Towards a Z-Buffer and Ray-Tracing Multimode System based on Parallel Architecture and VLSI chips

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INTRODUCTION

After the hidden surfaces algorithms for 3D rastergraphics, hardware design is the main problem, for many applications, such as : Audiovisual animations, CAD-CAM, and simulation.

After a short description of our CUBI 7 system (a 3D real-time Z-buffer system), and its CRISTAL module which increases RAY-TRACING computations, we present our hardware project based on :
- Parallel architecture for RAY-TRACING, special effects ; This module is also useful for pre-processing the image : (rotations, clipping, perspective transform ...).
- A or Z-BUFFER which will be designed on VLSI chips polygon filling will be also designed with pipe-lined chips.

SUMMARY

1 - THE CUBI 7 SYSTEM

For 3D rastergraphics, computation time is very long : on a VAX 750, 2 000 polygons need about 5 to 10 mn before display. So, 3D animations costs are very expensive from $ 2 000 up to $ 3 000 for ONE second.

In order to decrease these costs, we have designed a special purpose architecture called CUBI 7, which reduces computation time to about 40 ms for 1 000 polygons, with no limitation in terms of facets.

We use, for this system :

- A Z-buffer frame-buffer memory, with 16 bits for depth, and 3 times 8 bits for RGB colors.
  This system is modular and can accept :
  512 x 512, or 576 x 720, or 1 024 x 1 024.
- 4 slots for parallel wired processors :
  - A vector generator ;
  - A facet generator, which computes in parallel :
    . smoothing shadows and colors,
    . Z depth,
    both in 0.1 microsecond.
  - A Ray-Casting generator which can superpose Ray-tracing computed objects on the Z-buffer memory. This generator is called 'CRISTAL' and is described later.
- One or more bit-slice Microprocessors with 4K of 112 bits for microprograms, and 32K of 32 bits for datamemory.

Polygonal shapes are structured in objects, with their own rotation and translation matrix ; just as for Ray-tracing objects.

A general rotation and translation matrix is used for the observer's point of view. These matrices are combined with each object matrices.

CUBI 7 system operates the following tasks :
- Rotation and translation of each object, according to the two matrices ;
- Integer conversion in a + or - 2**16 sphere ;
- Shadows computations ;
- Clipping ;
- Perspective transform ;
- Display on the Z-buffer frame memory after : polygon filling in 0.1 microsecond per pixel.

Simultaneously, the Ray-Casting module, which is called CRISTAL, computes RAY-TRACING elements contained in a binary tree.

The host computer may be :
- A VAX or a Micro-Vax in standard ;
- Or a SM90 multimicro-processor system (68 000 + floating point based) which is designed by TELMAT company.

The host computer contains all the database for 3D animation and computes a super-set of PHIGS tree.
This PHIGS tree may contain : Polygons, Vectors and CSG binary trees for RAY-TRACING objects. All the tree (comprised binary CSG tree) can be converted in polygons and displayed on CUBI 7 for quick displays.
Very high quality scenes can be obtained by a multimode process : that is to say, CUBI 7 can accept and mix in Z pixels generated directly by polygon filling, or by RAY-TRACING or also generated by a TV camera.

2 - THE RAY-CASTING MODULE

This module is a special purpose architecture based on 16 to 128 parallel micro-processors units composed with : NS 32032 and NS 16081 floating point unit.

All these units are driven by a same NS processor called Supervisor processor.

A drain, which is designed with the same processor, receives all the pixels generated by each processor.
The drain sends these pixels to the Z-buffer memory, which superposes in depth the :
- Polygonal image ;
- The Ray-tracing image ;
and eliminates hidden parts of each one.

NOTA : One can, however, display polygons with RAY-CASTING algorithm, and PHIGS tree with Z-BUFFER. Pixels computed by CRISTAL module can be send and mixed into the Z-BUFFER of CUBI 7.
The interest is to compute only critically parts of scenes which need really RAY-TRACING (with reflections, refractions, and shadows). Moreover, CUBI 7 has a wired anti-aliased algorithm implemented on its Z-BUFFER, (less than 1s for 1 024 x 1 024). So, RAY-TRACING pixels can be anti-aliased very quickly.

3 - MULTIMODE APPLICATIONS

A - RAY-TACING and Z-BUFFER advantages :

- Polygonal computations are linear, and easily wired : we have obtained a ratio of 1 000 on CUBI 7 compared with a VAX 750.
  But special effects are not easily obtained with polygons such as : shadows, multiple reflections, refractions, etc ...
- At the contrary, RAY-TRACING algorithms displays very high realistic pictures ;
  But computation time is very important.
  One hour for about 10 primitives, 2 light sources, and transparency

B - 3D Animations :

- So, it is very interesting :
  - To design databases (objects) and animations (trajectories) with polygons very quickly, and very short response time ;
  - To compute the definitive images with RAY-CASTING algorithms.
- So, it is needed to have the same database for both algorithms.

We have choosen for this structure a new language support, which is called NIAL (a concatenation of NIL (LISP) and APL).

4 - PARALLEL ARCHITECTURE FOR PRE-PROCESSING

This part of our future system will be used for :
- RAY-TRACING computations ;
- Pre-processing Z-BUFFER ;
- Special effects.

- This module will be based on a highly parallel architecture using TRANSPUTERS chips.
  So we can obtain a compatibility with CRISTAL, as TRANSPUTERS are programmed with the OCCAM language, which is near of C language.
  Ray-tracing algorithms, which are now written in C language on VAX and CRISTAL, will be implemented on these parallel TRANSPUTERS.

5 - A AND Z-BUFFER AND POLYGON FILLING

The pre-processing module can compute :
- Directly pixels by RAY-TRACING algorithm ;
- Vertices of polygons for area filling and Z-BUFFER display.

For the second process, it is necessary to decrease the computation time for :
- AREA FILLING ;
- Z-BUFFER process ;

by VLSI chips.

Because those two algorithms can be easily implemented in hardware, at the opposite side, for RAY-TRACING it is very difficult to do so, because this algorithm is not linear, (for not planar primitives).

So, we are planning to design 2 sets of VLSI chips :
- One for area filling, with GOURAUD or PHONG shading, and texture possibly ;
- One for the control of the bit map memory. This controller could drive 4 independant blocs of memory, and could be connected up to 16 processors (mainly : area filling).

With an access time to the memory of 250 ns, it can display one pixel in 250/16-16 ns per pixel.
So, one 1 024 * 1 024 image can be displayed in 10**6 * 0.016 = 16 000 microsecond or 16 ms.
(compatible with real time needs).

The controller chips are bit sliced ; So, it solves the output pin problem.

It can be driven by one to 16 pixels generators in parallel, so it can be adapted to various problems :
- Real time problems for the display of up to 10 000 polygons in less than 40 ms ;
- High quality scenes with the area filling which can be driven by sophisticated texture generators.
- Low cost graphics on a PC with the use of only one channel connected to one area filler.

6 - APPLICATIONS AND CONCLUSIONS

This structure permits all kinds of animations :
- For audiovisual broadcasting applications ;
- For CAD-CAM and Education ;
- For simulation.

It solves many 3D animations problems and can be built part by part and interactively.

It solves very different graphics problems such as :
- Real time graphic system for CAD-CAM and simulation ;
- Personnal computer graphics on a PC.

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