

# Reality Co-Processor – The Power In Nintendo64

***Ken Hayes***  
**Engineering Manager**  
**Silicon Graphics, Inc.**



## ***Architecture for Consumer Game Console***

### ***Architectural Constraints***

- ◆ **Design for System cost of \$250 at introduction decreasing to \$100 at maturity**
  - **Clearly a separate class from other computing platforms**
- ◆ **Few Inexpensive Chips**
  - **High Integration Required**
- ◆ **Inexpensive Packaging**
  - **Low Pincount, Low Power**
- ◆ **Small Memory Footprint**



## Architectural Solution

### Highly Integrated Media Processing

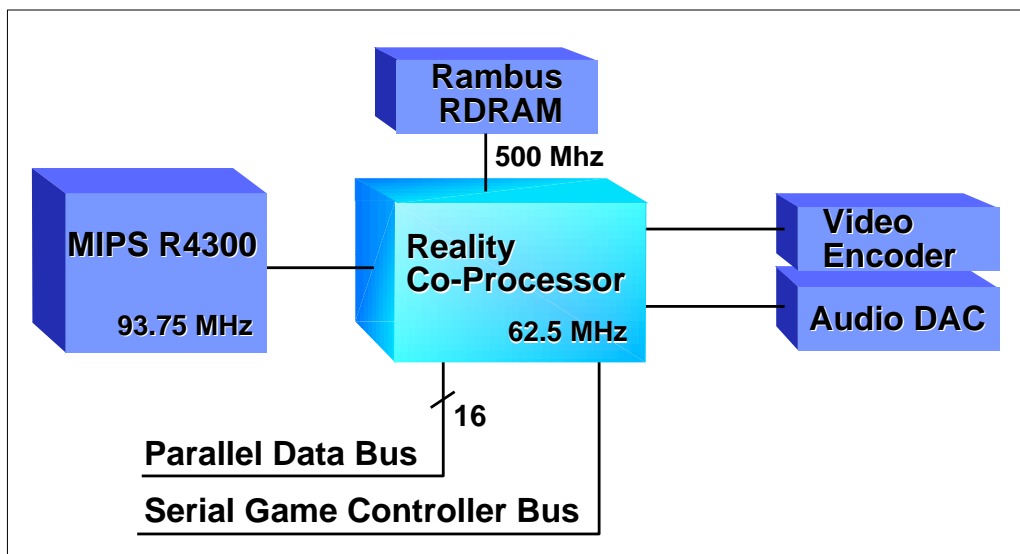
- ◆ Integrated Audio/Video/Graphics Processor
- ◆ 64-bit MIPS RISC Processor
- ◆ Unified Expandable Memory
  - Rambus RDRAM Memory
  - Low Pincount, High Performance
- ◆ Extendable I/O Structure

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## Architectural Solution

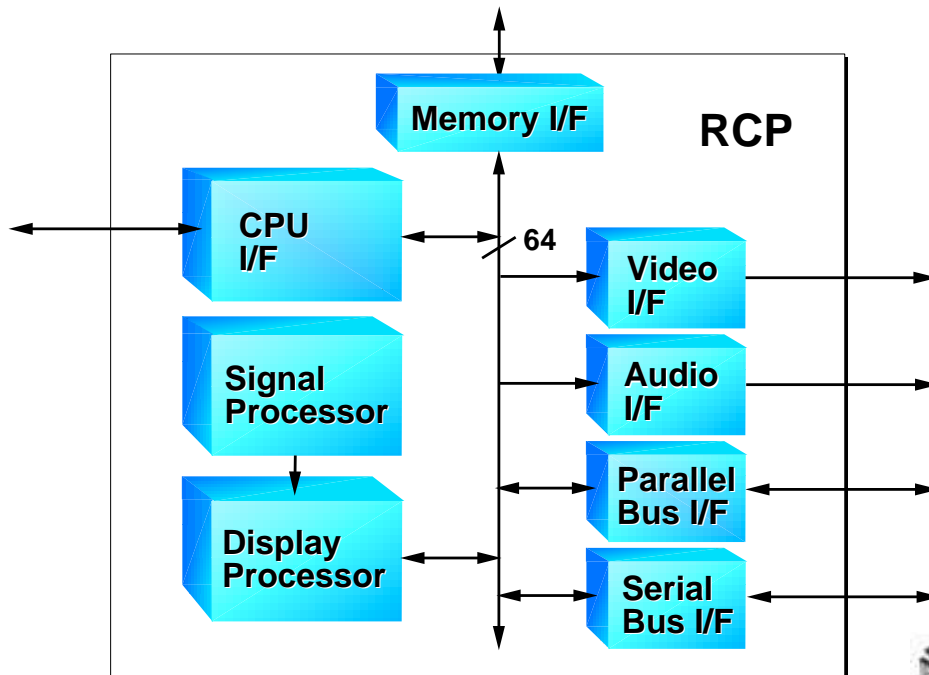
### System Level Block Diagram



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# Reality Co-Processor Block Diagram



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# Reality Signal Processor

## Programmable Media Processor

### ◆ Processes

- Audio Synthesis and Audio Decode
- Video Decode
- 3D Graphics Geometry and Setup Calculations

### ◆ MIPS RISC Scalar/Instruction Processor

### ◆ 8 unit Parallel Vector Processor

### ◆ 4 KB Data Memory

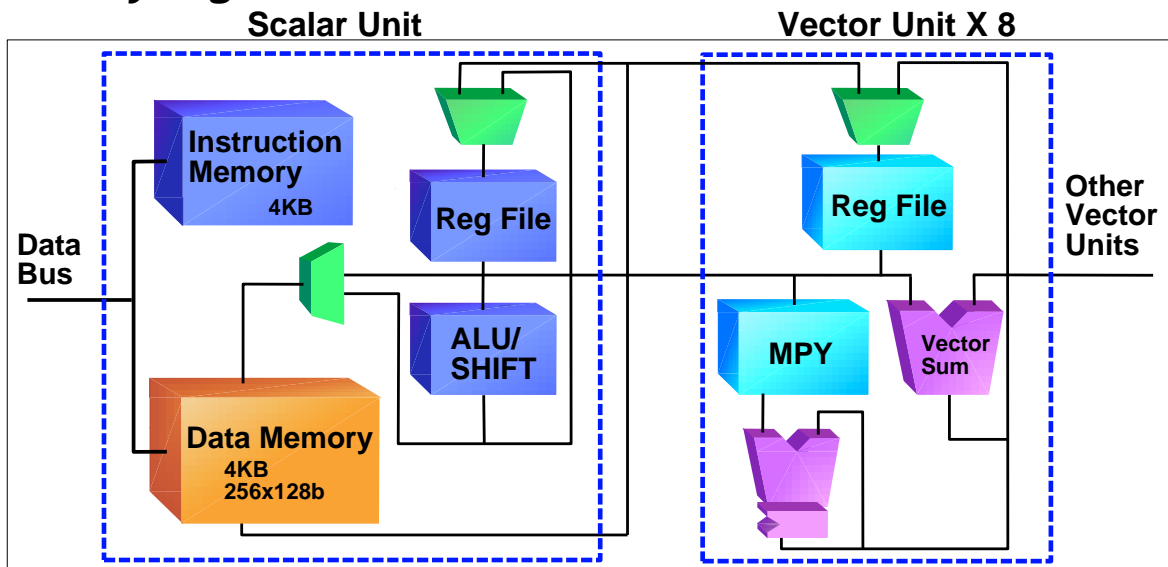
### ◆ 4 KB Instruction Memory

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# Reality Signal Processor Architecture

## Reality Signal Processor



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# Reality Signal Processor

## Scalar Unit

- ◆ MIPS IV Instruction Set
- ◆ 4K Byte Instruction Memory (1024 instructions)
- ◆ 4K Byte Data Memory explicitly loaded
- ◆ Linear DMA and Block region transfers

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# ***Reality Signal Processor***

***Vector Unit: A solution for variable media types***

- ◆ **What do Audio, Imaging, Video, and 3D Graphics operations have in common?**
  - **Lots of DSP like operations, Multiply Accumulates**
- ◆ **Design Approach: Focus on 16 bit calculations,**
  - **Support paired vectors for 32 bit operations**
  - **Support unpacking for 8 bit operations**

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# ***Vector Unit***

***8 parallel 16-bit Integer Processors***

- ◆ **Adds, Multiplies and Multiply Accumulate Operations**
  - **Paired vectors for 32 bit operations**
  - **Vector Sums of all Vector Units**
  - **Saturating integer arithmetic**
- ◆ **.5 Billion MAC operations per second**
- ◆ **32 128-bit vector registers**
- ◆ **Vector Load/Stores from Data Memory**
  - **Packed Load/Store and Transpose Load/Store**

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# *Graphics for Game Play*

## *High Quality Pixels*

- ◆ **Best possible image quality is required to create immersive visual experience. Must create the illusion that the picture is real.**
  - Level of detail filtered, perspective corrected textures
  - Edge anti-aliasing
  - Robust lighting, coloring and blending algorithms
  - Multi-pass textures

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# *Graphics for Game Play*

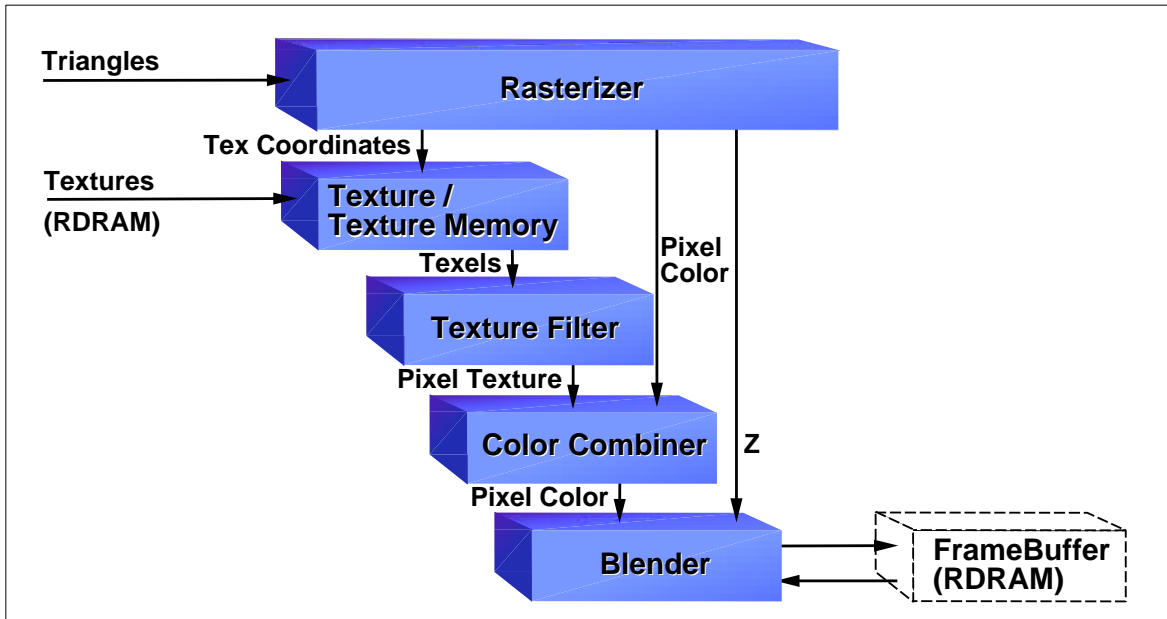
## *Broad Feature Set/Highly Flexible Programming*

- ◆ **Diverse set of primitive operators for ultimate flexibility**
  - 3D Geometry
  - Color Texture
  - Triangles
  - Color Keying
  - Z Buffering
  - 2D Sprites
  - Color Lookup Textures
  - Lines
  - Reflection Maps
  - Alpha Threshold Blending
- ◆ **Provide basic compute blocks, and let software select the set of operands to provide ultimate flexibility in describing the picture**

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# Reality Display Processor

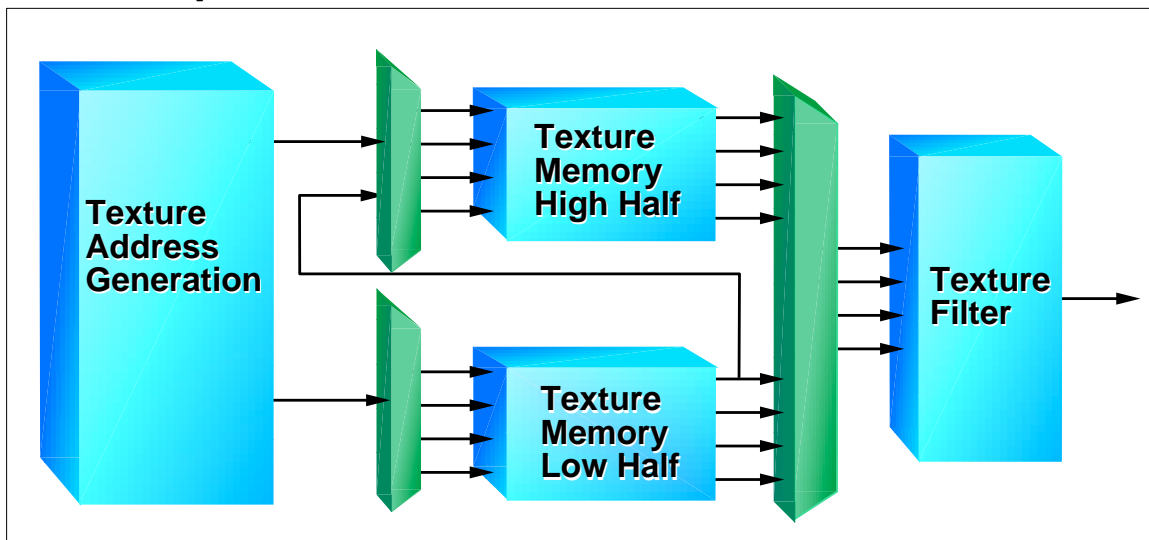


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# Reality Display Processor

## Texture Pipeline



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# *Reality Display Processor*

## *Texture Features*

- ◆ Two Halves of texture memory provide 4 texels each
- ◆ General use Texture Memory is configured into multiple texture tiles by programming a tile descriptor memory
  - Provide location of texture image in the memory and describe the data type of the texture

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# *Reality Display Processor*

## *Texture Features*

- ◆ General capability to filter between 2 texture tiles
  - LOD filtering becomes operation between two tiles which were stored as different resolution images of the same texture
  - Filtering between 2 different images, provides a texture morph
- ◆ Texture Color Lookup table implemented by allowing low half of texture memory to perform a TLUT on high half
  - Very high compression of texture image

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# *Reality Display Processor*

## *Texture Features*

- ◆ Numerous texture data types supported
  - 4, 8, 16, 32 bit textures
  - RGB, Alpha
  - YUV
  - Intensity, Alpha
  - Color Index TLUT Textures
- ◆ Square, or rectangular texture images

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# *Reality Display Processor*

## *Texture Features*

- ◆ Load FrameBuffer as a Texture
  - Provides multi-pass rendering capability
    - Reflection maps
    - Lighting effects
    - Special Effects: Reflective Metallic Objects
    - Video mapped as textures onto geometry

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# Reality Display Processor

## Texture Image Quality

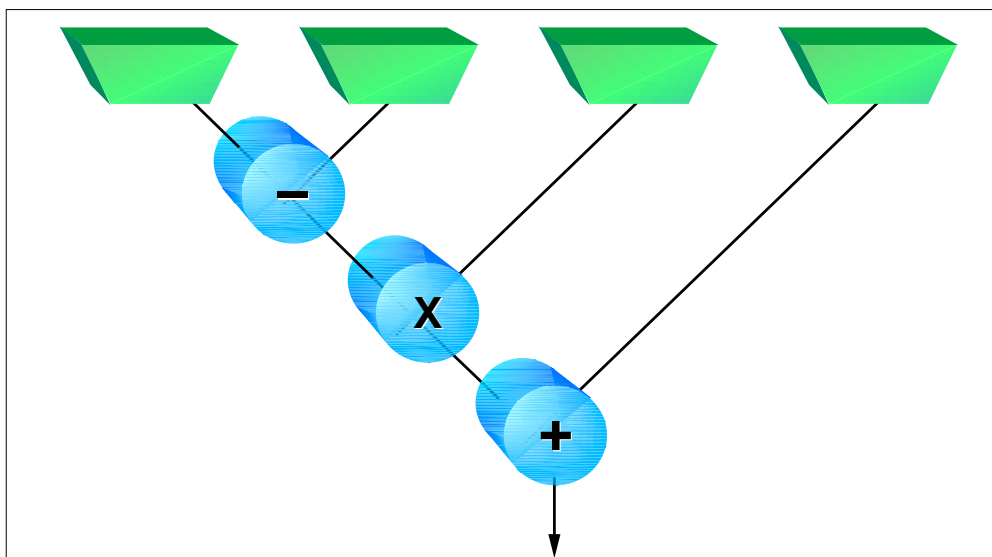
- ◆ Per Pixel Perspective Correction
- ◆ Point sample, bi-linear filter, Multi-resolution LOD filter
  - Filter between any 2 LODs
- ◆ Detail Textures add additional detail on fully magnified textures
  - Additional detail texture image is stored as another image tile and filtered with base texture tile
- ◆ Sharpen texture, sharpens otherwise blurry texture edges when magnified

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# Reality Display Processor

## Color Combiner



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# *Reality Display Processor*

## *Flexible Color Combine Features*

- ◆ Color Combiner function is to mix colors from various sources
- ◆ Rather than hardcode a few specific algorithms, provide a hardware pipeline, and allow graphics program to select a set of operands to obtain desired combinations

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# *Reality Display Processor*

## *Flexible Color Combine Features*

- ◆ Select inputs from:  
Texel Color, Shade Color, Primitive Color, Environment Color, Color Key controls, Alpha, Texture Alpha, Shade Alpha, Environment Alpha, LOD Fractions, Noise, Constants
- ◆ Provide Features:  
Filtering of multiple textures, Texture/Shading modulation, Decal Textures, Reflections, Specular Highlights, Chroma Keying, Noise Injection, Color space conversion

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## *Reality Display Processor*

*Blender adds visual Features and enhances Image Quality*

### ◆ Blender Features

- Per Pixel Z buffer priority determination
- Supports interpenetrating surfaces
- Computes per pixel Fog as a function of Range
- Supports translucent surfaces and blend to specified colors
- Conditional writes based on Alpha Threshold value, or on dithered alpha to create particle effect

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## *Reality Display Processor*

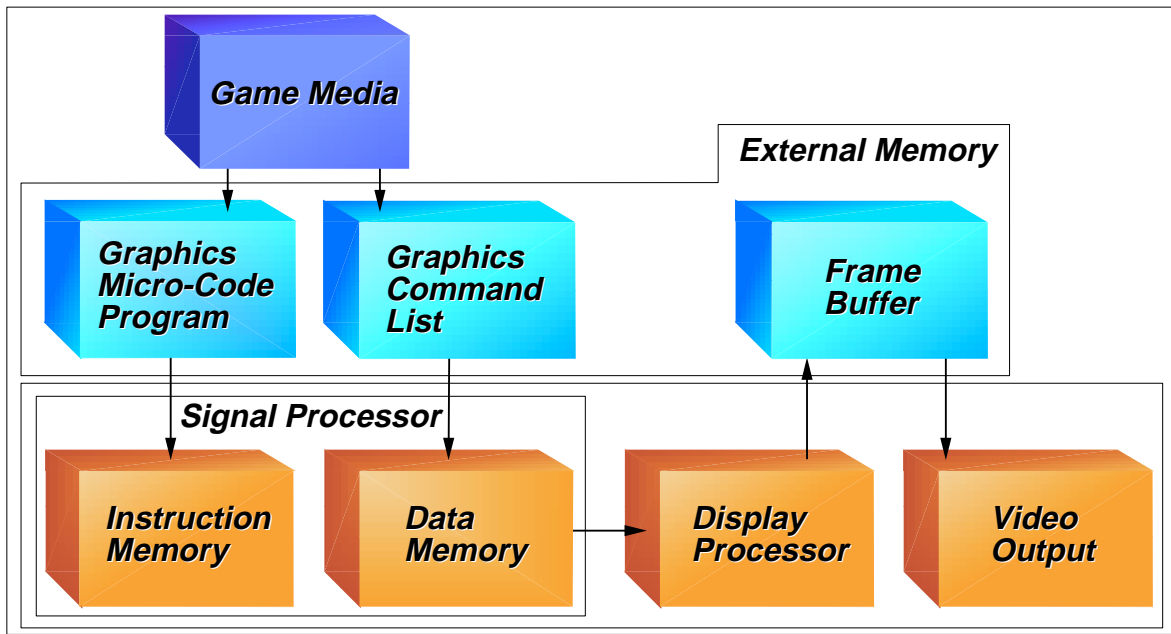
*Blender performs Edge Anti-Aliasing*

- ◆ Edge anti-aliasing removes stair step jaggies on surface edges
- ◆ Traditional algorithms require expensive memory intensive solutions
- ◆ Reality Co-Processor implements a proprietary low cost algorithm to satisfy need for High Visual Quality in systems designed for Game Play

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## Program Data Flow



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## Technology / Design Flow

- ◆ **Die per Wafer Dominates Process Choice**
  - .35 $\mu$  3LM NEC Process (1994 design cycle!)
- ◆ **Time to Market Determines Design Flow**
  - ASIC semi-custom design flow
    - Verilog RTL/ Synthesis/ P&R/ Static Timing
    - Custom Rams/Reg Files/Macro Functions
  - "Portable" std cell libraries re-drawn to target process
  - COTS design/release to FAB
    - Tapeout → Mask Generation

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# Technology Results

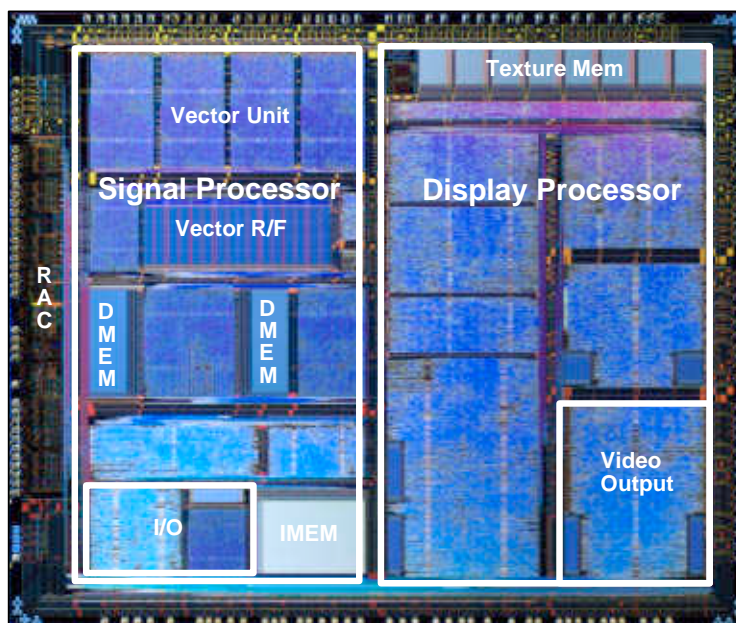
## *High Technology invades the Living Room*

- ◆ 2.6 M transistors
- ◆ 81mm<sup>2</sup>
  - Highly crafted packing, 32,000 transistors per mm<sup>2</sup>
- ◆ 62.5 Mhz
- ◆ 2.8 W
- ◆ 160 PQFP

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# Die Photo



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# ***Silicon Graphics/ Nintendo64***

## ***Measure of Success***

- ◆ **In Production for 1.5 years**
- ◆ **Over 10 Million Units Sold**
- ◆ **Production volume still "ramping up"**
- ◆ **Time Magazine "Machine of the Year" 1996**
- ◆ **Continued sellouts on 4 continents**