that are commonly employed. We identify these as edge stylisation, texture abstraction and colour variation. Our technique not only achieves these three classes of stylisation but also facilitates adaptive variable stylisation across the scene.

Edge stylisation can play an important part in NPR. Emphasizing edges in a scene enhances distinction between regions and can increase the saliency of a particular object or area. The *Difference of Gaussian (DoG)* filter, applied on the frame buffer image of a rendering of the 3D scene, was chosen as a good compromise between speed and accuracy. Object space silhouette edges are also obtained based on the technique discussed in [RD08]. The level of abstraction by the DoG filter can be modulated across the scene to find more edges within objects which need to be made more salient.

Painterly rendering, which we classify as **texture abstraction**, is the most well known device used in NPR. Two types of real-time painterly techniques were implemented for our experiments. The first, an *anisotropic diffusion filter*, as described in [WOG06] is a form of edge preserving smoothing. We extended the technique to allow for varying smoothing levels within an image in order to modulate the degree of abstraction across the scene. The second filter we use, the *Kuwahara filter*, is a simpler edge preserving smooth which also yields painterly-like results [MKK76]. We show in [RD08] how the filter can be used for varying abstraction levels.

Several different techniques were implemented for testing the impact of **colour variation**. One of these was a *colour quantization* filter, where colours are quantized into a set of bin boundaries whose size is dependant on the object's importance. Thus colour depth in unimportant objects can be reduced whilst leaving the significant objects in full colour-detail. Secondly a *saturation variation* was used to reduce the colour intensity of particular unimportant scene objects. Finally two simple filters were additionally used in this experiment classified under colour varation: one altered the *brightness* of each pixel dependant on objects importance while the other altered the *luminance*. Brightness is changed using simple operations on each pixel's RGB value while luminance is a single value measured within the HLS colour space.

4. Timed search experiments

Three experiments were performed to determine whether real-time non-photorealistic rendering filters can have an effect on recognition speeds in interactive scenes. The experiments also measured which styles of NPR were more effective than others. Within the timed search experiments scenes containing randomly generated textured spheres were used as they provided a scene with minimal semantic connotations. When there is little semantic information attached to the scene it allows us to obtain a good general indication of what effect various abstraction techniques can have on a user's behaviour. While a more meaningful scene is used in an experiment described later in the paper the initial intention was to reduce the number of external factors that could affect the measured impacts on user behaviour. Past research has shown that by reducing scene content to simplistic objects such as spheres, user's responses can be measured effectively to draw useful conclusions about more general sce-

narios [OD01] [NLB*07]. In each of the experiments all participants had normal or corrected vision and were unaware as to the purpose of each experiment.

4.1. Experiment One

4.1.1. Procedure

Twenty participants took part in this experiment. Each participant was shown a set of sixty-four animations each containing fifty spheres of the same size (see Figure 2(b)). In each scene the spheres revolved around a vertical axis directly in front of the camera. The distance from the axis to the spheres was fixed, but otherwise their placement was random. This was to ensure that all spheres were visible for close to the same amount of time while rotating. Each sphere was given a random texture and in each trial all spheres rotated around the centre of the scene at a constant speed in the same direction. Eight of the images shown were rendered using normal 3D local illumination, and the other fifty-six were rendered using seven different types of non-photorealistic abstraction (eight images per filter). The filters used for the experiment are below:

Filter 1: Kuwahara
Filter 2: Winnemoller
Filter 3: Difference of Gaussian edge detection
Filter 4: Saturation variance
Filter 5: Colour quantization
Filter 6: Brightness Variation
Filter 7: Luminance Variation

Users were instructed to click upon a particular textured sphere as quickly as possible in each animation. The same textured sphere was the target object in each image, although in many of the images the sphere was abstracted using one of the filters. A brick texture was chosen for the target sphere as it was visually distinct from the rest of the textures. Before the experiment started the user was shown examples of the appearance of the sphere normally and in each of the possible filters (see Figure 2(c)). It was ensured that there was no clipping of the target object in each animation and the animation played for a full scene rotation. The trials were also randomly ordered. The starting point of the sphere was random although it was ensured that the starting points were balanced throughout the experiment i.e. foreground/background and left/right. If the user succesfully clicked on the target object a new trial began, otherwise the animation continued for a maximum of twenty seconds. Half of each of the sets of abstracted images used multiple levels of abstraction within the image to eliminate unwanted detail and focus on the target sphere i.e. increase its saliency (see Figure 2(a)). The other half were focused randomly on a different scene sphere, thus abstracting the target sphere (see Figure 2(b)).

4.1.2. Results

The reaction times of the participants were averaged for all abstraction filters focused on the target and for the normal images, and an ANalysis Of VAriance (ANOVA) was then performed on the results. It was found that there was a main effect in the reaction times for normal and focused scenes ($F(1,19) = 6.3778, p < 0.02$). It can be seen from Figure 3(a) that when the target object was focused, average recognition speeds ($2.53s$) were faster than normally rendered images ($2.79s$). These results indicate that the NPR filters used were effective at improving task speeds.

Reaction times were also averaged for scenes when both the stylised focus was on the target object and when the focus was on some other random object. These times were averaged for each filter to discover how they performed individually. An ANOVA was again performed and it was seen that there was a main effect between focused and not focused scenes for all of the filters ($F(1,19) = 5.7467, p < 0.025$). The filters used produced consistently faster times with focus on the target object than when the focus was on another object as can been seen from Figure 3(b). It can also be seen from this figure that some filters resulted in faster reaction times than others. For example the Kuwahara filter (Filter 1) produced good average times ($2.18s$) in comparison with the quantization filter (Filter 5) ($2.72s$).

4.2. Experiment Two

4.2.1. Procedure

It was seen from experiment one that the individual NPR styles used can effectively influence user recognition times. A second set of experiments was run which looked at how combining styles can influence user times. This experiment was run with static scenes with spheres of varying size. Twenty participants who had not taken part in the first experiment participated. In this experiment users were shown a group of one hundred images each of which contained one hundred and fifty randomly generated spheres of varying size. The placement and size of each sphere was random and each sphere was given a random texture. Twenty of the images were again rendered using normal 3D local illumination, and the other eighty images were rendered using four different types of NPR (twenty images per style). It was ensured that there was no clipping or occlusion of the target object in each image. Like the first experiment half of the stylised images were focused on the target object while the other half were focused on a random other object within the scene. Four combinations of varied filters were chosen for the experiment ensuring that each filter within a style provided a different type of abstraction. The styles selected were as follows:

Style 1: Kuwahara filter, saturation variation and brightness variation
Style 2: Kuwahara filter, DoG edges, colour quantization and luminance variation

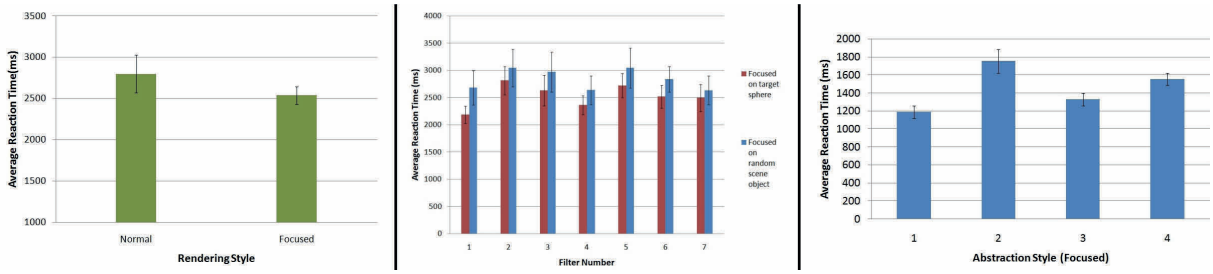

Figure 3: *(a) Average reaction times from experiment one for all filters. Note error bars represent standard errors of the mean in all graphs (b) Average reaction times from experiment one for each individual filter (c) Average reaction times for the focused abstraction styles from experiment two*

Style 3: Winnemoller filter, Saturation variation and luminance variation
Style 4: Winnemoller filter, DoG edges and brightness variation

4.2.2. Results

Participants' reaction times were averaged for each abstraction style and for the normal images, and an ANOVA was then performed on the results. It was found that there was a main effect in the reaction times for normal, focused and not focused images ($F(2,38) = 78.503, p < 0.01$). Post-hoc analysis was then performed using Newman-Keuls and it was seen that when the target object was focused, average recognition speeds ($1.45s$) were faster than normally rendered images ($1.64s$), which were in turn much faster than the images in which the focus object was some random sphere and the target object was abstracted ($2.28s$) ($p < 0.02$ in all cases). These results back up what was already discovered in experiment one.

It was also seen that some style combinations performed significantly better than others. Reaction times were averaged for each style when the image was in focus and an ANOVA was then performed on the results. It was found there was again a main effect of abstraction style ($F(3,57) = 13.677, p < 0.01$). Post-hoc analysis was performed using Newman-Keuls pairwise comparison of means. Style 1 resulted in excellent average times ($1.19s$) while the times from Style 2 ($1.75s$) were considerably greater than the average times for the other styles as well as the times for the normally rendered images. Style 3 resulted in good times ($1.33s$) while Style 4 ($1.54s$) did not perform quite as well ($p < 0.04$ in all cases except Style 1 vs Style 3). This difference in abstraction reaction times can be seen in Figure 3(c). Reaction times were generally faster than experiment one although this is due to the fact that this experiment was performed on static images and not moving scenes.

It was also seen from these experiments that the projected size of the target sphere in the scene was important. When times were averaged according to size an ANOVA was performed and it was seen that size was a significant factor ($F(1,19) = 256.00, p < 0.01$). When the sphere was close to the centre of the screen similar results were observed. Screen distance between the centre of the focus object and screen centre was seen to be a significant factor ($F(1,19) = 237.20, p < 0.01$), as users tended to find the sphere faster if the sphere was centred. Despite these results, the distribution of sphere size and screen distance were evenly spread throughout each style, so they did not have an impact on the overall results.

4.3. Experiment Three

4.3.1. Procedure

It was seen from experiment two that some abstraction combinations worked significantly better than others. In an attempt to isolate the reasons for this, another timed search experiment was run. Twenty new participants took part. The same format as experiment one was again used. This time there were eighty images, twenty of which were normally rendered. The remaining sixty images were divided into three sets of twenty images each and, as before, half were focused on the target object and half on a random object. The most successful style from the first experiment, Style 1, was again used. The other two styles in the experiment were generated by using Style 1 again but adding one other type of abstraction. Colour quantization and DoG edges were added as they generated slow results when incorporated as part of other styles in the first experiment. This was done to allow direct comparison between styles and show what effect each style addition had on recognition speeds.

Style 1: Kuwahara filter, saturation variation and brightness variation
Style 5: Kuwahara filter, saturation variation, brightness variation and colour quantization
Style 6: Kuwahara filter, saturation variation, brightness variation and DoG edges

4.3.2. Results

The reaction times of participants were again averaged for each style when the image was in focus and an ANOVA was

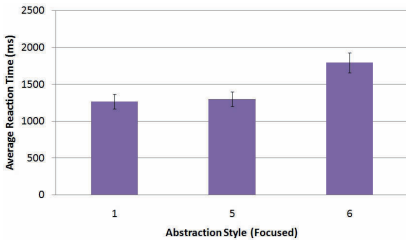

Figure 4: *Average reaction times for the focused abstraction styles from experiment three*

Figure 5: *Example frame from an animation shown to participants in eye-tracking experiment (Style 6)*

performed on the results. It was shown there was a main effect of abstraction style ($F(2,38) = 42.649, p < 0.01$). Post-hoc analysis using Newman-Keuls pairwise comparison of means showed that there was no significant difference between the average times between Style 1 (1.30) and Style 5 (1.27s). However, as can be seen from Figure 4 there was a significant difference in average reaction times between the set of abstracted images containing edges, Style 6 (1.79s) and the other two sets ($p < 0.002$ in each case).

It was also of interest that there was a main effect of style for average times when the target object was abstracted and some other random sphere was the focus object in the image. However the significance between these images was far less than when the target object was in focus ($F(2,38) = 3.5244, p < 0.04$). It was also noted that there was no significant difference in reaction times for recurring styles in experiment two and three. This was despite having different participants from experiment one and a new set of images. This is true for Style 1 when the target object was in focus (1.19s for experiment one and 1.27s for experiment two), Style 1 when the target object was abstracted (2.01s for experiment one and 2.28s for experiment two) and normally rendered images (1.64s for experiment one and 1.53s for experiment two).

5. Eye-tracking Experiments

5.1. Experiment Four

5.1.1. Procedure

The next set of experiments used an eye-tracker to investigate how implementing NPR within interactive scenes can

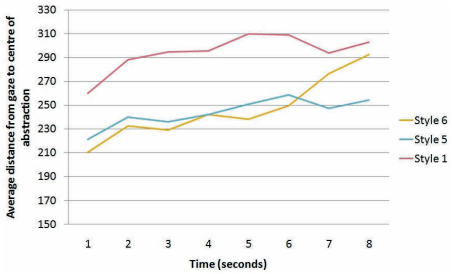

Figure 6: *Distance from gaze position to abstraction centre through time for each abstraction style in experiment four*

affect a user's gaze behaviour. An SR-Research Eye-link II eye-tracker was used. Ten participants took part and were all positioned 64cm away from an 18inch monitor using a chin rest. It was ensured the participants were focusing on the centre of the screen before each trial. Each trial contained fifty spheres rotating around the centre of the screen as in experiment one (see Figure 5). The participants were shown forty animations, each lasting eight seconds. In each animation the abstraction was focused on some sphere as the objects rotated. In half of each of the abstraction sets the focus object was a brick textured sphere, while the other half were focused on a random object. Ten of the animations were rendered using normal 3D local illumination. The other thirty were divided into three sets of ten animations, each with a different abstracted rendering style. The abstraction styles were the same as in experiment two, i.e. Style 1, 5 and 6.

The users were asked to count the number of brick textured spheres in each scene and state the number after each trial. The task was given to ensure participants were searching the entire scene throughout the animation and their performance in the task was not actually used in the evaluation. There was between one and three brick textured spheres in each animation. The purpose of the experiment was to investigate whether the focus sphere and its surrounding area drew more attention than the rest of the scene during a search task.

5.1.2. Results

For the eye-tracking experiment the distance between the centre point of abstraction and the user's gaze point was measured for each frame. A two factor ANOVA with repeated measures was performed on the average distances per frame grouped into abstraction styles. The results found that there was a main effect of abstraction style ($F(2,18) = 20.916, p < 0.01$), indicating that some styles drew gaze more effectively than others. There was also a main effect of time ($F(7,63) = 7.9485, p < 0.01$), where user gaze was drawn to the focus of the abstraction early on in each animation. Post-hoc analysis was again performed using a Newman-Keuls test for pairwise comparisons among means. This showed that there was a significant difference between Style 6 and the other two styles ($p < 0.002$), although the

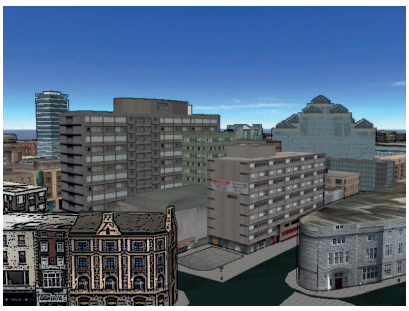

Figure 7: *Example frame from a scene in experiment five*

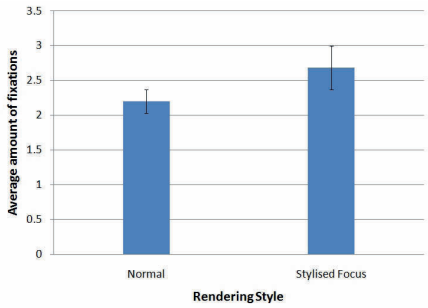

Figure 8: *Average fixation amounts for experiment five*

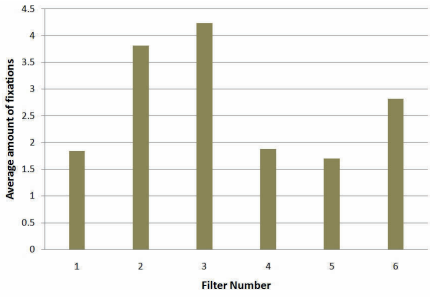

Figure 9: *Average fixation amounts for each individual filter in experiment five*

difference in Style 1 and 5 was not significant. It was also proven that the tendency for the gaze to be drawn to the objects in focus was significant for the first second of the animations ($p < 0.02$).

Our results strongly indicate that the abstraction styles can effectively draw user gaze to specific objects in the scene. As can be seen from Figure 6, there is a trend for user gaze to be immediately drawn to the area surrounding the focus object, regardless of whether that object is the search target or not. Gaze then generally moves away from these focus areas as users search the rest of the scene. From this experiment we can see that Style 6, which contains edge detection, performs significantly better than Style 1 and Style 5 in drawing user gaze.

5.2. Experiment Five

5.2.1. Procedure

The final experiment looked at how the NPR styles used performed within a interactive scene containing semantic information. While the results of the previous experiments were useful it was interesting and worthwhile to see if those results are consistent with a more detailed and meaningful scene. The eye-tracking equipment described in the last experiment was again used. For this experiment the scene chosen was an interactive urban simulation [HO03]. Ten new participants were shown thirty-two scenes, each six seconds long and randomly ordered. An example frame from a scene can be seen in Figure 7. Each scene was rendered in real-time during the experiment and showed one of four walkthroughs of the urban environment. Each walkthrough was shown eight times, once rendered normally and also with each of the individual NPR filters used in experiment one. In each abstracted scene the focus was on one of four buildings in each walkthrough. The buildings chosen were of varying prominence within the scene. The users were given no task but asked to look around the scene normally. Eye tracking fixations were then extracted and it was determined which object was being inspected at each fixation.

5.2.2. Results

The total amount of fixations on each object was averaged for all NPR filters and for the normal renderings. An ANOVA was then performed and it was found there was a main effect between the normal and stylised renderings ($F(1,9) = 12.081, p < 0.01$). As can be seen from Figure 8 the user spent a significant amount more time looking at the target object if the building was in stylised focus. The average times for each individual filter were then averaged and after an ANOVA was performed on the results it was seen that there was a main effect of rendering style ($F(6,54) = 11.564, p < 0.01$). Post-hoc analysis was then performed using a Newman-Keuls test for pairwise comparisons among means and it was seen that some filters performed significantly better than others (As can be seen from Figure 9). In particular filter 2 and filter 3 were significantly better at drawing user attention to target objects than the rest of the filters used ($p < 0.02$ for each case).

6. Conclusion

In this paper we have shown that using real-time non-photorealistic rendering techniques can successfully influence user recognition times and gaze behaviour. We have also seen that the effectiveness of different NPR techniques can vary largely depending on the style and also the task. For example the addition of edges was very successful at

increasing object saliency during animations while performing badly in the timed search task in static frames. While edges do seem to make objects more salient within scenes a number of participants noted that recognition of objects containing edges took slightly longer than when it was rendered normally. Similarly the Kuwahara filter was very successful in all search tasks whereas it performed significantly worse in drawing user gaze in both the eye-tracking experiments. Some styles such as colour quantization performed poorly in comparison to other styles in all tasks.

This information will be useful in creating and developing NPR techniques which can effectively influence user reaction times and behaviour in interactive scenes. Real-time NPR techniques which can affect user behaviour would be useful within any interactive application where it is necessary to emphasise a certain point or object to the user while eliminating extraneous detail. Possible areas of utilisation for the system are applications such as route finding, games or tourist applications. We also believe the system would work well in educational diagrams or in medical and scientific visualizations to highlight important elements as has been done in the past for off-line NPR visualizations [THE07].

We believe that the experimental framework described in this paper can be a useful tool in the future for evaluating real-time non-photorealistic rendering techniques. Indeed there are a number of NPR techniques not mentioned here which require further investigation. We also believe the framework would be valuable when evaluating NPR techniques off-line. While certain styles may successfully influence user behaviour it is also important that the style be aesthetically pleasing for the user. This is a factor which we will research when further developing abstraction styles. We intend to continue investigating which abstraction styles can successfully create salient regions and we will use the information gained from these experiments to improve upon current techniques.

References

[CDF*06] COLE F., DECARLO D., FINKELSTEIN A., KIN K., MORLEY K., SANTELLA A.: Directing gaze in 3D models with stylized focus. *Eurographics Symposium on Rendering* (June 2006), 377–387.

[GG01] GOOCH B., GOOCH A.: *Non-Photorealistic Rendering*. A.K. Peters Ltd, 2001.

[GRG04] GOOCH B., REINHARD E., GOOCH A.: Human facial illustrations: Creation and psychophysical evaluation. *ACM Trans. Graph. 23*, 1 (2004), 27–44.

[HMH*03] HALPER N., MELLIN M., HERRMANN C. S., LINNEWEBER V., STROTHOTTE T.: Psychology and non-photorealistic rendering: The beginning of a beautiful relationship. 277–286.

[HO03] HAMILL J., O'SULLIVAN C.: Virtual Dublin - A Framework for Real-Time Urban Simulation. *Journal of WSCG 11* (Feb. 2003), 221–225.

[IFH*03] ISENBERG T., FREUDENBERG B., HALPER N., SCHLECHTWEG S., STROTHOTTE T.: A Developer's Guide to Silhouette Algorithms for Polygonal Models. *IEEE Computer Graphics and Applications 23*, 4 (July/Aug. 2003), 28–37.

[IKN98] ITTI L., KOCH C., NIEBUR E.: A model of saliency-based visual attention for rapid scene analysis. *IEEE Transactions on Pattern Analysis and Machine Intelligence 20*, 11 (1998), 1254–1259.

[MBG08] MCNAMARA A., BAILEY R. J., GRIMM C.: Improving search task performance using subtle gaze direction. In *APGV* (2008), pp. 51–56.

[MKK76] M. KUWAHARA K. HACHIMURA S. E., KINOSHITA M.: *Digital processing of biomedical images*. Plenum Press, 1976.

[NLB*07] NUSSECK M., LAGARDE J., BARDY B., FLEMING R., BÜLTHOFF H. H.: Perception and prediction of simple object interactions. In *APGV '07: Proceedings of the 4th symposium on Applied perception in graphics and visualization* (2007), pp. 27–34.

[OD01] O'SULLIVAN C., DINGLIANA J.: Collisions and perception. *ACM Trans. Graph. 20*, 3 (2001), 151–168.

[RD08] REDMOND N., DINGLIANA J.: A hybrid technique for creating meaningful abstractions of dynamic 3d scenes in real-time. In *Proceedings of WSCG 2008* (February 2008).

[SD02a] SANTELLA A., DECARLO D.: Abstracted painterly renderings using eye-tracking data. In *NPAR '02:* (2002), ACM Press, pp. 75–ff.

[SD02b] SANTELLA A., DECARLO D.: Stylisation and abstraction of photographs. In *SIGGRAPH '02* (2002), ACM Press, pp. 769–776.

[SD04] SANTELLA A., DECARLO D.: Visual interest and npr: an evaluation and manifesto. In *NPAR '04:* (2004), ACM Press, pp. 71–150.

[SS02] STROTHOTTE T., SCHLECHTWEG S.: *Non Photorealistic Computer Graphics: Modeling, Rendering and Animation*. Morgan Kaufmann, 2002.

[SSWR08] SUNDSTEDT V., STAVRAKIS E., WIMMER M., REINHARD E.: A psychophysical study of fixation behavior in a computer game. In *APGV* (2008), pp. 43–50.

[THE07] TATEOSIAN L. G., HEALEY C. G., ENNS J. T.: Engaging viewers through nonphotorealistic visualizations. In *NPAR '07: Proceedings of the 5th international symposium on Non-photorealistic animation and rendering*. 2007, pp. 93–102.

[WOG06] WINNEMOLLER H., OLSEN S. C., GOOCH B.: Real-time video abstraction. In *SIGGRAPH '06* (2006), ACM Press, pp. 1221–1226.