Walkthrough—Exploring Virtual Buildings

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Part I - Prose Report

duction

ual world system is a computer graphics system allowing natural real-time interaction with a 3-sional model world. Walkthrough is a virtual world system for architects and their clients to explore ngs before they are built, so as to iteratively refine their specifications.

of our virtual-world research at Chapel Hill has involved molecules or human anatomy. In neither of applications does one know exactly how the virtual world *should* seem to the explorer. In Walkthrough, other hand, the researcher can easily tell how closely the virtual world matches the real in the ways that .

virtual-world research project must continually improve in four aspects, shown in the figure. The ape, which constitutes Part II of this report, shows where we are today, and gives short previews of of the advances not yet integrated into the system.

gure also serves as the outline of this prose report. Each of the items shown in ordinary type in the figure ents accomplishments since the first annual progress report in the summer of 1988; each shown in italics tes things we plan, most of which we will achieve in 1989.

te Rate

al motion is *the* crucial factor for realistic interaction. This is achieved through faster image display rates. ty speed also limits other effects important to image realism, namely, realistic shading and texturing, of detail, and stereoscopic viewing. We have developed preprocessing software algorithms that accelerate display on our current hardware. These algorithms will probably remain important through several generations of image generation hardware as we can envision image improvements that will soak up all display power.

ystem currently in use is the Pixel-Planes 4 system which can display close to 30,000 gouraud shaded ons a second. Using a model with 8,000 polygons gave us about 4 updates per second. We used a m developed by John Airey to automatically partition the model which allowed update rates of 15, but presented the viewer with some views that were not correct, such as at the boundary between ons. This algorithm has been extended by Airey to compute the subset of polygons necessary for a t image for each partition. Thus the viewer sees a correct image everywhere in the model.

se the algorithm takes a long time to run, we have only applied it to an old version of the building model, se the newer, more accurate model is still changing frequently. This older version has incorrect colors you may notice in the video. The automatic partitioning algorithm splits the model into 269 partitions or he average number of polygons which must be displayed to get a correct image for any cell is about 237. leans that we have obtained a 30-fold average speedup. The maximum number of polygons which must played for any cell is about 2200, which means we have a worst case speedup of 3.25.

pect to test the algorithm on other data sets, in particular the Orange United Methodist Church. We plan
grate this algorithm with our advances in the use of the radiosity lighting model which greatly improves
alism of the image but makes drastic demands on our update rate. At present we are limited to using
ity on small data sets or moving very slowly through larger radiosity data sets.

osity Lighting Model

rimary attack for increasing the realism in the Walkthrough project this year has been the use of the
ity lighting model, pioneered by Donald Greenberg et al. at Cornell. This model is especially applicable
riors lit with artificial lighting. It models the physics of radiation transfer in enclosed areas with methods
o finite element analysis. All surfaces are diced into smaller subsurfaces. A program calculates the
nt of energy that each subsurface receives and radiates per unit time. This value is then used to determine
lor of each subsurface. The results are interpolated during display to give a smooth variation in color,
ng in the shaded images seen in the videotape.

time of the last report, the best radiosity algorithm known cost time and disk space proportional to the
e of the number of subsurfaces in the model. This effectively precluded its use on something as large as a
ng. In August 1988, the Cornell group published a new technique which had linear space requirements.
irey has implemented this approach and has further improved its time performance four-fold through
e of adaptive sampling methods. Further adaptive methods developed with Ming Ouh-Young have been
to yield a seven-fold speedup. We plan to incorporate these new methods in our main model this year.

sity researchers have typically used specially designed data sets which simplify several problems, such
interpolation step. A significant contribution by the Walkthrough project has been our use of data sets
ed with a commercially available CAD program, AutoCad. The real-life physics nature of the radiosity
ng model calculation has exposed a whole set of problems arising in real models, as opposed to "nice"
al ones: interpenetrating polygons, coincident polygons, and nonorientable surfaces.

irey developed an interpolation and filter algorithm to remove shading discontinuities from data sets
ere not designed with the needs of radiosity display in mind. John Airey, John Rohlf, Clement Cheung,
andy Brown have built other tools to deal with other model inconsistencies.

diosity lighting calculation is a linear system and thus we can apply the principle of superposition to
te the effects of individual lights in a model. This allows us to *interactively* modulate the intensity of
dual lights in the model. We have tested this on small data sets such as the room with two lights seen in
deotape. Penny Rheingans, Randy Brown and John Rohlf have modelled the larger lighting systems
ed in the lobby of Sitterson Hall and The Orange Baptist Church. We hope to produce images which
tely duplicate these lighting systems. As the video was in production, we managed to run radiosity on
terson Hall lobby. Seventeen independents sets of light sources were modelled, including daylight. The
consists of 25,000 surface patches. This makes it difficult to operate in real-time. The update rate is
1 per 10 seconds. We will increase this through the use of micro-coded display routines rather than
y routines written in C. In the title and credit sequences you can see the office lights come on, followed
indirect lighting in the recessed ceiling turning off.

plans are to improve the image-quality-per-polygon ratio of radiosity images. It may be possible to dice
rfaces intelligently so as to maximize the effect on the viewer without increasing the number of polygons
ust be displayed.

er means to improve realism is the use of texturing. Rohlf has successfully implemented the texturing
thm proposed for Pixel Planes. There is not enough memory available at each pixel to allow this
thm to be successfully integrated with the Walkthrough display system, but we expect to experiment
xturing more in the coming year.

l Building

rst building model was built by Dana Smith using the Sitterson Hall blueprints, the Caesar chip-layout
ire from UC-Berkeley and several special purpose C programs. The specialized nature of this modelling
n makes it difficult for anyone other than Dana to effectively modify this model. However, it is

ony to the difficulty of modelling that we continue to use this model to test our display acceleration
hms.

ve adopted the AutoCad program for all future modelling efforts. It handles several problems very well,
ost important being its function as a database and file manager. Any member of the team can contribute
modelling effort. More important is the ability to import AutoCad databases from architects. On the
hand, AutoCad was not designed to make models suitable for photorealistic rendering, but rather for
rint-style drawings. This has forced us to spend considerable modelling resources developing tools to
t these models, but we judge the benefits of the use of AutoCad to outweigh these disadvantages. One of
cools is demonstrated in the video-tape. A re-tesselation and filtering algorithm was developed by Airey
w Pixel-Planes to display a smooth image from discrete patches produced by the radiosity calculation.

or effort in modelling has been to encode lighting system information into the AutoCad model and
ent our file translators to interpret this information properly. A model designed for a virtual world is
complex; one wants a specialized language to encode the characteristics of that world. The translator
ped by Penny Rheingans and John Airey, based on the Unix compiler tools, Lex and Yacc, has proved to
y to extend and maintain.

lans for the future are to work with a real collaborator, an architect with a building in AutoCad format,
us identify important areas to work on.

Machine Interface

Hill has spent months re-engineering the software used for the interface to the display system, to make
to maintain and flexible. The evaluation of interfaces is necessarily an empirical process. We plan to
is newly engineered system to evaluate interface performance through psychological studies.

ample, the joysticks device, two three-degree-of-freedom joysticks with a slider, has proved to be very
to those who use the system often, but they require practice and do not properly give a sense of space to
er. The steerable treadmill system on the other hand is very appropriate for those who use the system
ften, such as clients. It has a very low learning curve and gives a good sense of space to the user.
ver, it is inappropriate for the software developers because it takes longer to get to a certain desired
ze point. The head-mounted display system appears to offer the greatest rewards, but the technology is
imitive.

se the developers use the system everyday, it is difficult to judge interface systems objectively. A
lled experiment that tested learning curves and ease of use would be an important research contribution.

Part II - Walkthrough Videotape 1989

econd, and more vivid, part of our 1989 Technical Progress Report consists of a VHS videotape that
ates the progress. It is enclosed herewith. For those without viewing facilities, we include the script.

Script

ver Sitterson Lobby displayed using radiosity lighting model. Watch the office lights on the lower level.

s Walkthrough system helps architects and their clients by letting them explore buildings while still on
The research purpose is to study computer graphics systems for virtual worlds.

ay diagram of research expansion

l world systems research should expand in four directions.

he update rate must be sufficient for a realistic motion effect.

xcess computation power may be used to improve image realism. The radiosity lighting model is a step
direction.

ing the information used to create virtual worlds requires sophisticated modelling systems.

ve user interfaces must be created and tested on virtual world systems.

lown hall without the benefit of display acceleration preprocessing algorithm.

use of Pixel-Planes 4 on a simple model of the building yields a 4-update-per-second display rate. This
has 7125 polygons.

down the hall and into the lobby using Airey's display acceleration algorithm.

ve developed a preprocessing algorithm that yields an average 30-fold speedup and worst case 3-fold
up on this simple model.

nodel space is recursively subdivided, by planes perpendicular to the coordinate axes, into smaller
es or cells. This produces a tree data structure, with cells at the leaf nodes and splitting planes at the
r nodes. The tree used in this example has 269 cells.

bset of the model that is visible from all viewpoints within a cell is then computed for each of the cells.
equired several days of Sun 4 computer time.

play time, the tree data-structure is searched each frame, using the viewer's position as the key, to find
bset of the model that must be displayed.

ve modified this display program to explicitly show the boundaries between cells as black polygons.

er debugging option allows us to continue to use the display list for a cell even while we are outside it.
eature can be used to show how polygons that are hidden to an observer in the cell are not displayed.
arolina-blue color is the background color. Polygons not visible from the northeast entrance are not
yed.

the speed gained from using the preprocessing algorithm we can add furniture and apply a more icated lighting model.

diosity lighting model can produce stunning images but greatly slows the update rate.

y room with furniture cut into radiosity patches.

ergy transfer calculation computes the amount of energy leaving each patch per unit time in a cessing step. This model required only a few minutes of preprocessing time.

y room with furniture with interpolated patches.

nergy values of the patches are then transferred to polygon vertices with a preprocessing filter. At y time, Pixel Planes linearly interpolates the vertex colors to give smooth shading. The radiosity ation is a linear system and this allows us to apply the principle of superposition. The contribution of ight may be computed independently in the preprocessing step. A weighted sum computed at display llows us to modulate the lights in real-time.

y church Fellowship Hall.

ve improved the performance of the radiosity calculation so that it can be run on large data sets. We lso developed several utilities that make it feasible to run radiosity on data not explicitly designed for liosity lighting model.

y wall of church hall, raw patches.

ve developed a program to re-tesselate and filter patch data obtained from AutoCad data, which otherwise exhibit shading discontinuities. The raw patch data appears here.

y wall of church hall, averaged with naive algorithm.

ive algorithm performs poorly on this real example.

y wall of church hall, re-tesselated and averaged with Airey's algorithm.

-tesselation and filter algorithm removes the shading discontinuites.

ad display.

rimary advances in the modelling area since the last report have been to use AutoCad to encode lighting information in the model.

ill and big screen display.

ve re-engineered the user interface system to emphasize flexibility. We hope to use this feature to do lled studies of interface performance. The devices include the treadmill with big screen display shown oysticks, a head-mounted display system and a bicycle.

radiositized.

credits.