

## Sounds of Silence - How to Animate Virtual Worlds with Sound

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### Abstract

Sounds are an integral and sometimes annoying part of our daily life. Virtual worlds which imitate natural environments gain a lot of authenticity from fast, high quality visualization combined with sound effects. Sounds help to increase the degree of immersion for human dwellers in imaginary worlds significantly.

The virtual reality toolkit of IGD features a broad range of standard visual and advanced realtime audio components which interpret an object-oriented definition of the scene. The virtual reality system "Virtual Design" realized with the toolkit enables the designer of virtual worlds to create a true audiovisual environment. Several examples on video demonstrate the usage of the audio features in Virtual Design.

## 1 INTRODUCTION

Virtual reality applications are mainly characterized by realtime processing capabilities in order to react immediately to user actions and by close integration of humans by novel output and interaction devices. Realized applications either focus on the imitation of real worlds (interior design, architecture, landscapes) or the creation of imaginary, abstract worlds with even different behaviour (experimental research, art).

Today many virtual reality applications concentrate on the output side on the generation of a sufficiently high image frame rate. This approach was motivated by the availability of high performance graphics workstations, adequate rendering techniques and the stimulation of one primary human sense - our visual perception capability.

Within the last years low-cost personal computer and mid-size workstations have been equipped with audio devices originally for multimedia purposes. On the other hand electronic music devices like synthesizers have made rapid progress in sound generation and usability especially with the introduction of digital components and the midi programming and controlling interface.

Although audio hardware and software is readily available today, few systems use acoustic sensations to enhance the man-machine communication in virtual reality. Acoustical simulations - in certain aspects similar to visual light simulations - contribute a great deal to a realistic impression of virtual worlds. The algorithms presented can either be applied in realtime or they can precompute acoustical characteristics which will be evaluated later in realtime.

The virtual reality system "Virtual Design" of IGD concentrates on the imitation of natural environments, i.e. offices, buildings, cities, landscapes. It is completely data-driven, i.e. the scene with all visual and aural objects and associated attributes is defined in a datafile-interface.

This paper introduces the facilities at the VR demonstration centre of IGD in Darmstadt and the architecture of the VR system "Virtual Design". The available qualities of acoustical simulations are explained and an overview over the specification of worlds with the datafile-interface is given. Furthermore the interpretation and processing of the audiovisual objects is outlined. Several examples demonstrate the usage of the system and the achievable audiovisual effects.

## **2 THE VIRTUAL REALITY DEMONSTRATION CENTRE OF IGD - HARDWARE FACILITIES**

Since the beginning of 1993 the Fraunhofer Society has established a demonstration centre for virtual reality partly located in Darmstadt. The intention was to provide and establish a facility where different systems can be demonstrated and evaluated, where consulting, know-how-transfer and training is offered.

The demonstration centre in Darmstadt provides a high quality environment of virtual reality hardware (figure 1) to run different applications. Central node is a high performance graphics workstation (SGI RE), to which various input devices (dataglove, flying joystick, spaceball, spacemouse, 3d tracking system) and output devices (head-mounted-display, large screen stereoscopic projection, video) are connected.

The graphics workstation is linked to a multimedia-workstation and a personal computer, which controls the midi-equipment (synthesizer and effect processor), the 3d audio processing card and a power unit control card. The audio output signals of both machines are combined in a mixer, which also includes the signals of a compact disk player, a digital audio tape, a microphone and a video player. The mixer drives speakers as well as the headphones in the head-mounted-display via the 3d audio card.

There are many different processing tasks to solve in virtual reality applications: the simulation of world behaviour, the computation of the visual and acoustic representation, the management and access of peripheral devices and the interpretation of user actions. As there is no integrated machine available which satisfies all needs, specialized computing nodes distributed in a net offer optimal use of processing power. Besides the high performance graphics workstation a compute server (Convex) for simulation purposes and a multimedia workstation (SGI Indigo), 3d audio processing hardware (focal point) and midi-equipment (Akai S1000, Alesis QuadraVerb) for sound rendering are available.

To manage and utilize the full processing power of a heterogenous net a distributed system is required. In Virtual Design a sound server addresses multimedia workstations as well as midi-devices via a common programming interface. The server stores a table of digitally sampled sounds, which can be manipulated.

The multimedia-workstation permits calculation (e.g. the convolution of impulse responses with dry sound samples) and subsequent rendering of digital sounds plus basic manipulation (volume). The midi-equipment consists of a synthesizer and an effect processor. The synthesizer permits the realtime manipulation of volume, frequency and stereo level. The effect processor has a number of controllers to simulate the reverberation of a sound in an enclosure. Adjustable parameters of the effect processor are:

- enclosure type (room, hall, echo chamber),
- decay time,
- degree of diffusion (number of reflections),
- reverberation density (density of impulse response),
- low frequency decay,

high frequency decay.

The devices installed at the demonstration centre allow the presentation of virtual worlds to a large audience via stereoscopic large screen projection and speakers as well as an individual self-experience via head-mounted-display and headphones (also simultaneous).

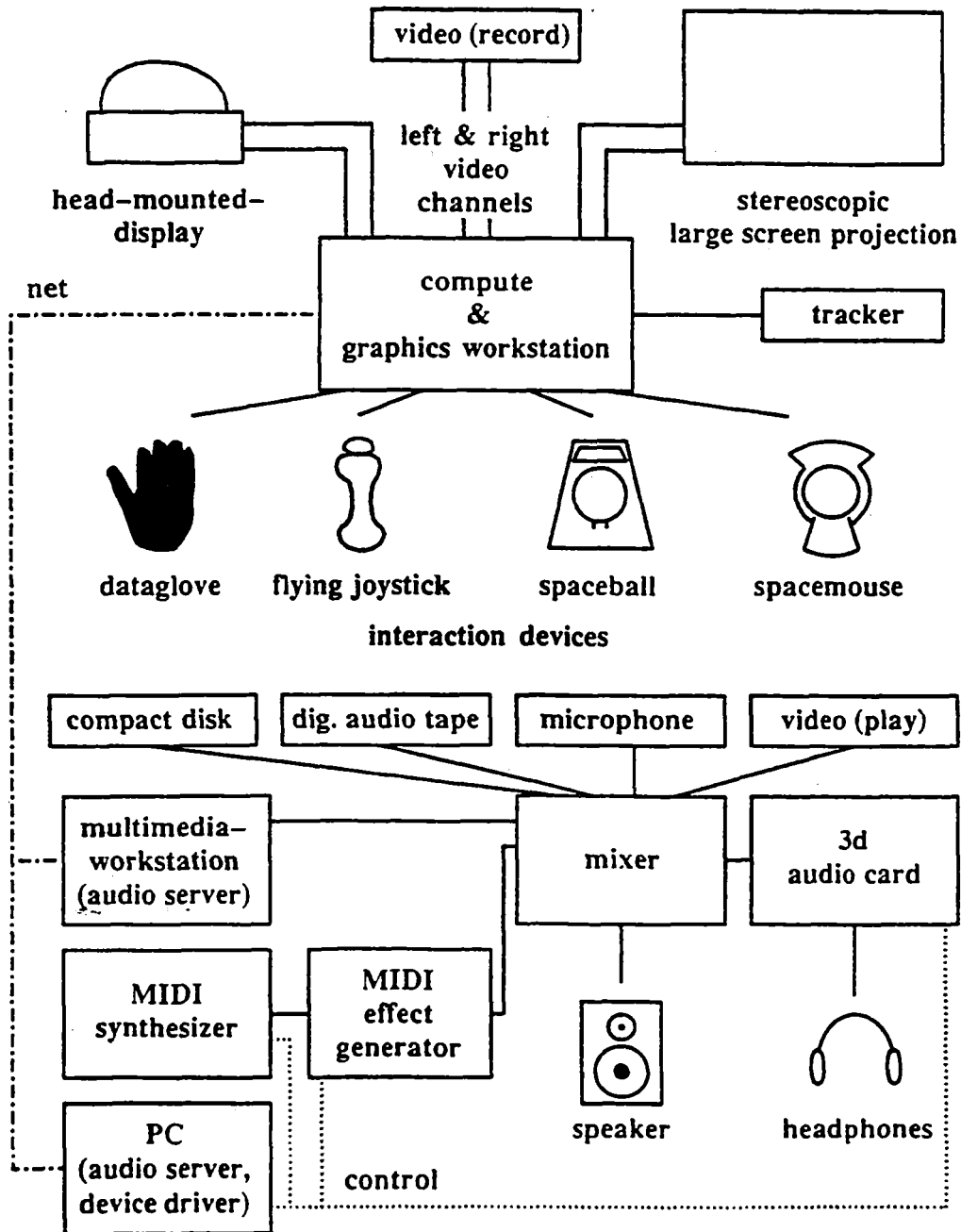


Figure 1 Facilities at IGD's demonstration centre in Darmstadt

### 3 QUALITIES OF ACOUSTICAL RENDERING

To animate virtual worlds with sound which have been designed as models of our real world, realistic sounds of our environment have to be integrated. Common environmental sounds are discrete (steps on the floor, door closing etc.) and continuous sounds (teapot boiling, drilling etc.) caused by material interaction (sound events), vibrating objects (machine parts), liquids (splashes), aerodynamic sounds (exploding balloon) or sounds from loudspeakers (radio, tv). Sounds are also used for alarms (fire alarm), warnings (r.p.m. of engine getting too high) and messages (engine going). Sounds are damped through objects (windows), they can "crawl" around objects (pillar, especially low frequencies) and the reflections are mostly specular (due to wavelength). A frequency shift can be noticed from passing objects (police car with siren). Humans can detect the position of a sound source in space (azimuth better than elevation).

To satisfy at least some of the above mentioned acoustic effects Virtual Design offers several acoustic rendering qualities. The room acoustical simulation algorithms have many parallels to visual simulation algorithms, the main differences caused by the different propagation speed and wavelength of sound and light and the time resolution.

**Sound events:** An object is assigned an acoustic material which has a reference to a sound source. Ideally a matrix of sounds should be stored containing all possible collision sounds between moving objects. In the toolkit this is reduced to a list for the cursor (fingertip of dataglove echo) and all collision-sensitive objects. A sound source indexes a sound stored in the sound server. The toolkit cycles an action loop to update image frames; in each cycle collisions are tested and a callback function is eventually evoked. When an object has an audio event attribute the referenced sound source is triggered. Examples show a drum kit which can be played with the dataglove and an assembly/disassembly system (3d puzzle).

**Direct propagation:** In our daily life three acoustic parameters can be noticed when sound propagates directly from a sound source to a receiver: volume damping (caused by distance and medium), frequency shift for moving objects (doppler effect) and position in space. If a sound source, a receiver and an object have been assigned direct propagation attributes, these objects are passed for computation of the audio parameters to the algorithm. Then the parameters are passed for auralization to the sound server. An example shows a beetle proceeding over a plain.

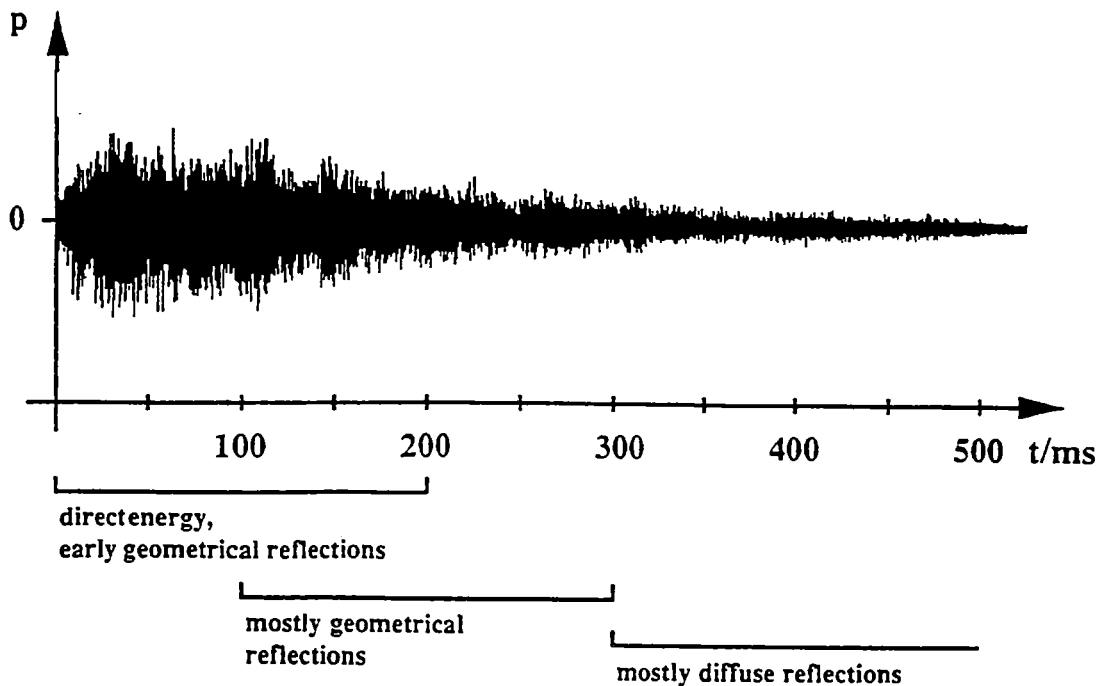
**Statistical approach:** This approach is based on assumptions stated by W.C. Sabine. The algorithm computes an average reverberation time independent of receiver and sound source position. Thus it is possible to characterize a room type, e.g. a living room, a conference room or a church hall. The computed parameter value configures the effect processor, which performs the reverberation in realtime. Whenever an alternative acoustic model is chosen, the reverberation value is recalculated. An example shows a conference room with different reverberation characteristics.

**Room Acoustics:** Room acoustical simulations compute the energy distribution of an energy pulse emitted from a sound source and detected by a receiver within an enclosure. The simulation considers the exact geometry with reflections, absorption, dispersion and air turbulences (wind). The receiver detects the so-called impulse response (figure 2) which can be convoluted with any dry sound sample.

The image source algorithm mirrors actual sound sources at enclosing faces, which can be executed quite easily for rectangular rooms. In Virtual Design the user navigates to the desired listening position, then the impulse response is calculated at this position, visualized and sent to the audio server for convolution. The original, dry sound and the convoluted sound can both be rendered to compare the results.

Ray tracing algorithms trace the propagation of sound particles or rays in an arbitrary world. They are similar to visual simulation algorithms in respect to ray propagation and intersection calculation.

**Database:** The acoustic renderer require additional objects like sound sources, receivers and acoustic material attributes. Visual and acoustic renderer are in many respects very similar; they both operate on geometrically defined scenes. It is the different propagation speed of light and sound which causes algorithmic differences. The renderer compute parameters which are used by an audio server to manipulate digitally sampled sounds.



**Figure 2** Impulse response

The visual model comprises polygonal objects, lights, camera and a scene description with multiple object references. Additional acoustic objects supplement the visual model:

- medium (propagation speed of sound, damping),
- acoustic material (local reflections, sound),
- sound source,
- listener (can be coupled with the observer),
- impulse response,
- sound sample format.

The medium and material data are held in a table with some predefined entries like air medium or carpet material. Objects have visual as well as acoustic attributes; they can be classified to be processed by the desired renderer. A datafile-interface (see chapter 4) provides a convenient definition of the visual as well as the acoustic scene model. When all model description data is loaded into the database, a cyclic rendering process (see chapter 5) is started. In a single cycle each object is inspected, the attributes are evaluated and the object is passed to the specified visual or acoustic renderer for further processing. Typically all visual objects are rendered and acoustic parameters are computed which will alter e.g. a continuous sound.

## 4 THE DATAFILE INTERFACE

An application processed by Virtual Design is defined by a set of environment variables and data files. The environment variables specify device ports, output screen size and device configuration. The model and interaction modes are defined in various data files:

**Control file:** References all other data files (root file). Moreover a lot of parameters can be specified to define the coordinate system, background colour, logo, dataglove representation and tracking parameters, alternative object representations, collision-sensitive objects, images, menu configuration and appearance. Functions can be assigned

to menu entries like fly mode, converter level, automatic camera recording, toggling of system states, triggering of sound sources and acoustic rendering algorithms.

**Scene file:** References and places all objects in the scene, sets objects attributes and transformations, camera and lights.

**Visual definition files:** Defines the object geometries (set of polygons), attributes, colours and textures.

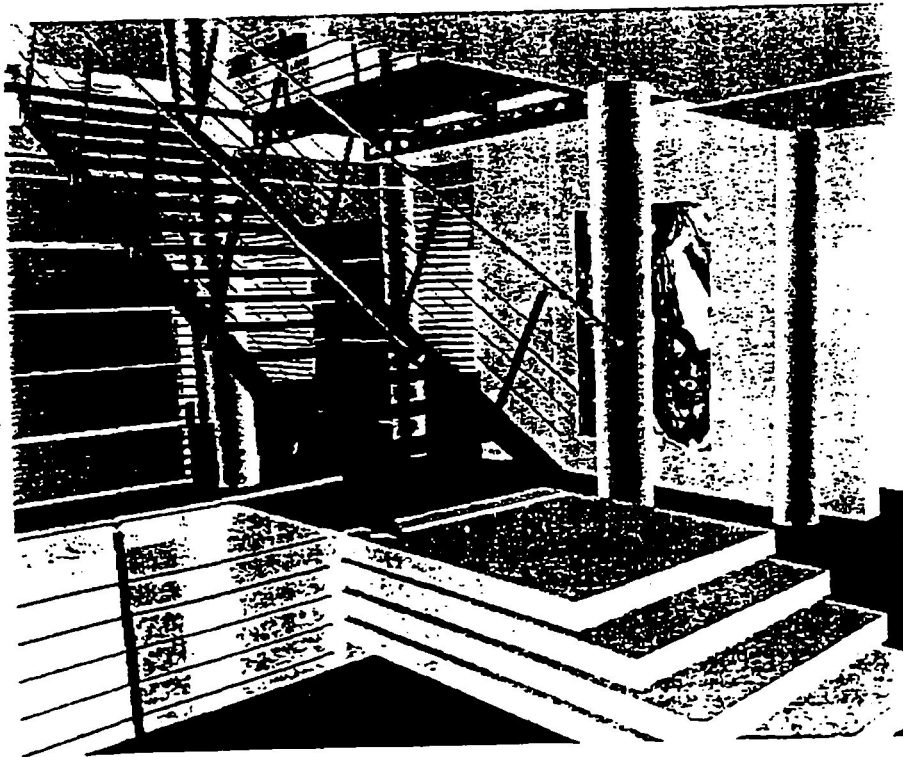
**Acoustic definition file:** Defines receivers and sound sources with attributes, acoustic object properties and configures the audio server.

**Camera file:** Defines a set of specifications for the camera (observer), can be used to load and replay prerecorded walkthroughs.

**Animation file:** Defines a set of transformation matrices for objects. With these data objects can be animated in a world (the beetle for instance).

To integrate geometric models into Virtual Design a number of CAD formats of various modelers including Autodesk's AutoCad are supported.

## 5 VIRTUAL DESIGN - A FRAMEWORK FOR VIRTUAL REALITY APPLICATIONS



**Figure 3** Snapshot of a walkthrough in interior design (CAD data by Asplan, postprocessing by CAD & Art)

Virtual Design provides a convenient and powerful development platform for virtual reality applications (figure 3).

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OF POOR QUALITY

Virtual Design is an example for a system with abilities corresponding to aspects specified near the end of the axis of the DIP-model [EAFF-93]. At the heart of the virtual reality toolkit of IGD a central database is located. Many modules with different tasks operate on the database and manipulate database objects (figure 4).

Objects can be attributed as collision-sensitive. These objects are tested each frame against a cursor object (forefinger of dataglove object for instance). Whenever a collision is detected, a callback function is evaluated to perform a predefined action [Zach-92].

The tracking system transforms device-specific position and orientation data in space into a world coordinate system, which can be interpreted by the navigation module. This module computes the transformation matrices for the observer object and interaction objects driven by devices like the dataglove [FeFG-93].

Human hand gestures detected by dataglove sensors are compared against a table of predefined gestures. Upon recognition the appropriate action function is evoked [Wirt-92].

A radiosity system can be used to precalculate colour values of polygon patches. An integrated ray tracer computes photorealistic images, which can be shown as still frames during a walkthrough as an example for high quality rendering [MüUG-93]. The radiosity system features also level-of-detail object hierarchies, visibility culling, context-sensitive object transformation and time management of frame display rates. It serves as a testbed for further enhancements of the toolkit.

Standard modelers like AutoCad can be used to create and update a scene model. A number of CAD object formats can be imported and loaded into the database to define the scene geometry and the visual objects with their attributes. Additional objects like a hand model and a 3d menu object are included by default for visual feedback of interaction.

A sophisticated rendering system provides an object database interpreted by several visual and acoustic renderers with realtime processing capabilities. The object database comprises up to now for visualization a two level hierarchy: For modelling purposes the objects are grouped into sets, for rendering purposes the objects are transformed into a flat, referenceless but fast interpretable cache structure. To master very large and complex scenes visibility culling, level-of-detail scene analysis and a hierarchical database is currently under development. The visual renderer uses SGI's GL to achieve the necessary performance.

The acoustic renderer requires additional objects like sound sources, receivers and acoustic material attributes. The rendering system currently comprises four different acoustic renderers [AsGö-93]. The renderers compute parameters which are used by an audio server to manipulate digitally sampled sounds.

A programmable video-recorder integrates motion pictures into virtual reality applications. A peripheral device controller steers AC-powered electric devices like fans to create the illusion of movement.

With these modules a sample virtual reality system "Virtual Design" has been realized, which permits the processing of highly differing applications. Virtual Design is extremely flexible and can be configured through a data interface. Possible interactions are specified with a configurable 3d menu.

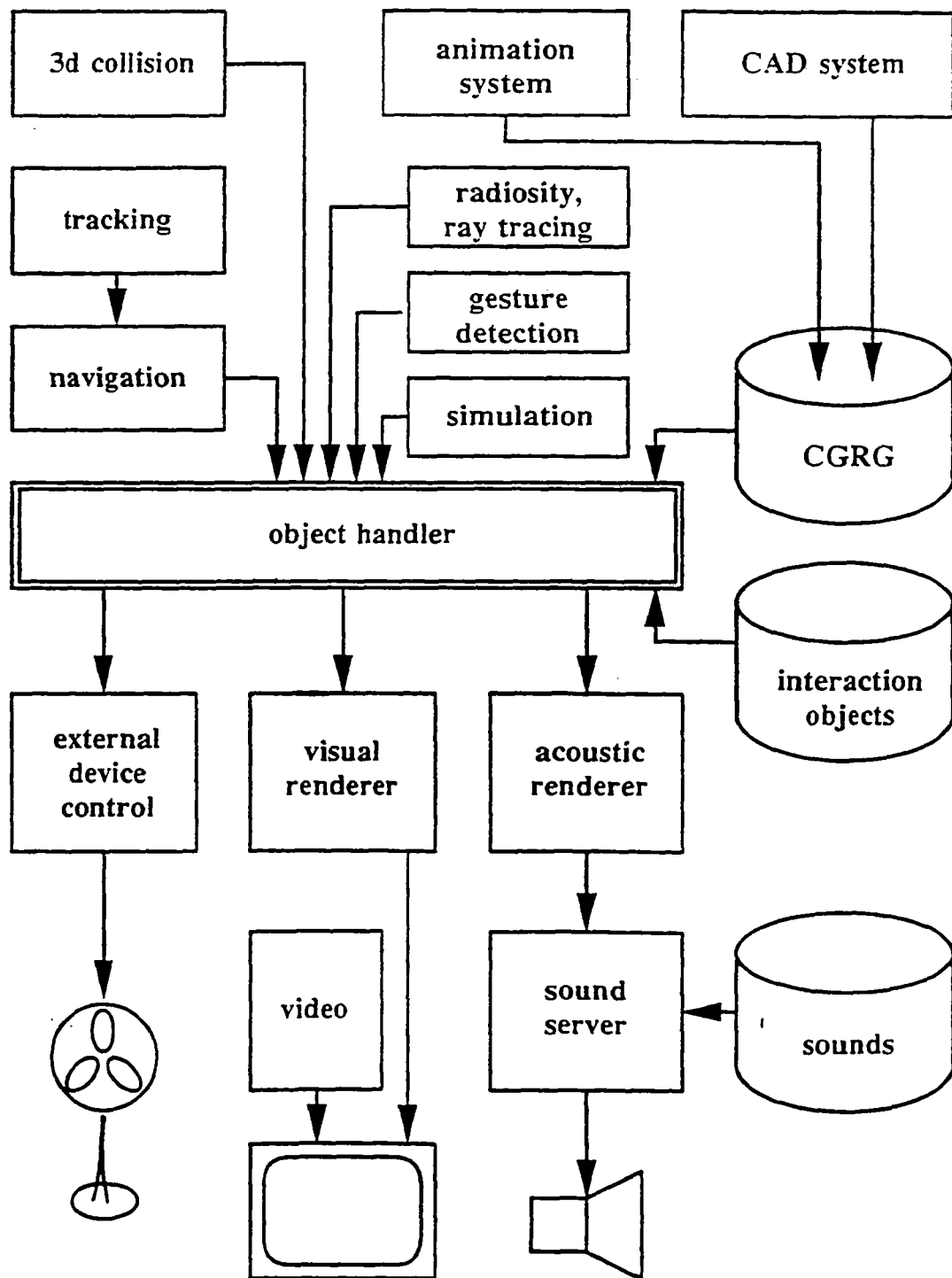


Figure 4 Module architecture of Virtual Design

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The basic structure of Virtual Design in respect of acoustic rendering is as follows:

main:

```
load system configuration
load scene
initialize peripheral devices (interaction device, tracker, audio server)

if (any object with statistic attribute)
    evoke statistic renderer
    send reverberation value to audio server

navigation loop

    get navigation data
    render next frame

    if (any objects with direct attribute)
        send play (object->source, volume, frequency, 3d position) to audio server

    if (menu evoked)
        disable navigation
        evaluate selected menu item:

            image source renderer:
                evoke image source renderer
                visualize impulse response
                send impulse response to audio server

            trigger sound source:
                send play (source) to audio server

            trigger convoluted sound:
                send play convoluted sound to audio server

        enable navigation

    if (collision detected)
        if (detected object has event attribute)
            send play (object->source) to audio server
```

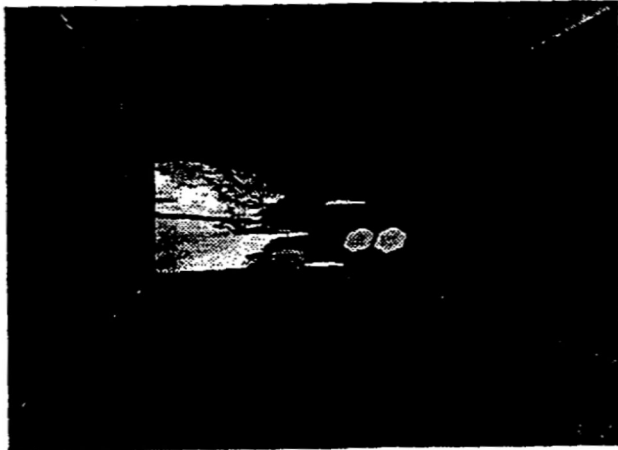
## 6 Examples

The acoustic rendering qualities described in chapter 3 are demonstrated in exemplary virtual world applications, which can be seen on the supplemental video tape. Some snapshots from these virtual world explorations are shown below. Each application is generated by loading and interpreting file data for the visual and acoustic scene.

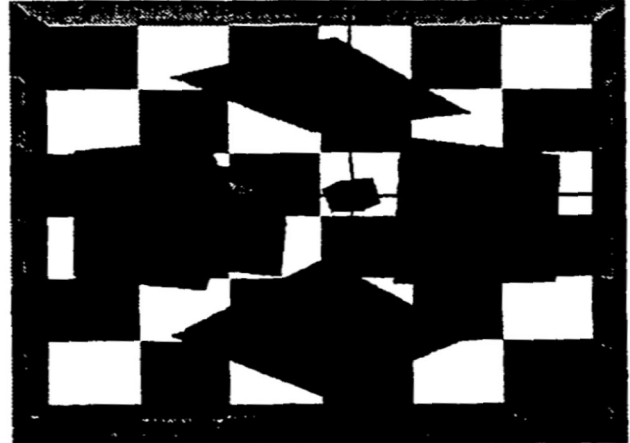
In figure 5 an example for the application of sound events is pictured: a drum set placed in the middle of a virtual room can be played with the dataglove.

Figure 6 shows an example of an assembly/disassembly system with sound feedback. Notifying sounds are released when a part is grabbed, when two parts collide and when they fit together and finally an applause rewards the lucky user.

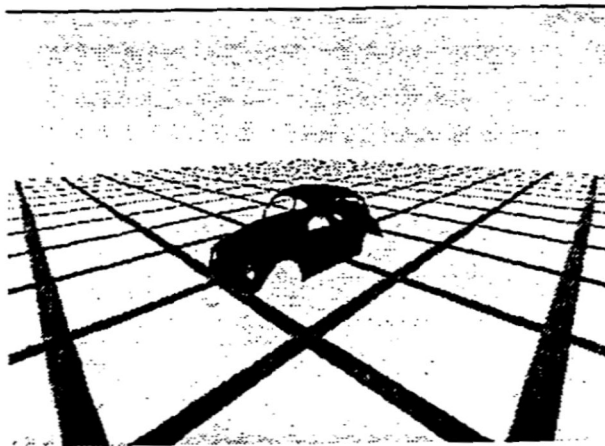
Figure 7 pictures a beetle standing in the middle of a plain. When the simulation is switched on, the beetle passes several times the observer (equals listener). Change of volume, frequency shift and stereo position can be noticed.



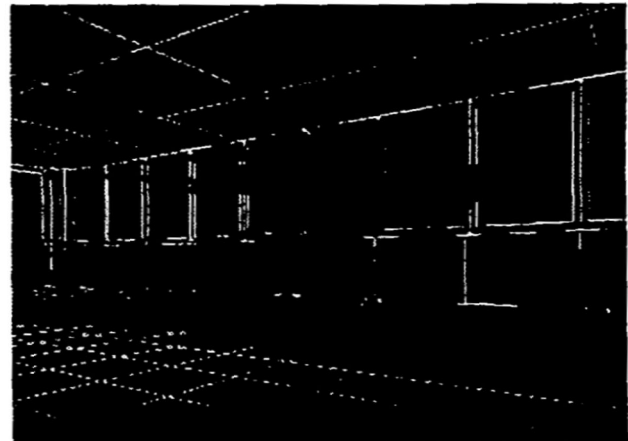
**Figure 5** Drum kit



**Figure 6** Puzzle



**Figure 7** Passing beetle



**Figure 8** Image source algorithm

Figure 8 shows a snapshot from an audiovisual virtual world, where the visual model is shown in wire frame quality, the acoustic model in solid representation with absorption attribute mapped onto a blue colour scale. In the center of the model the calculated impulse response is visualized; the vectors depict direction and detected energy of a sound source, the colour depicts the arrival time on a red (early) to blue (late) colour range.

All examples have been realized with predefined scenes modeled with standard CAD packages. Acoustic objects with attributes (receivers, sound sources) and geometry-related attributes as absorption coefficients have been added in the acoustic datafile.

## 7 Conclusion and Future Work

The integration of audio features in virtual reality applications contributes a great deal to a natural simulation of imaginary worlds. It leads a step further to the ultimate goal to stimulate all human senses and let humans totally

immerse in virtual worlds. With the Virtual Design system of IGD a variety of audiovisual worlds are easily defined and presented for exploration to the user.

Standard CAD packages and animation systems allow the specification of scenes with objects, geometry, visual attributes, camera parameters and light sources; they do not support the interactive modeling of acoustic object attributes, receivers and sound sources. The extension of available modelers with acoustic related functions will be one area of research in future. Furthermore the integration of a particle tracer, a geometry simplification module and the connection and application of appropriate signal processing hardware for binaural convolution of sounds in realtime will be evaluated.

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