Introduction to Game Programming

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Introduction to Game Programming

Introductory stuff

Look at a game console: PS2

Some Techniques (Cheats?)

What is a Game?

Half-Life 2, Valve

Designing a Game

Computer Science

Art

Music

Business

Marketing

Designing a Game

Music
Art
Computer Science
Business
Marketing
History
Geography
Psychology
Sociology
Physics
Literature
Education
Writing
Civics/Politics
…Just to name a few

Designing a Game

Find out more from an industry veteran @

Professor Jesse Schell’s class:
 Game Design

(Entertainment Technology Center)

The Game Engine

Graphics & Animation

Physics

Controller Interaction

AI Primitives

Sound

Networking

Scripting system

The Game Logic

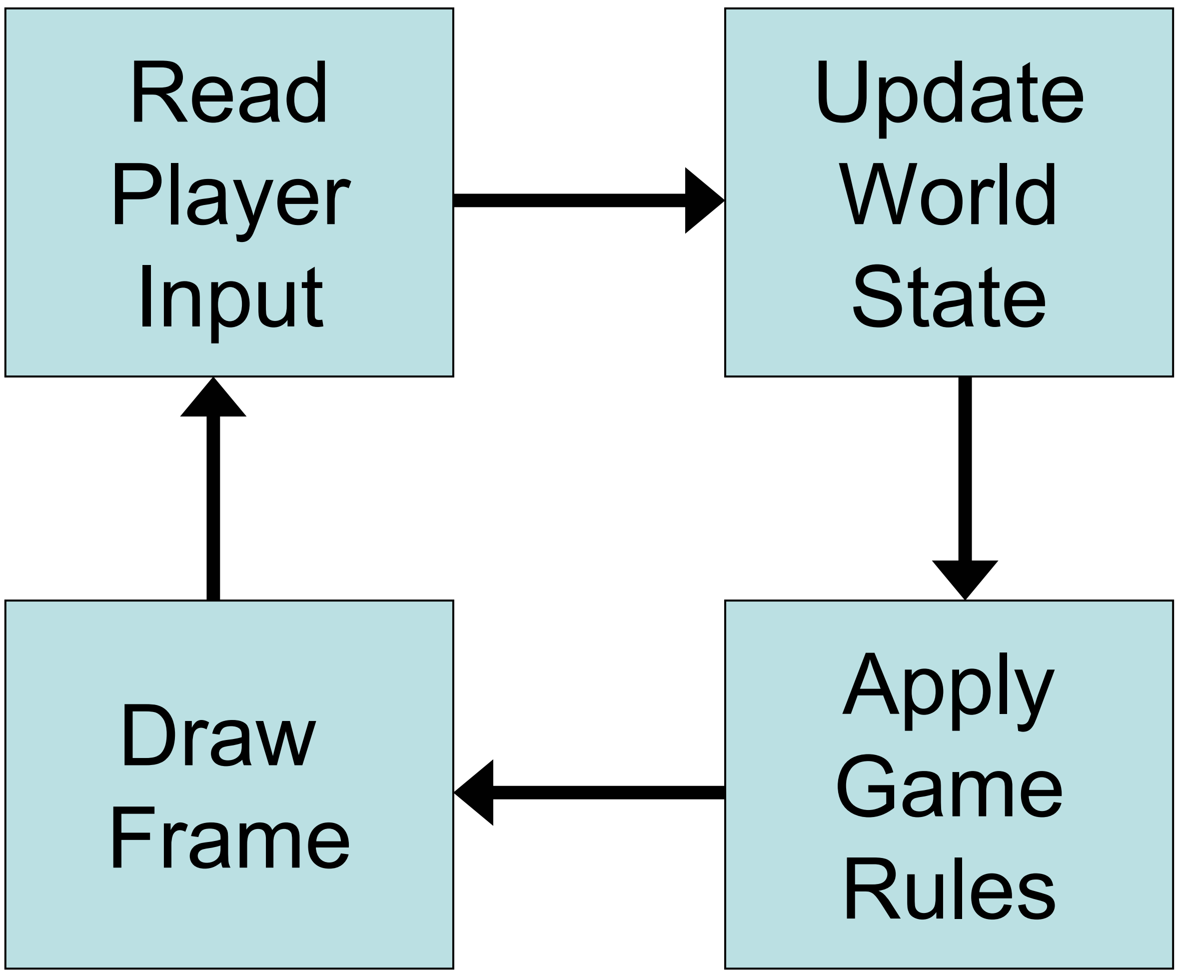
Game rules

Non-Player Characters (NPC) AI

Interface, etc.

Often (but not necessarily) implemented in scripting language

Magic Formula



Game Programming is *hard*

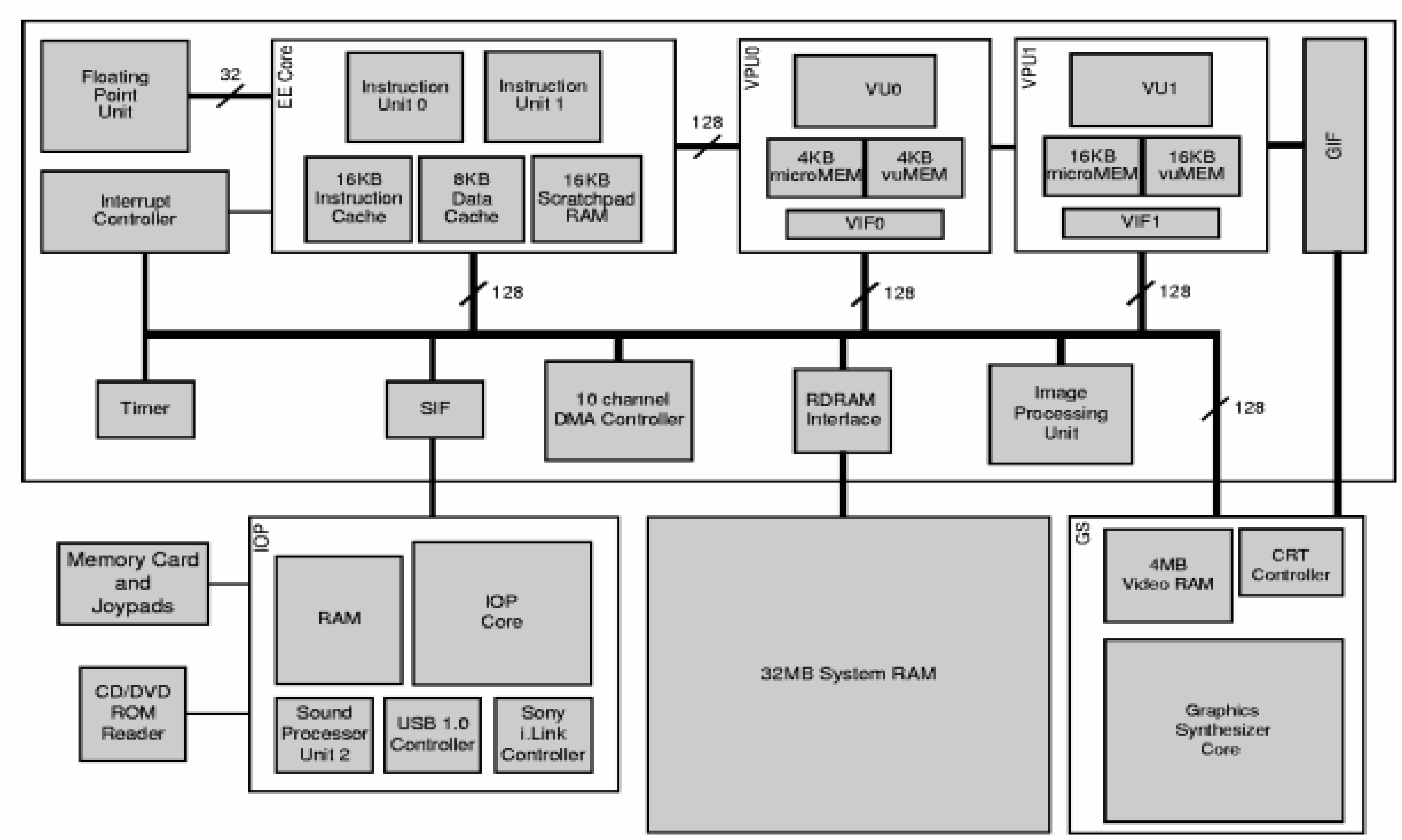
- Players want complex graphics (why?)
- Game must run fast (30fps+)
- AI isn’t exactly trivial
- We want networking but no latency
- Physics is already hard. Now do it in real-time

- … And do it all in time for Christmas

To most, this is the PS2

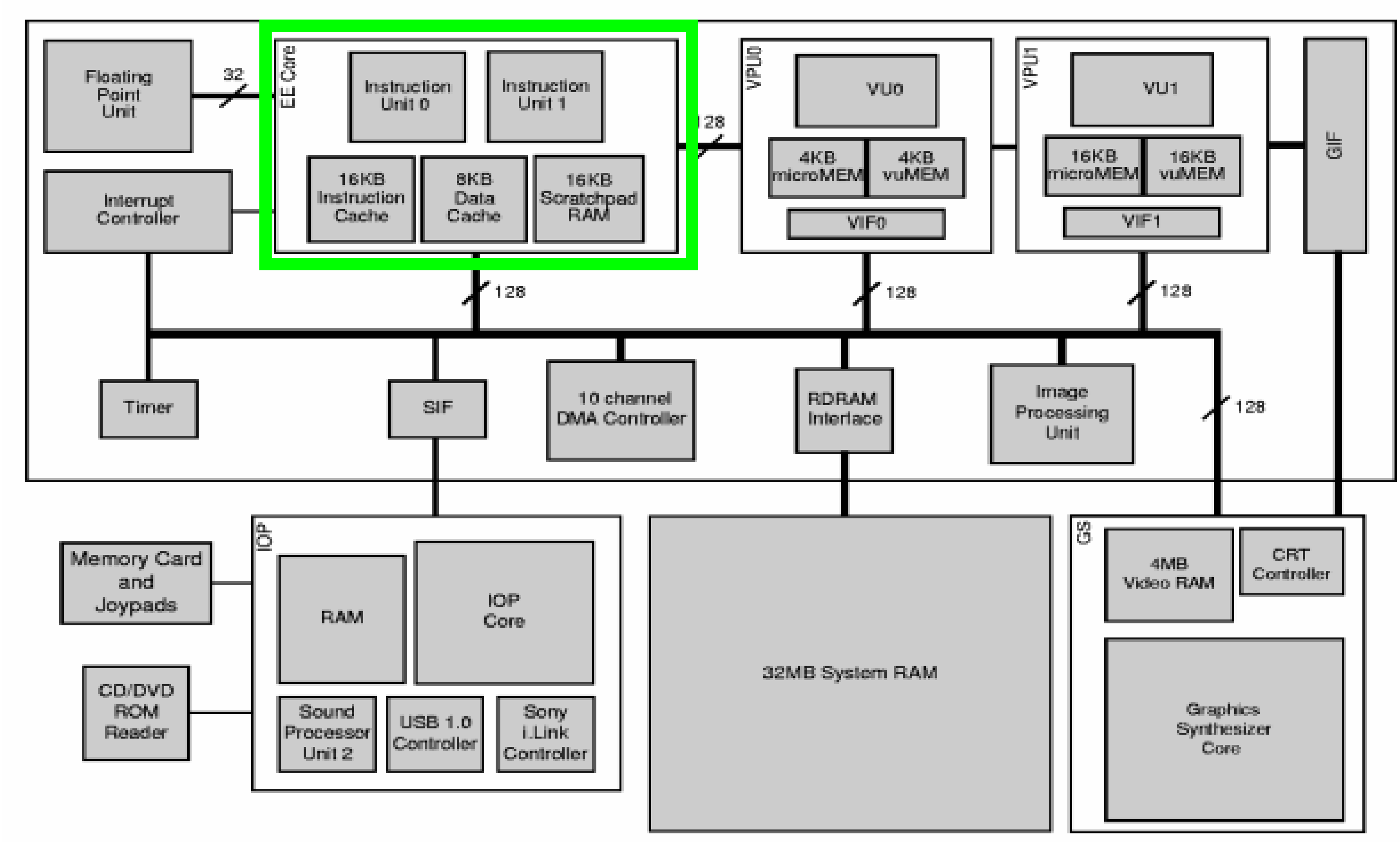
To technophiles, this is a PS2

To us, this is the PS2



Source: http://playstation2-linux.com/projects/p2lsd

Emotion Engine Core “EE Core”



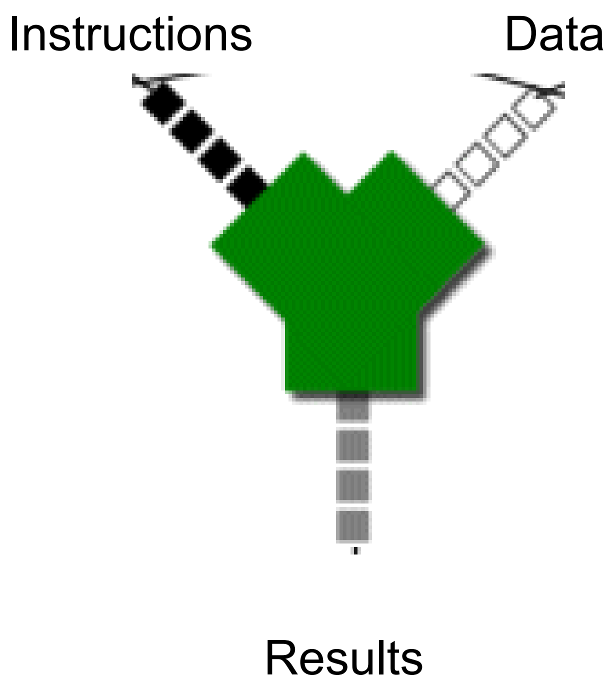
Source: http://playstation2-linux.com/projects/p2lsd

Emotion Engine Core “EE Core”

Runs at about 300 megahertz
MIPS I & II, subset of MIPS III & IV
Math coprocessor
SIMD Instructions

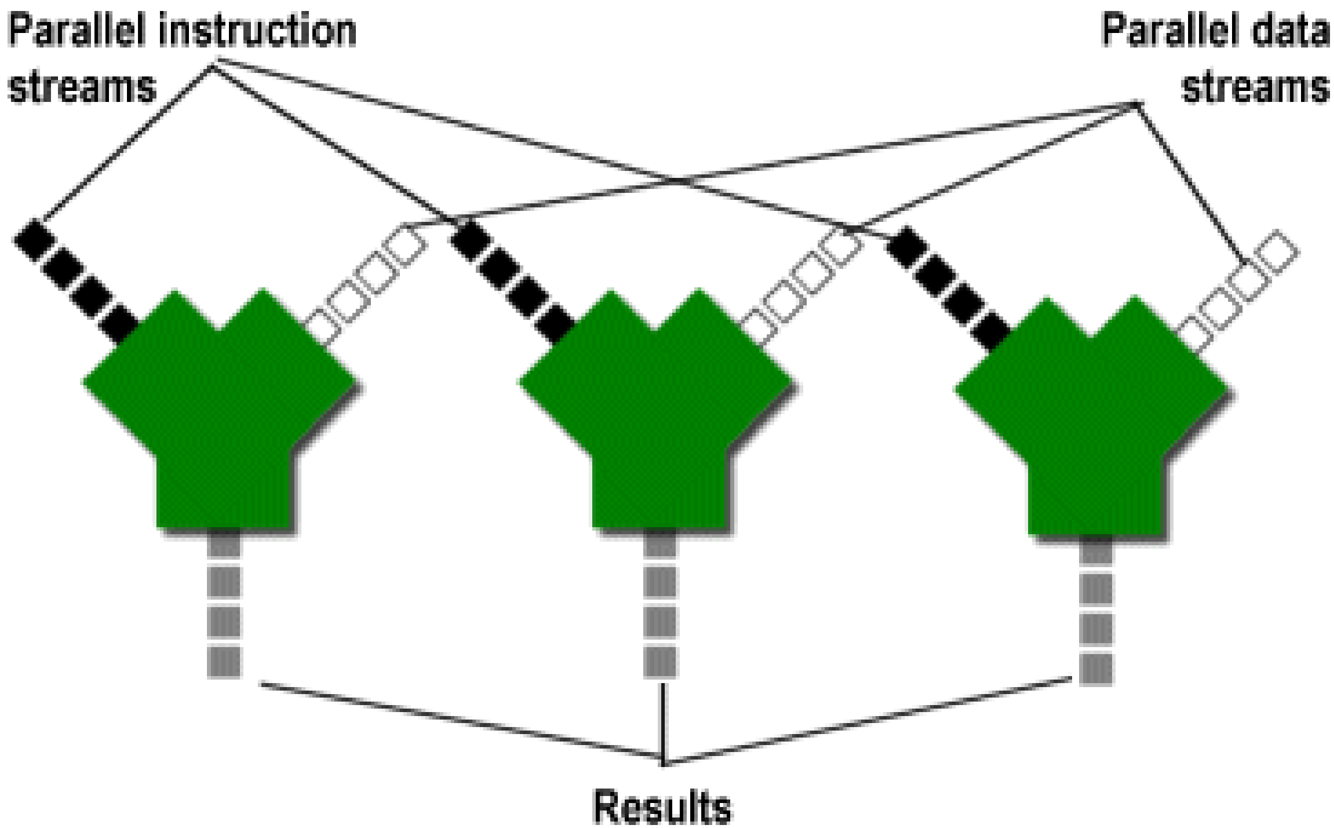
16k instruction cache
8k data cache
16k scratch pad

SISD Instructions
Single Instruction, Single Data



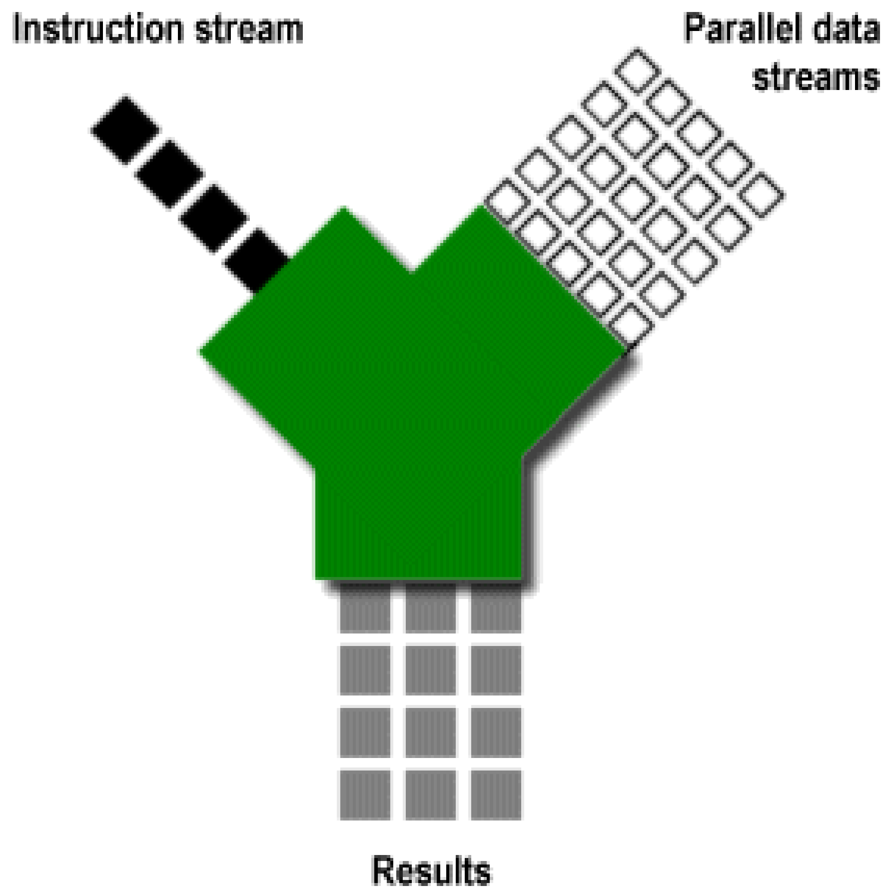
Modified from: http://arstechnica.com/articles/paedia/cpu/ps2vspc.ars/5

MIMD
Multiple Instruction, Multiple Data



Source: http://arstechnica.com/articles/paedia/cpu/ps2vspc.ars/5

SIMD
Single Instruction, Multiple Data



Source: http://arstechnica.com/articles/paedia/cpu/ps2vspc.ars/5

Which is Better?

Sure, 4 independent instruction streams (MIMD) would be nice, but it would require more memory

But media applications do not require instruction-level parallelism, so SIMD is fine

Sneak Peek

The safe money says next generation from Sony will be highly parallel (=MIMD)

There's a good chance that this may include parallel SIMD instructions

Now go ask your Architecture professor what that's even called! (I like MIM^2D)

PS2 SIMD Support

PS2 has lots of SIMD support:

Parallel instructions on core CPU

- 2x64-bits, 4x32-bits, 8x16-bits or 16x8-bits
  → Homework 4 example

Vector Unit 0 through micro & macro mode

Vector Unit 1

- Both VU's do 4x32-bit floating point

SISD Example: Vector/Matrix Multiplication

$$\begin{bmatrix} a & b & c & d \\ e & f & g & h \\ i & j & k & l \\ m & n & o & p \end{bmatrix} * \begin{bmatrix} s \\ t \\ u \\ v \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \\ w \end{bmatrix}$$

```
x = a*s + b*t + c*u + d*v
y = e*s + f*t + g*u + h*v
z = i*s + j*t + k*u + l*v
w = m*s + n*t + o*u + p*v
```

16 multiplications, 12 additions.
Additions can be eliminated with MADD.

SIMD Example: Vector/Matrix Multiplication

$$\begin{bmatrix} a & b & c & d \\ e & f & g & h \\ i & j & k & l \\ m & n & o & p \end{bmatrix} * \begin{bmatrix} s \\ t \\ u \\ v \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \\ w \end{bmatrix}$$

First, load columns into registers:

VF01 = {a, e, i, m}

VF02 = {b, f, j, n}

VF03 = {c, g, k, o}

VF04 = {d, h, l, p}

VF05 = {s, t, u, v}

SIMD Example: Vector/Matrix Multiplication

VF01 = {a, e, i, m}

VF02 = {b, f, j, n}

VF03 = {c, g, k, o}

VF04 = {d, h, l, p}

VF05 = {s, t, u, v}

```
MUL ACC, VF01, VF05[x]      // acc = {a*s, e*s, i*s, m*s}
MADD ACC, VF02, VF05[y]     // acc += {b*t, f*t, j*t, n*t}
MADD ACC, VF03, VF05[z]     // acc += {c*u, g*u, k*u, o*u}
MADD VF06, VF04, VF05[w]    // VF06 = acc + {d*v, h*v, l*v, p*v}
```

Only 4 instructions! (compared to 16 or 28 instructions)

SIMD Example Continued

Matrix/Matrix multiplication is 4 dot products

Compare:

16 (=4 x 4) instructions

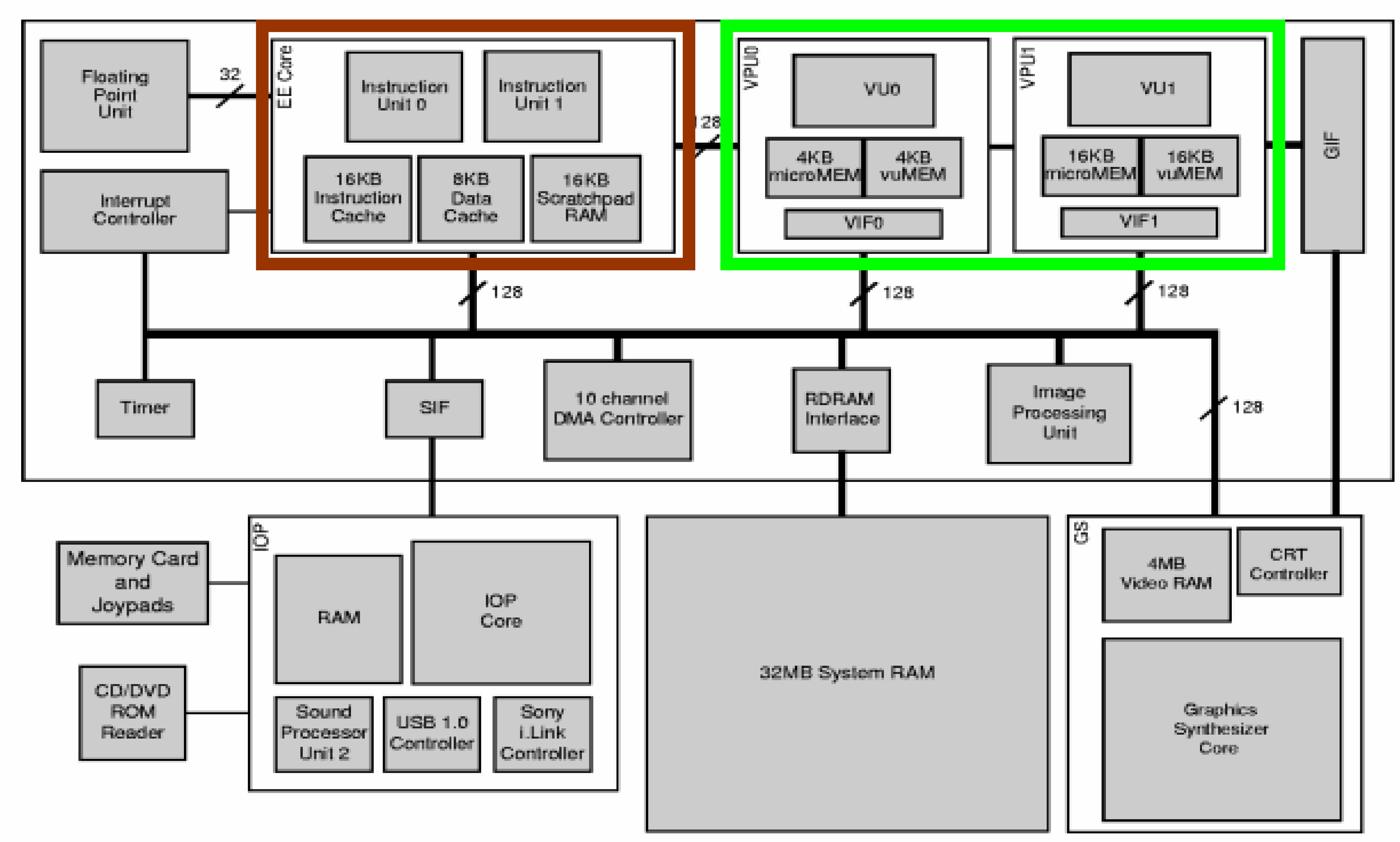
to

64 (=4 x 16) assuming MADD

or

112 (=4 x 28) instructions, without MADD!

Vector Units (VU0 & VU1)



Source: http://playstation2-linux.com/projects/p2lsd

Vector Units (VU0 & VU1)

VU0 – 4k data, 4k code

- Can be used in “Micro” or “Macro” mode

VU1 – 16k data, 16k code

- Micro mode only
- Connected directly to the GS
- Can do clipping & a few more instructions

Vector Unit = Vertex Shader?

Absolutely not.

The vector units do much, much more than a vertex shader!

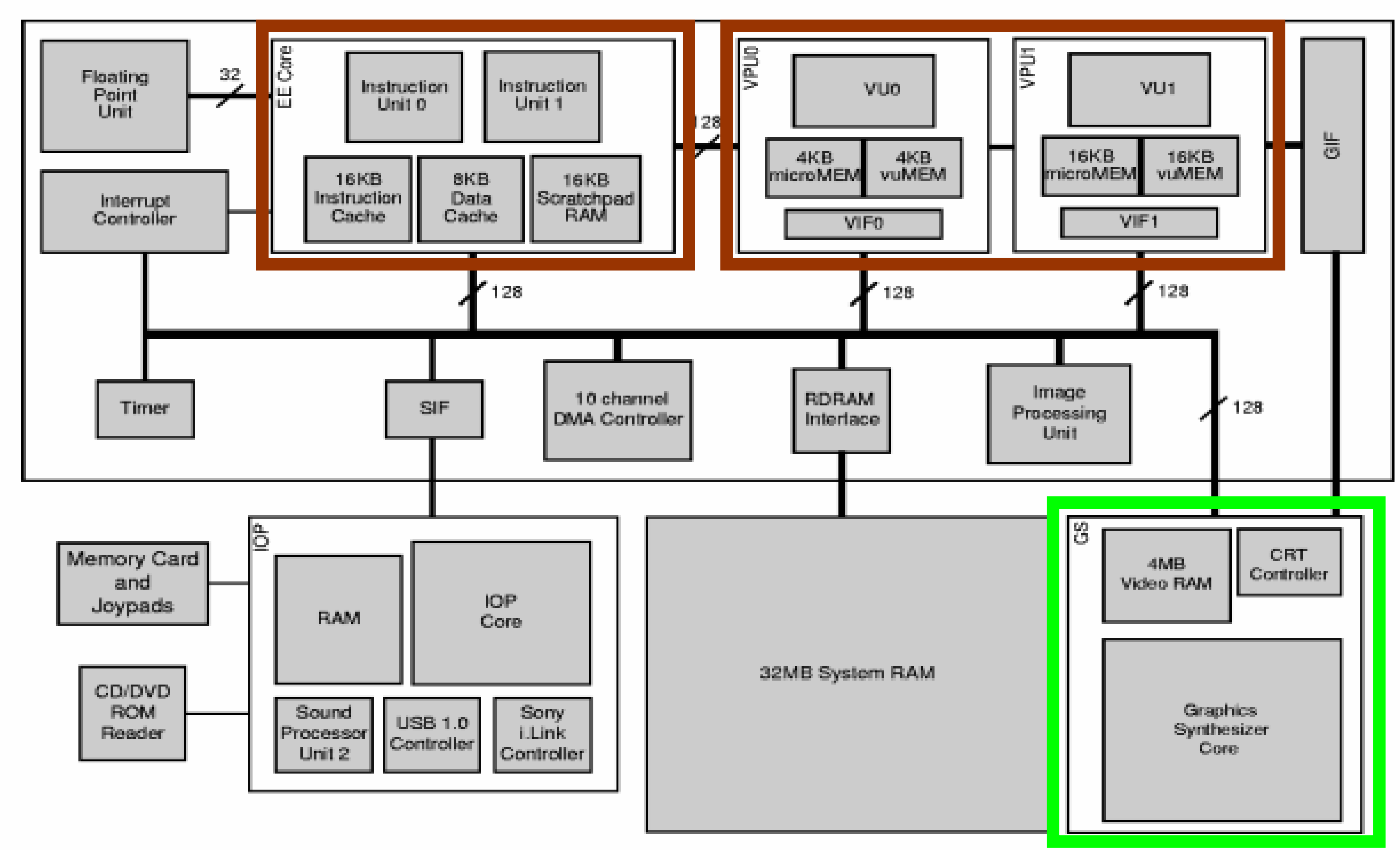
At the most trivial level, a vertex shader (not sure about the absolute latest) cannot create geometry.

What are they for?

One approach
VU0: Animation, Physics, AI, Skinning, etc…
VU1: Transformation, clipping & lighting

Another approach
VU0: Transformation, lighting
VU1: Transformation, lighting
* I don’t think anyone ever uses it this way

Graphics Synthesizer (GS)



Source: http://playstation2-linux.com/projects/p2lsd

Graphics Synthesizer

The “graphics chip” of the PS2

Not a very smart chip!

… but a very fast one.

Supports:

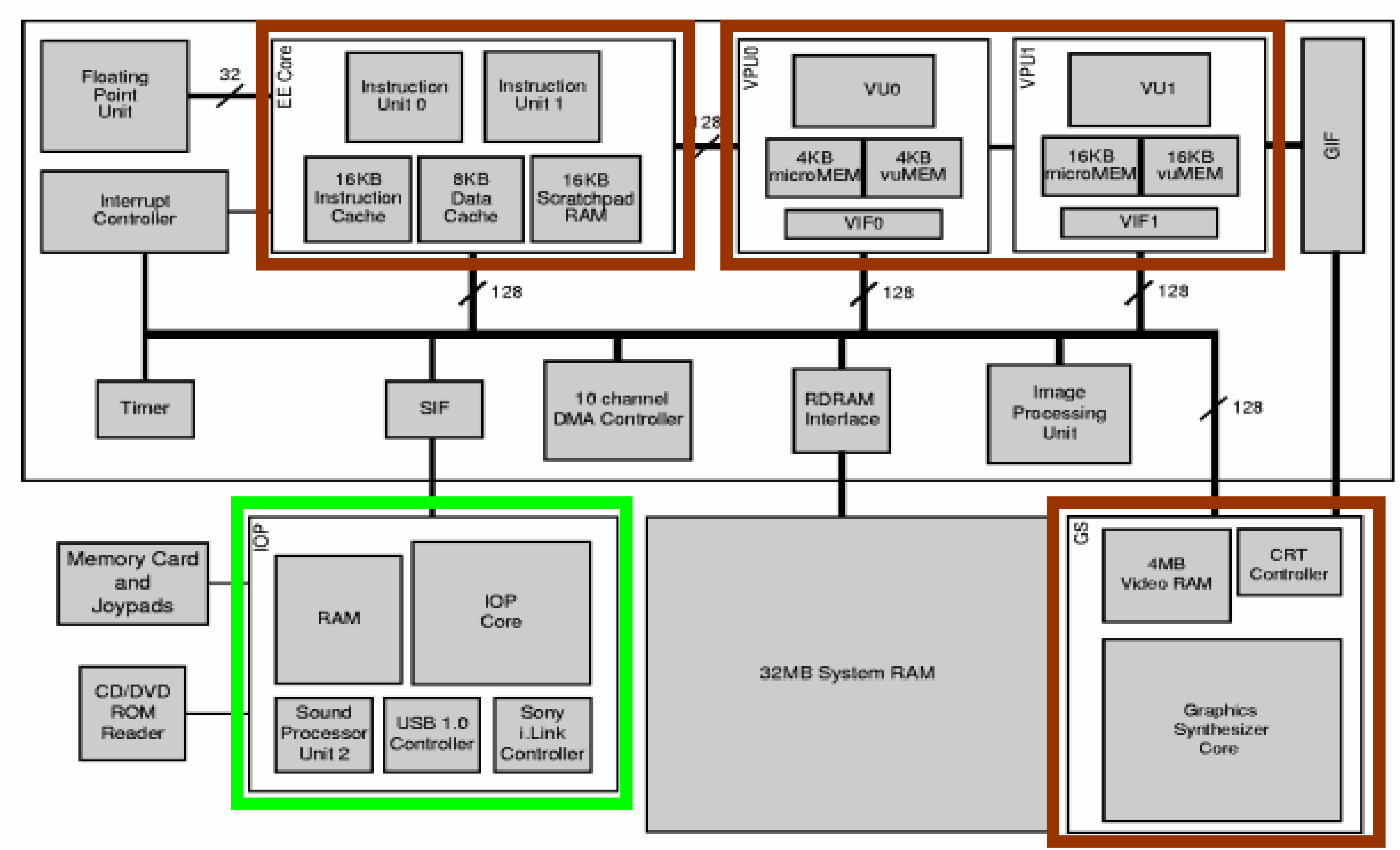
- Alpha blending
- Z Testing
- Bi- and tri-linear filtering

Graphics Synthesizer (GS)

Per-second statistics:

- 2.4 gigapixel fill rate
- 150 million points
- 50 million sprites
- 75 million untextured triangles
- 37.5 million textured triangles

I/O Processor (IOP)

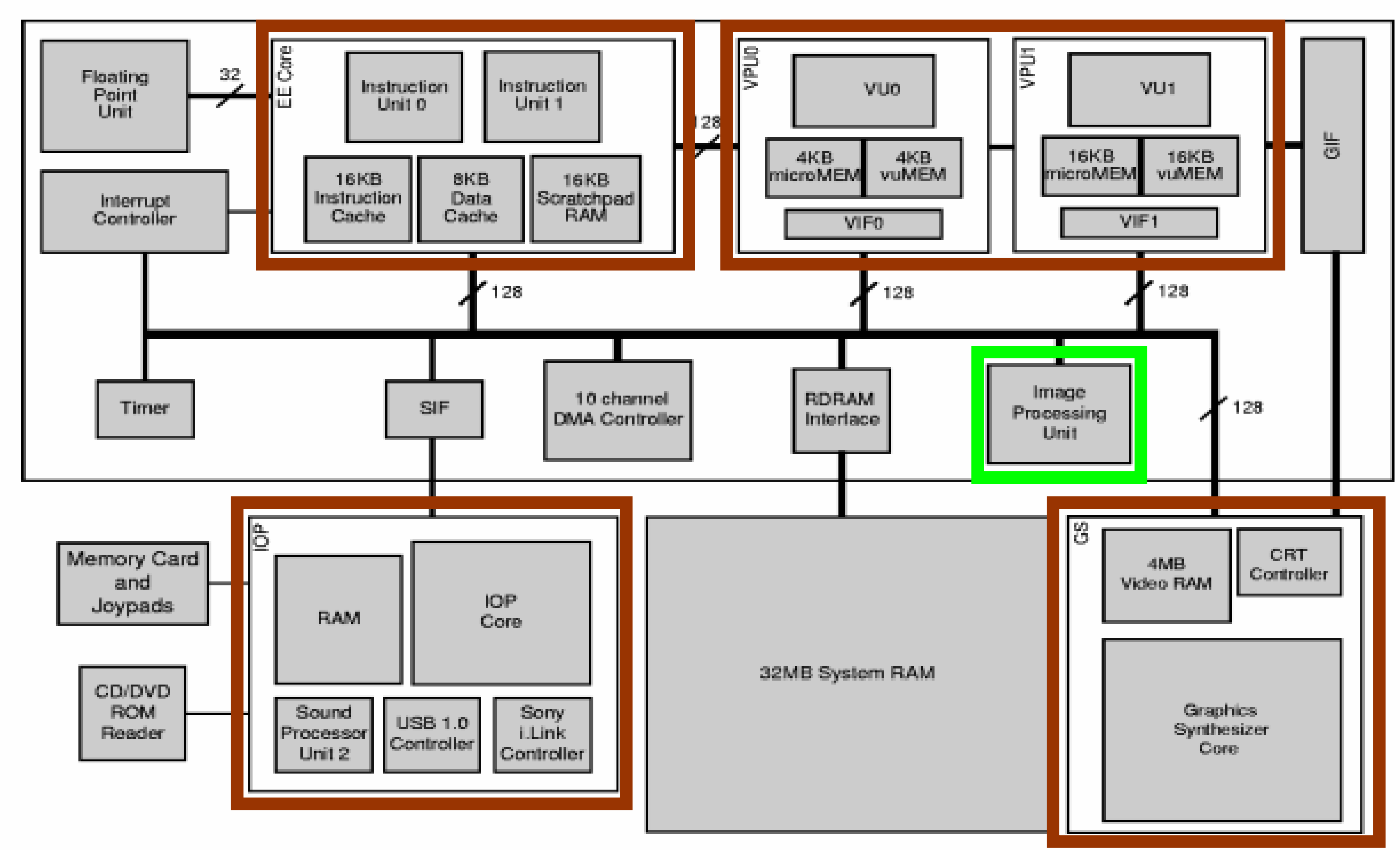


Source: http://playstation2-linux.com/projects/p2lsd

I/O Processor (IOP)

- Built from a PlayStation!
- Gives backward compatibility
- IOP used to access the Sound Processing Unit (SPU2), controllers, CD & Hard Drive, USB and FireWire port
- IOP has 2MB memory
- SPU has 2MB memory

Image Processing Unit (IPU)



Source: http://playstation2-linux.com/projects/p2lsd

Image Processing Unit (IPU)

MPEG 2 decoding support

At a high level, hand over encoded data, retrieve results when they're ready

The Job of a PS2 Programmer

Keep the system busy!

Have all processors running

- Double buffer everything
- Reduce waiting on others

→Stream textures for next model while processing current model

- Reduce data dependency stalls
- Pair instructions where possible

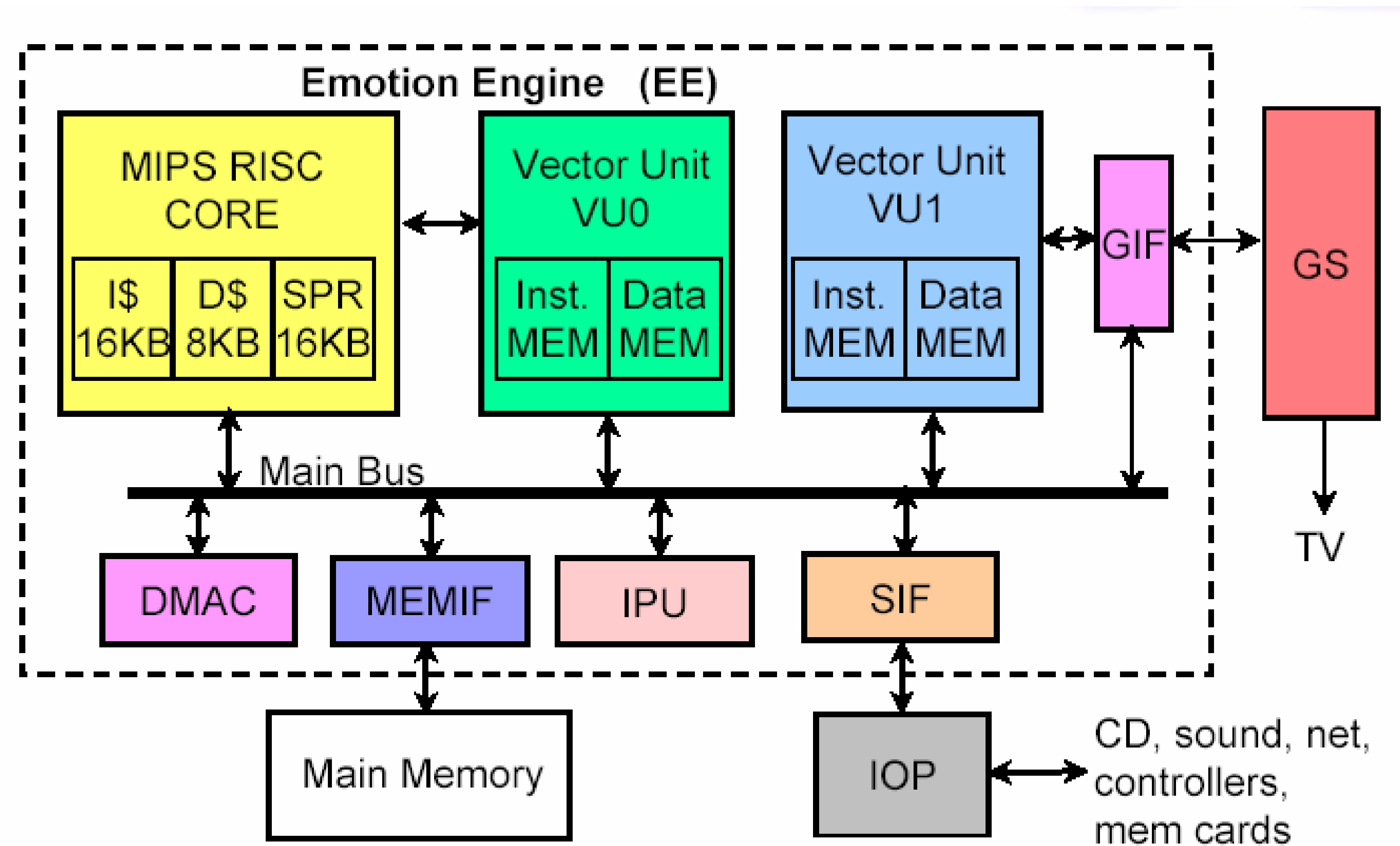
The Job of a PS2 Programmer

Avoid stalling on memory access

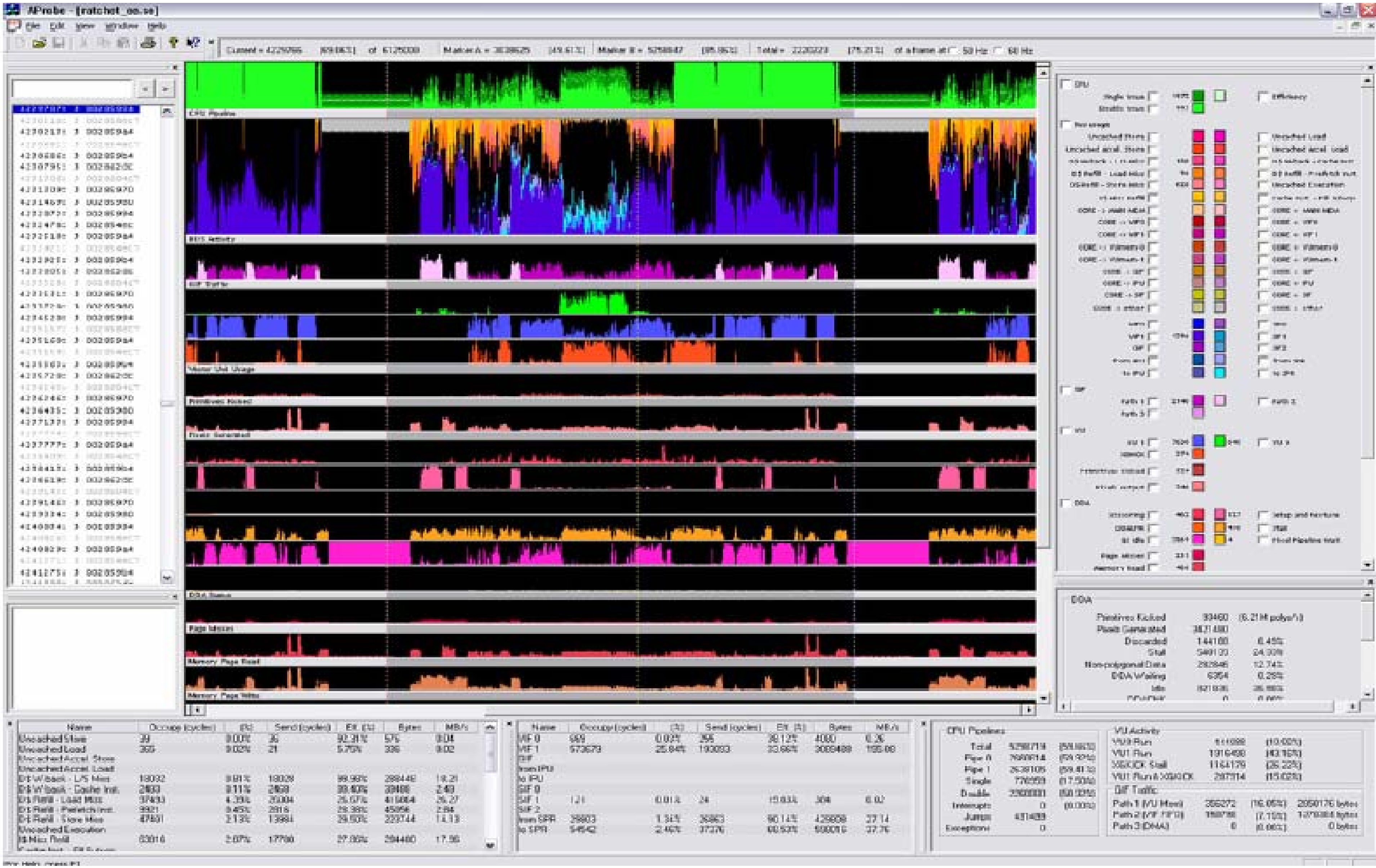
- Use the scratch pad

Avoid cache misses as much as possible

- Use the scratch pad
- Code & Data locality
- Avoid C++ overdose
- Prefetch data into cache

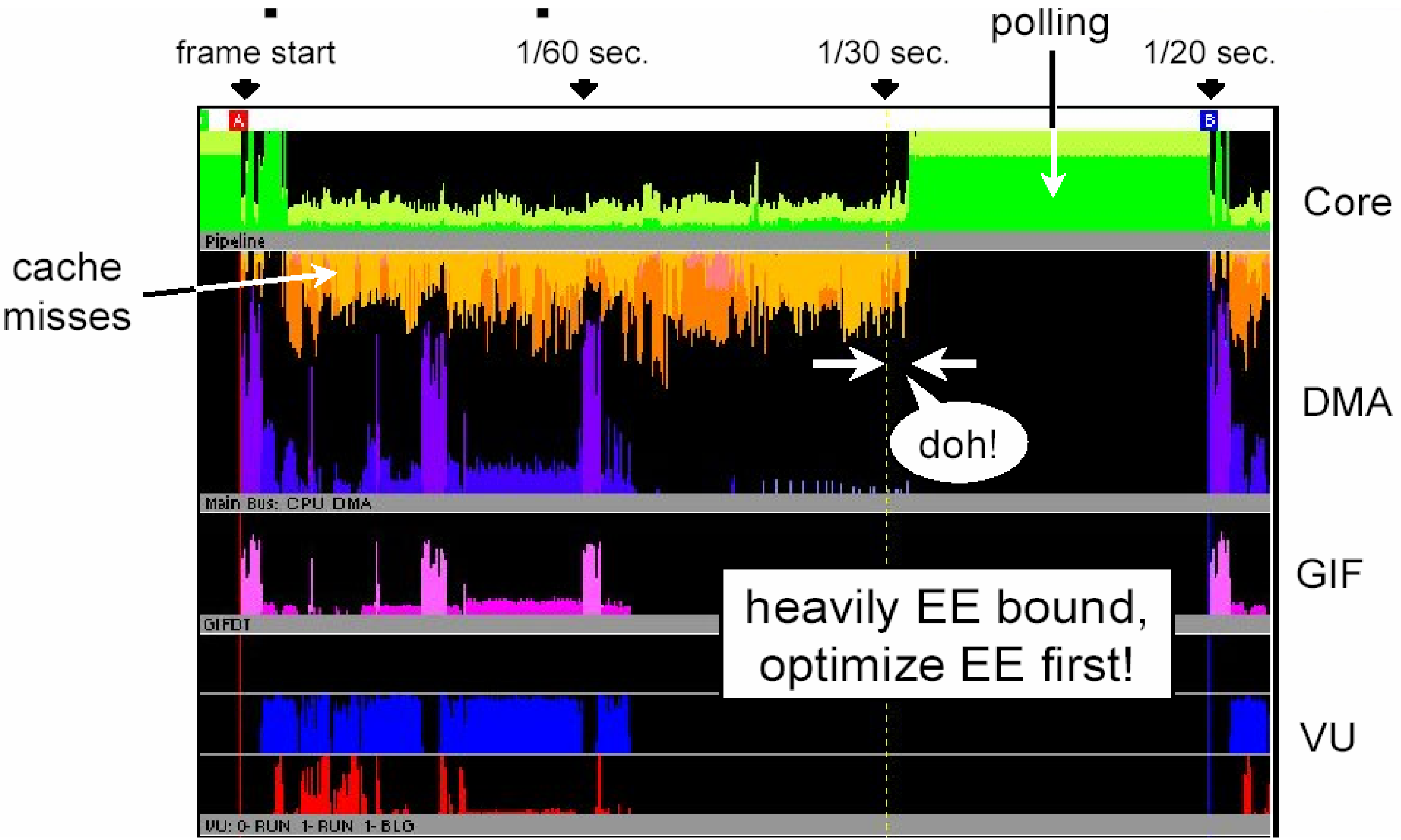


Source: http://www.research.scea.com/



Source: http://www.research.scea.com/

Frame Rate Drop



Source: http://www.research.scea.com/

Let's draw a triangle

Ultimate goal is to prepare a "GIF Packet":

GIF tag

→ Description of data to follow

Register data (already transformed & lit)

→ XYZ Coordinates

→ RGB Colors

→ UV or ST Texture coordinates

Sample GIF Packet (Parsed)

```
⊟┬0x048 GIFtag NLOOP=36 EOP=1 FLG = 0 (PACKED) PRE=1 NREG=3
 ├─PRIM PRIM = 3 (Triangle) IIP=1 (Gourard) TME=0 (Untextured) FGE=0 (No Fog) ABE=0 (Alpha Off) AA1=0 (AA OFF) FS
 ├─REGS 0x02 (ST), 0x01 (RGBAQ), 0x05 (XYZ2)
 ⊟┬Loop 0
 │├─0x049 ST (S,T)=(0.000000,0.000000) Q=0.222039
 │├─0x04a RGBAQ (R,G,B,A)=(0,127,0,128)
 │└─0x04b XYZ2 (X,Y,Z)=(1989.3750,2080.8125,741756) (0x7c56,0x820d,0x000b517c). ADC=0
 ⊟┬Loop 1
 │├─0x04c ST (S,T)=(0.221729,0.000000) Q=0.221729
 │├─0x04d RGBAQ (R,G,B,A)=(0,127,0,128)
 │└─0x04e XYZ2 (X,Y,Z)=(2107.5625,2080.6250,740717) (0x83b9,0x820a,0x000b4d6d). ADC=0
 ⊟┬Loop 2
 │├─0x04f ST (S,T)=(0.000000,0.222672) Q=0.222672
 │├─0x050 RGBAQ (R,G,B,A)=(0,127,0,128)
 │└─0x051 XYZ2 (X,Y,Z)=(1988.8125,2016.0625,743881) (0x7c4d,0x7e01,0x000b59c9). ADC=0
 ⊟┬Loop 3
 │├─0x052 ST (S,T)=(0.222366,0.222366) Q=0.222366
 │├─0x053 RGBAQ (R,G,B,A)=(0,127,0,128)
 │└─0x054 XYZ2 (X,Y,Z)=(2107.3750,2015.8750,742854) (0x83b6,0x7dfe,0x000b55c6). ADC=0
```

Let’s draw a triangle

Step 1 (EE): Do animation to update object, camera & light matrices

Step 2 (EE): Cull objects that cannot be seen

Step 3 (EE): Send camera, lights and untransformed objects to VU, texture to GS

So far, just like OpenGL, right?

Let’s draw a triangle

Step 4 (VU1): Transform vertices, do “trivial clipping”

Step 5 (VU1): Non-trivial clipping – chop up triangles. More triangles or triangle fan.

Step 6 (VU1): Compute lighting

Step 7 (VU1): Assemble GIF packet

Step 8 (VU1): Kick data to GS

Case Study 1: Shadows

Stencil Buffer

Stencil Buffer is sort of like the Z-Buffer:

Additional bit plane(s) that can determine whether a pixel is drawn or not.

OpenGL Stencil Buffer Support

```
glutInitDisplayString("stencil>=1 rgb depth double");
glutCreateWindow("stencil buffer example");
…
glClearStencil(0); // clear to zero
glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT |
        GL_STENCIL_BUFFER_BIT);
…
glEnable(GL_STENCIL_TEST);
glDisable(GL_STENCIL_TEST);
```

Tests: never, always, =, !=, <, >, <=, >= some value

Source: http://developer.nvidia.com

OpenGL Stencil Buffer Support

To use the stencil buffer:

```
glStencilFunc(GL_EQUAL, // comparison function
              0x1, // reference value
              0xff); // comparison mask
```

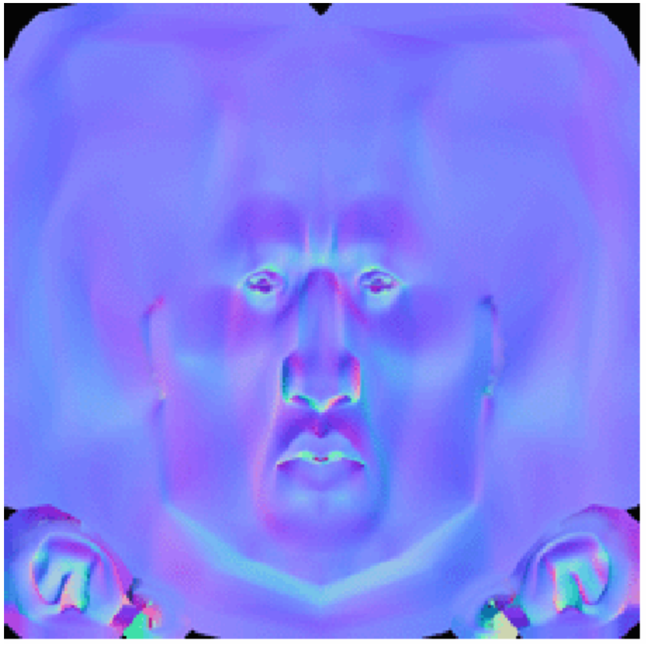
To update the stencil buffer:

```
glStencilOp(GL_KEEP, // stencil fail
            GL_DECR, // stencil pass, depth fail
            GL_INCR); // stencil pass, depth pass
glStencilMask(0xff); // Which bits to update
```

Source: http://developer.nvidia.com

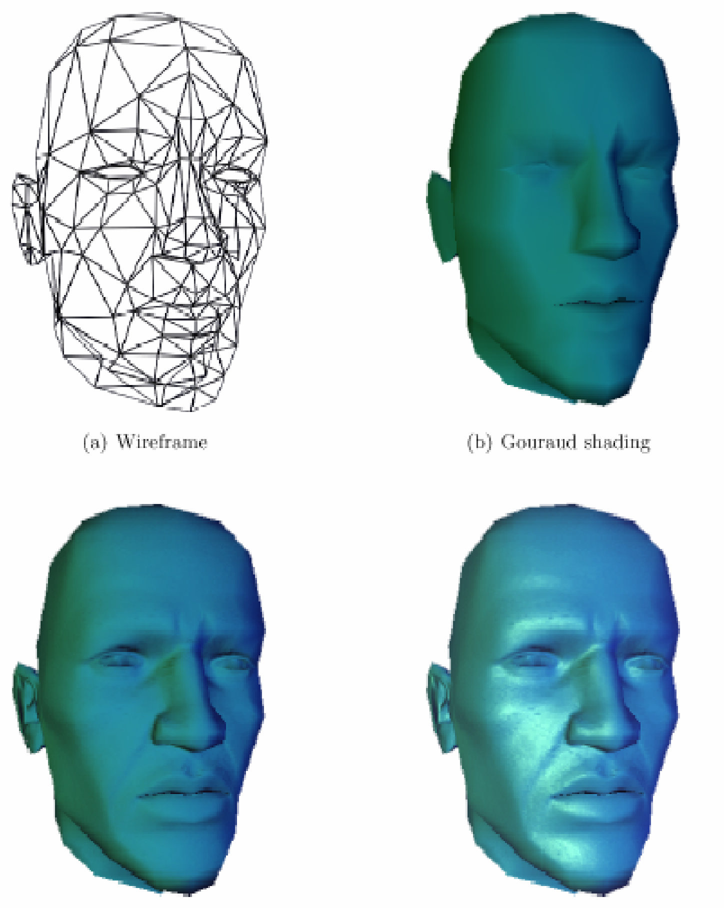
Case Study 2:
Normal Mapping

What if we could read in normals from a texture?



Source: http://playstation2-linux.com/download/p2lsd/ps2_normalmapping.pdf

Normal Mapping



(a) Wireframe (b) Gouraud shading

(c) DOT3 diffuse (d) DOT3 diffuse + specular

Source: http://playstation2-linux.com/download/p2lsd/ps2_normalmapping.pdf

Normal Mapping

These normals don't need to be simple interpolations of the vertices – we can add the appearance of detail

With a "pixel shader," it's fairly easy – at each pixel, read in the normal from the map

Can it be done without one?

Normal Mapping

High-level Overview:

Instead of a texture being color values, let it be normal values.

Instead of vertex colors being colors of edges, let them be light direction from that edge.

Normal Mapping

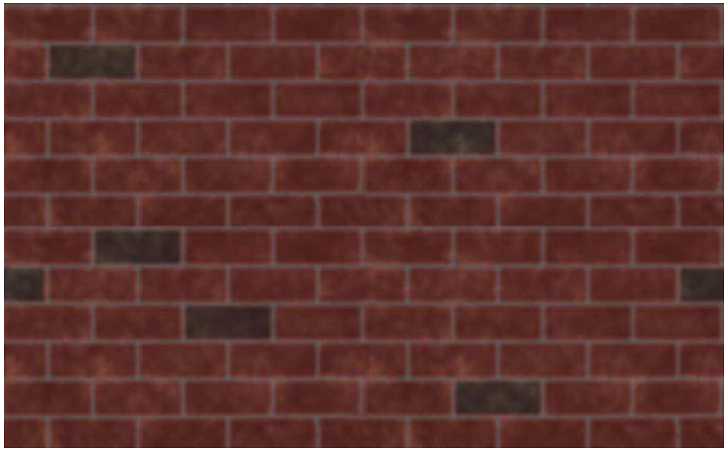
Now when we render the scene we get:
  v.r*t.r, v.g*t.g, v.b*t.b
(v=vertex color, t=texture color)
But since v=l, and t=n…

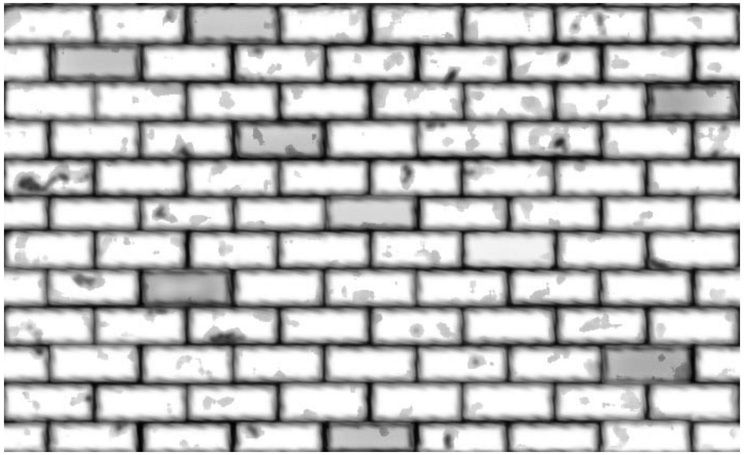
We just need to add the r, g, b for n dot l !
Just multiply the resulting colors by the light intensity, I

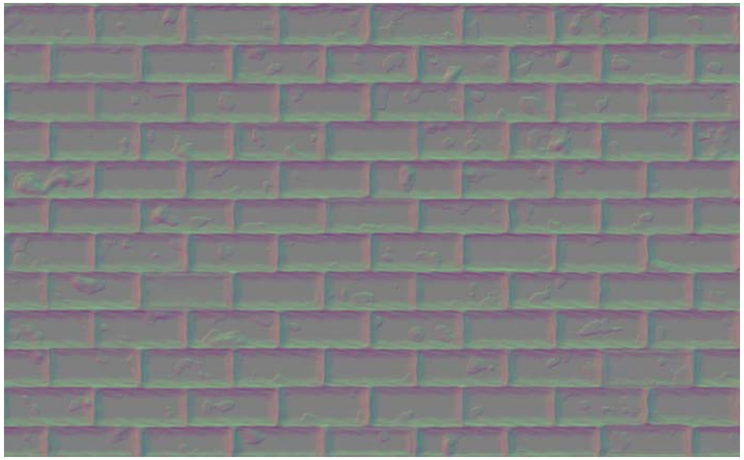
Bump Mapping

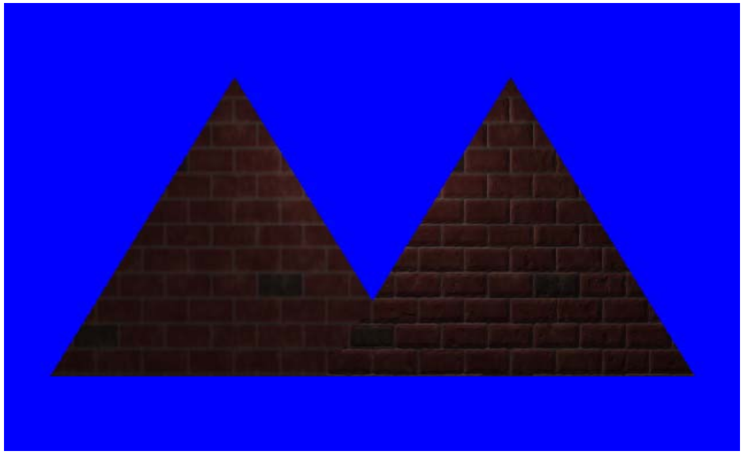
- Take a height-field
- Compute its gradient
- This gives you “deltas” to add to your current normals

Bump Mapping









Top images from: http://www.3dxperience.com/html/resources.html

The future?

Case Study 3: Simple Motion Detection

Image A=$\{r^a_1, g^a_1, b^a_1, r^a_2, g^a_2, b^a_2, \ldots\}$

Image B=$\{r^b_1, g^b_1, b^b_1, r^b_2, g^b_2, b^b_2, \ldots\}$

PixelChangeBitmask=$\{C_1, C_2, \ldots\}$

Where C_i=changed(r^a_i, r^b_i) ||
changed(g^a_i, g^b_i) ||
changed(b^a_i, b^b_i)

Simple Motion Detection

```
Trivial_Changed(a, b) {
   bigger=max(a,b);
   smaller=min(a,b);

   return a-b > delta;
// or
   return a-b > delta && a * fraction >= b;
}
```