# LEVEL OF MOTION DETAIL IN VIRTUAL REALITY

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## ABSTRACT

This paper presents an optimization technique which modulates the computation complexity of the animation in virtual reality (VR). As this technique is based on the commonly used approaches in the domain of LOD, we call it LOmD (Level of motion Detail). We extend the classical LOD mechanism based on geometry removal according to the retinal image of the moving object, velocity of the object, and position of the object in the periphery of the visual field. The LOmD technique is based on the idea that our visual system is not able to recognize any differences in the quality of motions produced by different animation techniques (e.g. simple linear interpolation vs. physically based simulation) under different visual conditions (e.g. distance or eccentricity). Varying the motion detail we can balance the workload of the VR system in such a way that the only motions important for the user's view are refined using more complex simulation whereas other motions are linearly interpolated to guarantee the motion continuity. In order to achieve automatic behavior of the LOmD mechanism, we designed the visual acuity model based on visual perception which links the viewing conditions to the appropriate level of motion detail. The proposed method has been tested on implementation of a simple VR model. The results are presented in the section 5 of the paper.

**Keywords:** Computer Animation, Virtual Reality, Level of Detail, Virtual Environment

## 1 INTRODUCTION

Observing motions of objects in virtual environment (VE) we can find that according to the different viewing conditions (e.g. position in our periphery of vision or distance) our ability to recognize details on the objects changes. This feature of the human visual system (HVS) is often used as the base for optimizing techniques decreasing the complexity of computations in the VE. The high complexity of the VE causes delays in reactions of the VR system which negatively influence the real-time interactions between the user and the VR system.

[Reddy94] identified parts of a general VR system contributing to delays influencing the interaction with the user and classified the delays into three groups:

- the *rendering delay* produced by the graphics system,
- the *processing delay* occurring when computing animations, collisions, and other scene updates,
- the *sensor delay* produced by sensors (e.g. head mounted displays) when measuring, transporting and processing signals and responses between the user and the VR system.

The classical approaches based on LOD methods understand the term "detail" as the feature of the object's geometrical representation ([Hoppe97]). According to the previous classification, these LOD methods mostly reduce the rendering delay.

In order to achieve more realistic motions produced by the virtual actors, techniques based on physical features (as mass or moment of inertia) were proposed ([Barze88, Ko96]). The computations based on these methods represent an additional burden on the VR system increasing the processing delay. This implies the idea to vary complexity of motion computations according to user's interest similarly as in the LOD techniques.

This approach requires two phases:

- the extension of the classical "static" detail with an appropriate definition of the motion detail (and thus its representation),
- the design of a metrics to measure and compare the actual viewing conditions and design of the model (referred to as *visual acuity model*) associating the metrics with the appropriate levels of motion detail.

The classical LOD methods proposed during the last five years define the visual acuity model based on similar criteria. In [Ohshi96] the three-criteria method is presented. The first criterion is based on the angular distance of the observed object from the user's gaze direction (eccentricity).

The second criterion takes into account the velocity of the moving object where the higher velocity implies lower ability of the observer to register details on the object.

The last criterion is based on fusional vision which is related to mechanism of binocular vision, where the observed object is perceived as a single or double image depending on the position according to horopter[1].

The method employing spatial frequency as the measure of detail is described in [Reddy97]. Here, the appropriate LOD is selected based on velocity of the model, size, and eccentricity. This method uses pre-rendered images of the object to measure the spatial frequency on its surface. The measured values are then scaled according to the factors velocity, size, and eccentricity. After that, this information is used to predict the highest visible detail where the object should be presented to the user.

In this paper, we propose a method understanding different qualities of motion as a detail. We demonstrate the use of approaches known from LOD domain to balance the animation complexity in the VE. Therefore we call our method as Level of motion Detail. The following sections are consequently devoted to the definition of motion detail, design of visual acuity model, and presentation of the results with the implemented technique.

## 2 MOTION DETAIL

The motion detail can be interpreted as a quality of the motion which, more or less, provides the user with sense of being physically present in the computer generated world. The quality characteristics of the motion can be expressible as smoothness and/or degree of naturalness. Here, the term of naturalness is used as the correspondence between the mass of the object and its motion. It varies with character of the synthetic actor which can produce different gestures according to its age, mass, health, etc. In terms of physics, the motion detail is finally modeled by varying the acceleration of body parts of the synthetic actors.

With respect to the previous paragraph we can state a definition of the motion detail as follows: Let's suppose that a motion, given by its key positions, can be extended by any feature in such way that the motion is then perceived by the user as more natural – closer to the realistic feeling of the VE. Next, let's suppose that the motion extended by this feature will not lose its original meaning (e.g. will be performed along with the same trajectory, or will meet the given key positions at any rate). Then we will get two different representations of the same motion and the feature we will associate with the term *motion detail*.

According to this informal definition we can interpret the motion detail as the difference between two representations of the motion (using methods with different complexity, e.g. linear interpolation vs. physical simulation). Thus we can specify two representations and each of them is one **level of motion detail**. These representations will obviously vary in complexity of computations and thus selecting the appropriate levels of motion detail the workload could be balanced with respect to the given viewing conditions.

## 3 MOTION DETAIL SELECTION STRATEGY

### 3.1 Detail Selection Criteria

In order to determine an appropriate motion detail in the real-time, a measure specifying the viewing conditions in the virtual environment is necessary. This measure is then used to design visual acuity model which maps the viewing conditions to the appropriate level of the motion detail.

It is very hard to describe the motion detail using formal means and thus to relate it to the viewing conditions. Therefore, we have used stronger

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[1] Horopter is a circle intersecting the fixated point and the eyes of the observer. The light stimulus coming from the points laying on this circle deeps to the corresponding regions of the retinas in both eyes and thus these points are perceived as a single image. On the other side the stimulus coming from the points not lying on the horopter are perceived as a double image ([Troja94]).

criteria taking into account motion itself. Our approach is based on the idea where the human visual system is not able to recognize too slow or too fast motion (e.g. the legs of the walking human observed from large distance and the bird flying across our visual field near of us). This implies that also details of motions will not be registerable when the velocity of the moving object lies outside these two limits.

In addition, our visual sensitivity to the motion detail varies when changing some other factors. It is known from previous research (e.g. presented in [Kolb00]) that based on the anatomy of our retina, the density of photoreceptors rapidly decrease from the center of visual field to the periphery of vision. Hence, the ability to recognize the motion detail will decrease with the eccentricity.

Based on these observations we have selected three main factors which will be now discussed: angular velocity of the moving object, eccentricity, and the size of the object.

### Velocity

Velocity is the main characteristic of the motion itself. Owing to this parameter, we can classify objects changing their positions in time. According to the design of our visual system the motion is perceived more sensitively than static detail. On the other hand, there are also limitations which make it impossible to register differences in the quality of the motion.

Observing the walking human from different distances we can find that even if his motions have the same quality, we can not perceive the details of them from the large distance owing to small time changes of the viewing angle under which we observe the walker.

Therefore, the visual system has low limit in perception of the velocity. We can imagine the process of motion perception using the model known as the Reichardt's motion detector ([Reich89]). The model consists of two photoreceptors connected by comparing circuit with delay (see Fig. 1). The detector evaluates responses of the two photoreceptors in regular time steps. When the photoreceptor detects the presence of the stimulus it returns 1 otherwise 0. When the second photoreceptor's response is 1 and response of the first photoreceptor from the previous time step is also 1 then the motion with direction from left to right is detected.

If the object moves so slowly that it is detected by the first photoreceptor in time 1 and the second photoreceptor will not get strong enough stimulus at the time 2, then the motion detector will not indicate any motion of the object.

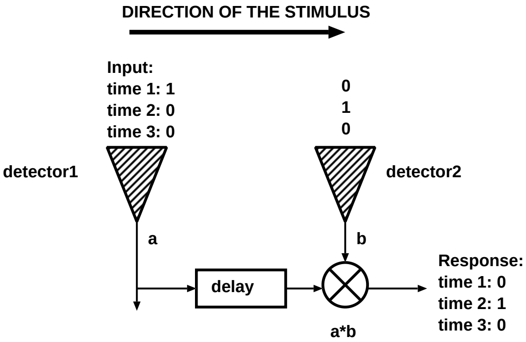

Figure 1: *A scheme of the Reichardt's motion detector model (redrawn after http://aris.ss.uci.edu/cogsci/courses/psych9b/lectures.html).*

To derive the low limit of recognizable velocity more accurately, we first need the distance between the two photo-sensors. After [Kolb00, Reddy97], the minimal angular distance between two points which the HVS is able to recognize is 0.5 min of arc. This value directly originates from the density of photoreceptors in the central region of the retina called as fovea. This is the first parameter used in our metrics.

The model based on the Reichardt's motion detector functions as the system which scans the values given by the photoreceptors in regular discrete time steps. The period of this time is given by two major factors: time of refractive phase of photoreceptors and signal-processing time. The direct extraction of its length leads to complicated model of the multi-layered neural visual system. Thus we simplified it taking the critical period of the flicker as the length of this desired time interval $\tau_L$. This is the time length threshold over which the human visual system processes the motion of objects on the display as a sequence of discrete images ([Glass95]).

Thus, we can express the low limit of velocity[2] by the equation:

$$\omega_{low} = \frac{\phi_{min}}{\tau_L}, \qquad (1)$$

where $\phi_{min} = 0.5\text{deg}$ and $\tau_L \approx 0.1\text{s}$ for foveal vision. Hence, we will approximate the minimal registerable velocity by value $\omega_{low} = 5$ min of arc per second. It means, for example, that object moving with velocity $\omega_{low}$ ob-

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[2] We express all parameters (size, velocity) in angular measure because this approach is easier when comparing their values independently on the distance.

served from distance 100m has the velocity $v = 2.distance.\tan(\frac{\phi_{min}}{2}) \doteq 15cm.s^{-1}$.

The high limit of the velocity will be determined as so fast motion where the HVS is not able to recognize the character of the moving object (only its motion can be registered). Thus, over all limitations of the HVS, this velocity can be defined as the velocity of an object of the size $\Psi$ which moves across the whole field of view $\Phi$ in the time interval shorter than a time period $\tau_H$ (Fig. 2).

Thus, the high limit of velocity can be expressed as:

$$\omega_{high} = \frac{\Psi + \Phi}{\tau_H}, \tag{2}$$

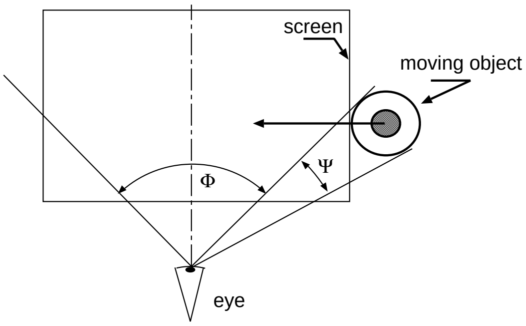

Figure 2: *The demonstration of an object with size $\Psi$ moving across the visual field ($\Phi$). As the object appears at the field of view crosses the whole angle $\Phi$ and disappears in time shorter than $\tau_H$ the eye is not able to register the most of the model characteristics.*

where the value of $\tau_H$ was experimentally set as $\tau_H = 1s$ (with preconditions $\Phi = 180deg$, $\Phi \gg \Psi$). With respect to equation 2, this value represents the angular velocity $180deg/s$ by which we turn our head from left to right without stopping our eyes (they normally try to fix on objects in the scene).

The growing size of the object implies higher stimulus on the retina and thus higher sensitivity to the motion detail. On the other hand, the equation 2 doesn't incorporate the special case when the size is zero and thus the object is not visible. This case is to be solved with a classical LOD method which can be combined with our method.

### Eccentricity

The ability of the HVS to recognize different details in the real scene changes with increasing eccentricity $E$. Based on studies presented in [Kolb00], the density of the photoreceptors decreases with an angular distance from the center of the visual field. It implies that relative distances of the photoreceptors, and thus the smallest visible angle $\phi_{min}$, increases.

It also implies that the sensitivity to the motion detail decreases with the increasing eccentricity. After [Reddy97] and [Kelly79], the shape of the function linking dependence of sensitivity to static detail on eccentricity is approximated by a magnification factor $M$:

$$M = \frac{M_0}{(1 + 0.29E)} \tag{3}$$

where $M_0$ is the value of magnification for the most central point, instantiated by the author as $M_0 = 1$, $E$ is the eccentricity multiplied by empirical constant 0.29 which was also used by [Reddy97] based on previous research concerning physiology of the HVS.

According to the low values of the velocity $\omega_{low}$, we can expect that the smaller visible change of position vector would be scaled by the similar factor. Therefore, we adopted the equation 3 for our visual acuity model.

Thus incorporating the equations 3 and 1 the dependence of low limit of velocity in dependence on eccentricity we have expressed as:

$$\omega_{low}(E) = \omega_{low}(0).\frac{1}{M} = \omega_{low}(0).(1 + 0.29E) \tag{4}$$

The $\omega_{low}$ increases with the eccentricity owing to the magnification factor $M$.

The high limit of velocity ($\omega_{high}$) we use as a parameter independent on the eccentricity. We derived this simplification from the precondition that owing to the high velocity of the object's image moving across the retina the measurement of eccentricity has small meaning in comparison with the low velocities.

### Discussion of Criteria

The factors used to measure viewing conditions under which the user observes a moving object (velocity, eccentricity, and size), are all expressed in angular measures. This leads to simple computations using fundamental operations with vectors.

Measuring the velocity using vector algebra (as shown on Fig. 3) has next two advantages. The visual acuity model is independent on the orientation of motion. It takes into account the stimulus which comes into the eye under actual conditions. Thus the motion performed in direction perpendicular to optical axis of the eye will be better detected than motions in parallel direction. This corresponds to the real situations, where our eyes better recognize the details of motions performed in direction perpendicular to the direction of our view.

The second advantage is that the velocity is measured with respect to the direction of the user's gaze. Thus the measure incorporates the motions not of objects only, but also of the eyes too. This corresponds to the situations when moving our head we are not able to register all details in the environment similarly as in case when our head is fixed and the objects are moving.

### 3.2 Visual Acuity Model

In order to complete the visual acuity model, we need to propose a function $A$ which simulate visual sensitivity of the HVS to the motion detail under the given conditions. The function $A$ links the degree of the visual acuity with velocity, eccentricity, and size of a moving object according to abilities of the real human eye to recognize details of motions in a specified interval of velocities.

Using the equations 2 and 4 we have designed the visual acuity function $A$ as follows:

$$A = \begin{cases} 1 & (\omega_{low}(E) < \omega < \omega_{high}) \\ 0 & otherwise. \end{cases} \tag{5}$$

where $\omega$ is the actual angular velocity of the object.

If the visual acuity function $A$ gives 1 as a result the motion of the object is to be refined by using a physical simulation method, whereas 0 represents switch to the lower detail. In this case, the motion will be computed using linear interpolation. The equation 5 represents our visual acuity model enabling classification of the motion according to the actual conditions measured as actual velocity of the model, eccentricity, and size of the model.

We have implemented and tested our technique with the simple VR model application. The following section is devoted to the main parts of our LOmD mechanism implementation.

## 4 IMPLEMENTING THE LOmD MECHANISM

### 4.1 Calculating Visual Acuity

Application of the LOmD mechanism consists of three stages. The first one lies in a computation of the object's angular velocity. This value is computed as the angular distance between two position vectors in sequence of the two following frames ($F_i$ and $F_{i-1}$) as shows Fig. 3. The position vector is defined by the position of the eye and the center of the smallest bounding sphere of the object. The diameter of this sphere is later taken as the size $\Psi$ of the object.

The computed angular distance between the position vectors is related to the period of time between the following frames and this gives us the actual angular velocity.

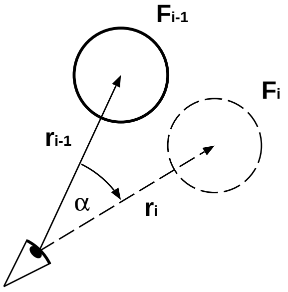

Figure 3: *Measurement of angular velocity for an observed object computed from angular distance of position vectors.*

As the motion of each object in the VE is described by a screenplay (or any formal description), the approximate positions of the object are known independently on kind of interpolation. Thus we can determine the velocity at each level of the motion detail.

Using physical simulations for a generation of high level of the motion detail produces motions with non constant velocity which can cause undesired motion inconsistencies (known as popping effect in the LOD) when using actual values of the velocity. Therefore, computing our function $A$ we use floating average value. This produces smoother reactions of the LOmD mechanism switching between two levels of the motion detail.

During the second stage, the visual acuity function $A$ is evaluated according to the equation 5. The motions of the user or the observed objects can cause oscillations of viewing conditions and it can also produce some inconsistencies of the motion. Therefore, a hysteresis is incorporated into the calculation of $A$ in order to eliminate these oscillations. It contributes to smoothness of the motion detail changes. This is more important than for changes of the static detail which does not require any time continuity so strongly.

The third stage lies in the selection of the appropriate level of motion detail with respect to the resulting value from the previous stage. The selected level of motion detail is represented by one of two algorithms used to produce the desired motion:

- **physical simulation**: the motion is computed by using a technique which incorporates the main physical characteristics of animated object (mass, moment of inertia). This kind of technique produces motions with high degree of naturalness but with high computational cost. Thus this method of motion generation represents high level of the motion detail.
- **linear interpolation**: the motion is computed using a simple technique dividing the motion in equidistant steps which are consequently performed one in each frame. This technique produces low level of the motion detail because of low naturalness of the motion produced by the model.

### 4.2 Integrating the LOmD into the Animation Control Scheme

The Fig. 4 shows the example of control unit for one model. It consists of *kinematic module* which receives key positions from the *scheduler* and generates intermediate positions by the linear interpolation. Next, the *LOmD module* determines which level of the motion detail will be generated with respect to the measured viewing conditions.

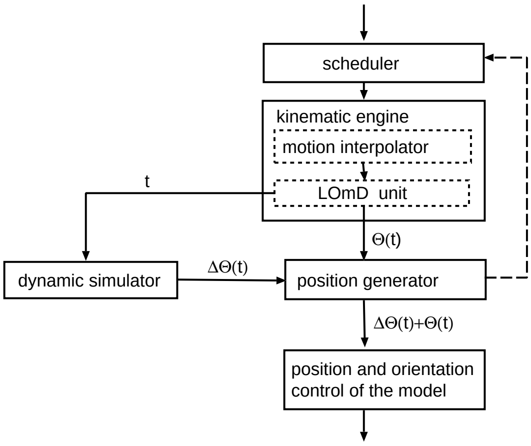

Figure 4: *The animation control scheme with LOmD module integrated in kinematic engine.*

If the motion detail is switched to the higher level, the control flow is directed to the *dynamic simulator*. It re-computes the position and orientation of the model with respect to its mass and the moment of inertia. The new state of the model is used in the rendering process and whole process is repeated in the next frame.

In order to guarantee the motion continuity, the *position generator* sends the information about corrections made by the *dynamic simulator* (if any) to the *scheduler*. It makes appropriate updates to intermediate positions generated in previous stage by *kinematic engine*. This feed-back is represented by dashed arrow on the Fig. 4.

## 5 EXPERIMENTAL RESULTS

### 5.1 Experimental Methods

We have performed two kinds of tests with a simple physical model of pendulum: user test and performance test. During the first test, our visual acuity model has been compared with function of the real human visual system. The second test has been devoted to speed-up measurement in the VE using the LOmD technique.

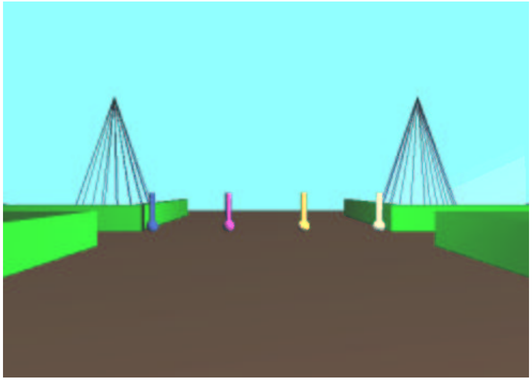

Figure 5: *Demonstration of the user test. Four pendulums swinging according to the different interpolation techniques – two of them use linear interpolation and the second pair uses physical simulation.*

### User Tests

The user test has been arranged so that the scene with four physical models were presented to ten subjects (see Fig. 5). The motion of two models were computed using physical simulation and the second pair was animated using linear interpolation. The models were presented to the subject twice: first with decreasing distance in the center of vision and next with decreasing eccentricity. The task of each subject was to determine viewing conditions under which he/she is able to recognize the differences among the motions of the models. The result was then compared with the estimations calculated by using our visual acuity model.

Fig. 6 demonstrates the difference between the time progress of linearly interpolated and physically simulated motion progresses with constant velocity whereas the physically simulated pendulum moves with respect to the gravity which seems more natural to the user. The task of the subjects was to distinguish these two characteristics in virtual environment.

The result of the comparison showed that when moving closer to the models, most of the subjects were able to distinguish details of motion later then the LOmD mechanism switches to the higher level of motion detail. Thus the user is not able to recognize that the LOmD technique is used.

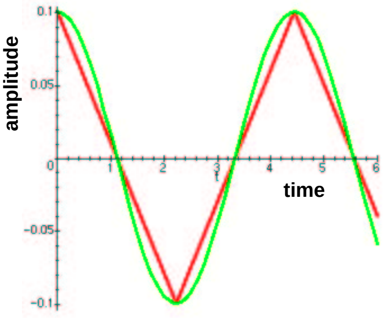

Figure 6: *The graph of comparing the time progress of amplitude for simulated and linearly interpolated motion of a pendulum.*

During the test, the LOmD mechanism switched the levels of motion detail between distances 36 and 46 virtual meters[3] whereas the average response of the subjects was 45Vm which lies inside the previous interval. We should note that the responses of the subjects were influenced by the knowledge about the differences and that they studied the scene for relatively long time which is not so probable in real virtual scenarios.

According to the measured data we have found that the reactions of the most of subjects were very close to the responses of the LOmD mechanism. Hence, this test showed that the visual acuity model used by our LOmD technique can successfully approximate the function of the real HVS.

### Performance Tests

During the performance tests, three kinds of scenes with 100, 200, and 300 physical models were tested by arbitrary walkthroughs in the VE. The scenes differed in pattern of model distribution in the scene. We tested regular, circular (with ten concentric circles) and random positioning of the models. Each scene was passed twice – first without and then with the LOmD. Comparing these two measurements we have got speed-up for each pattern. The graph on Fig. 7 presents the measured data.

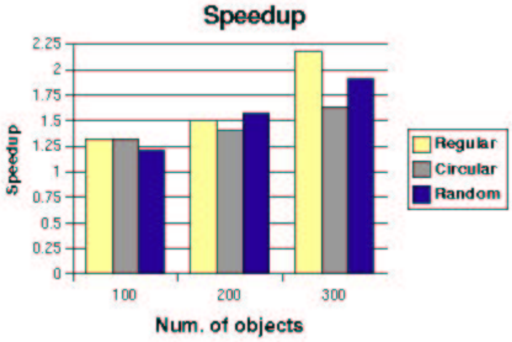

Figure 7: *The speed-up of VR system employing LOmD mechanism.*

Overviewing the graphs corresponding to the measured patterns we can find that the speed-up of the VR system decreases when the density of models in the visual field rapidly changes (circular concentric pattern). On the other side, we achieved the higher speed-up with the random and regular pattern.

The character of the scene with circular concentric pattern of model positions corresponds rather to the closed scenes (e.g. rooms) where the moving objects are usually concentrated in one place. In contrast to those scenes the regular or random patterns better correspond to open scenes where many objects can move but they do not usually concentrate in and can be observed from large distances. Thus, the proposed technique is more suitable for large scenes (e.g. a landscape or squares) then for closed environments as rooms.

The graph on Fig. 7 shows that the speed-up in scene with 300 models was about 2. This relatively small value is given by small degree of freedom (DOF) of the testing model. We can expect that using more complex models with the higher degree of freedom we will achieve higher speed-up. Thus the presented data we interpret as the smallest value achieved with use of the proposed technique.

## 6 CONCLUSIONS

We have introduced the notion of the Level of motion Detail. Hence, we generalized the term of detail to use it in wider context then in the classical LOD method using this term for only

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[3] Vm – the measure used in our project to distinguish between units in real and virtual environment

static features of the models in the VE. The definition of the motion detail is based on abilities of the human visual system to register differences of motions with different degree of naturalness. The differences in naturalness of the motion are given by the different methods (with the different computational complexity) used to control the moving model. We have proposed mechanism using two levels of the motion detail represented by two animation control techniques differing in the complexity of computation: linear interpolation and physical simulation.

Based on the anatomy of the eye and on the methodology used in the classical LOD methods we have selected three parameters as the criteria to determine an appropriate motion detail recognizable by the user under given viewing conditions: angular velocity of the object (with center in eye of observer), eccentricity, and the angular size of the object.

We have designed a model associating these parameters with the appropriate level of motion detail. This model is referred to as *visual acuity model*.

As the LOmD mechanism is based on visual perception, it functions automatically without any interventions of the animator. He/She does not need to know about the LOmD method included in the animation control system. This feature we call as **transparency**.

Implementing a new model it is possible to integrate in the system without any significant changes in the LOmD method. Thus, we can find the **universality** as the second feature of the technique.

Using *animation control scheme* described in 4.2 the LOmD mechanism switches between two representations of motion without loss of the time continuity. On the other hand, our method does not solve behavior of the animated model during interactions with the environment. In a general approach, the animation should be switched to the higher level of motion detail after each interaction. But it is still subject of further work.

The next problem concerns motions of objects rotating around the center of the bounding sphere. Such the motions are not detectable by the LOmD mechanism and this limitation can cause loss of generality of our method. It seems the general solution, how to measure velocity of an object, does not exist. Thus the idea would be computation of an "out-of-center" point specially for each object with respect to its preconditioned kind of motion.

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