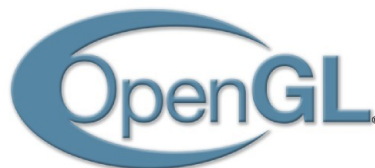
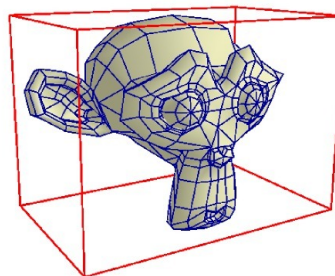
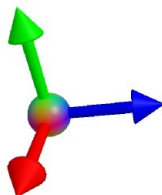
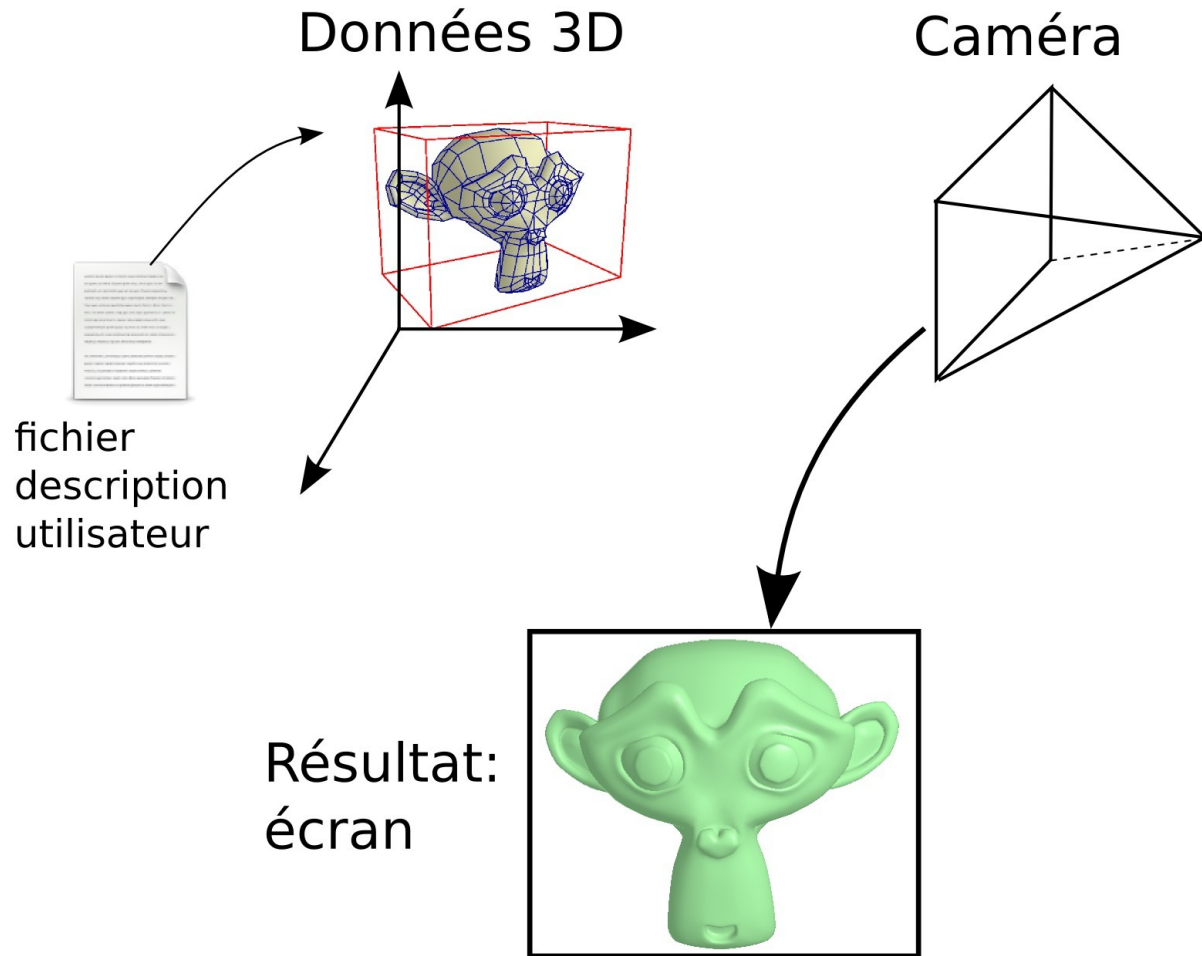


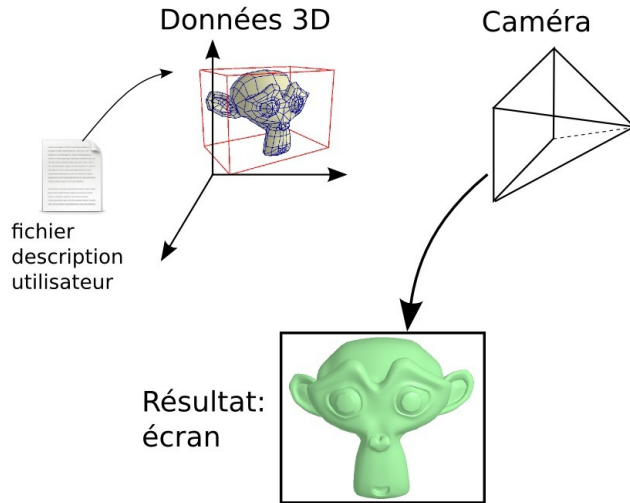
Synthèse d'images



Affichage 3D



Affichage 3D



Ordre de grandeurs:

Objets 3D:

100 - 10^5 triangles

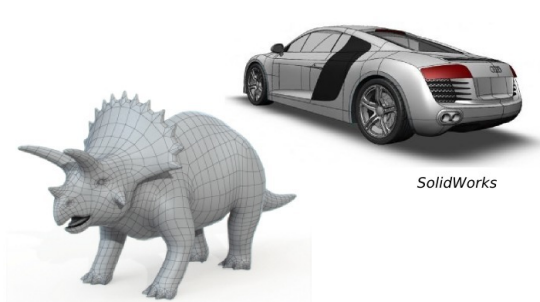
1 Triangle $\sim$ 3000 pixels

25 images par secondes

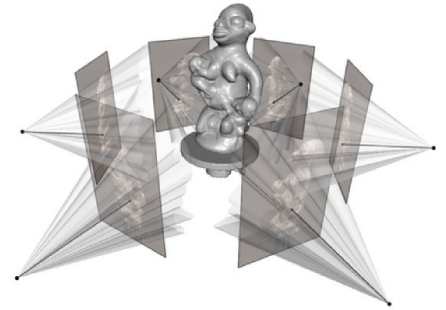
Affichage 3D = calcul intensif

Les domaines de la 3D

Modélisation



SolidWorks

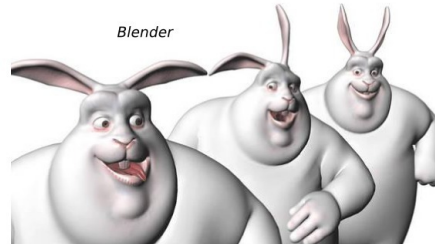


<http://carlos-hernandez.org>

Animation



DreamWorks



Blender

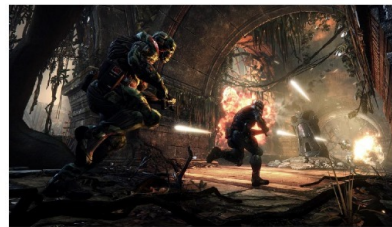


<http://www.ima.umn.edu>

Rendu



Sam Lapere



Crysis



<http://www.plemasson.fr>

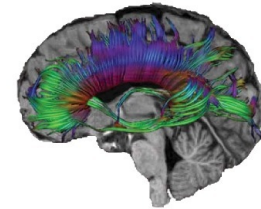
Les applications de la 3D

Domaine emergent

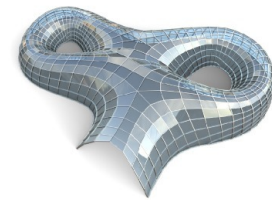
- Loisir (Jeux-Vidéo, Cinéma, ...)



- Simulation, Calcul, Analyse données



- Design, prototypage, reconstruction



- Interaction (RV, Réalité augmentée, ...)



Loisir: Jeux Vidéos



Ubisoft

Ubisoft



Naughty Dog



NVidia



Ubisoft



The Crew



<http://eelgod.deviantart.com/>

Loisir: Cinéma



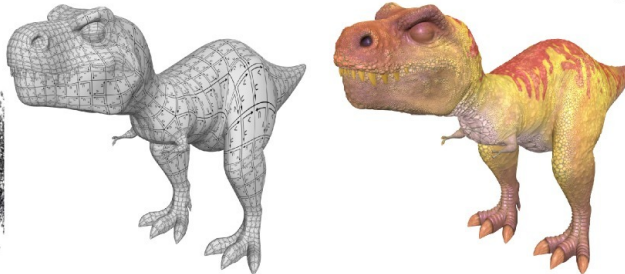
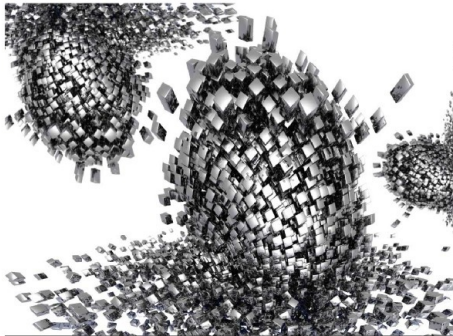
Autodesk Maya



Weta



Matrix



PTex

Loisirs

Types de métiers

Développement
C++
Rendu/Shader
GPU
Scripting
Automatisation
Pipe-line création

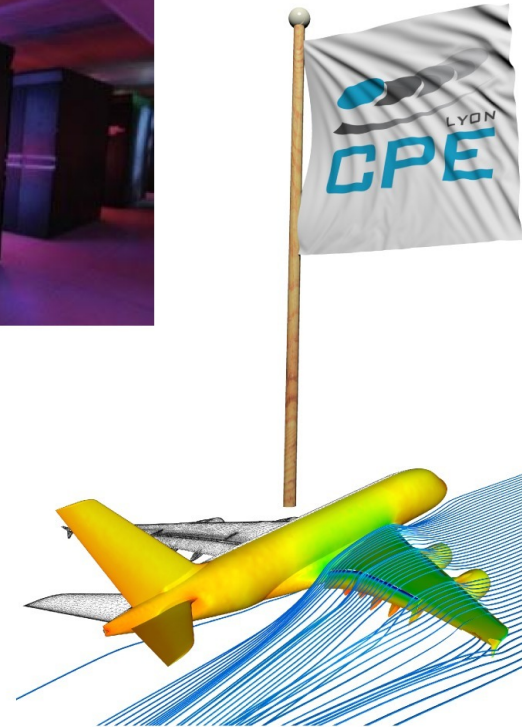
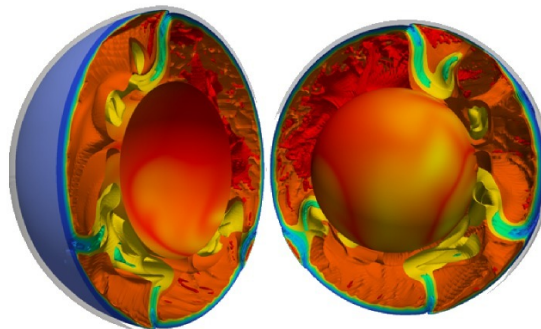
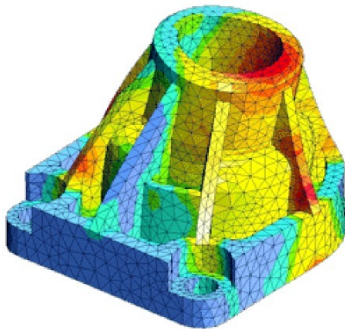
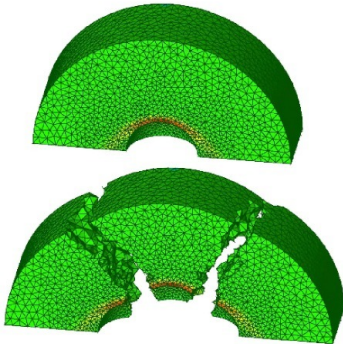
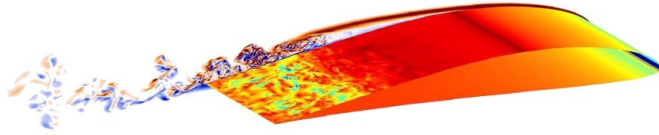


Stages/Anciens CPE

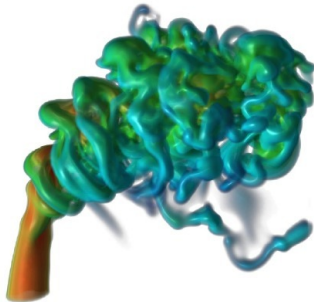
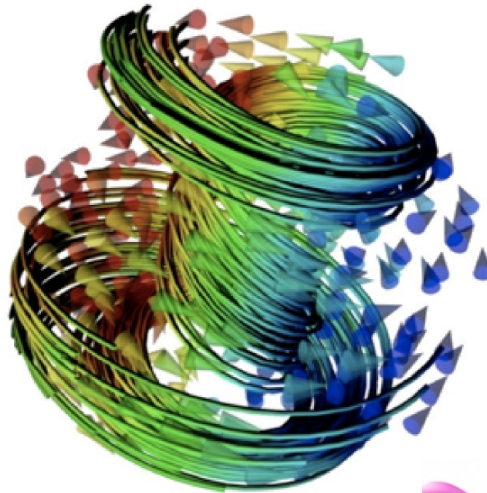
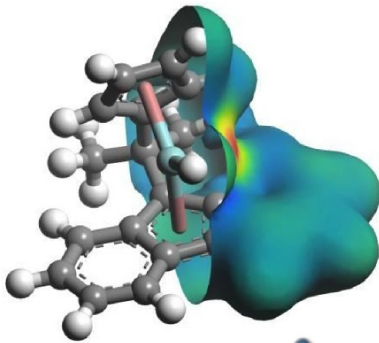
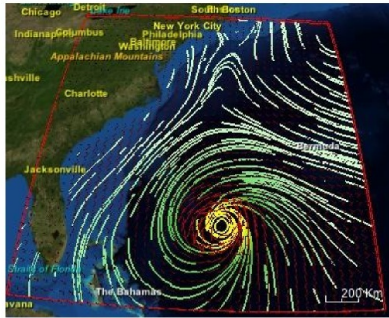
Gestion occulsion
(*GameLoft*)
Dev. Android
(*AppSolute*)
Gestion de version, évolution
(*Asobo*)
Personnage non joueurs
(*Ubisoft*)
Dev. The Crew
(*Ivory Tower*)



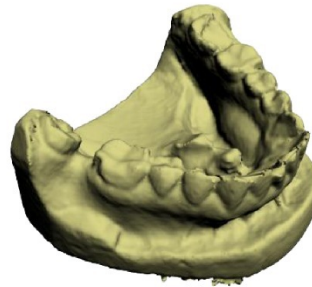
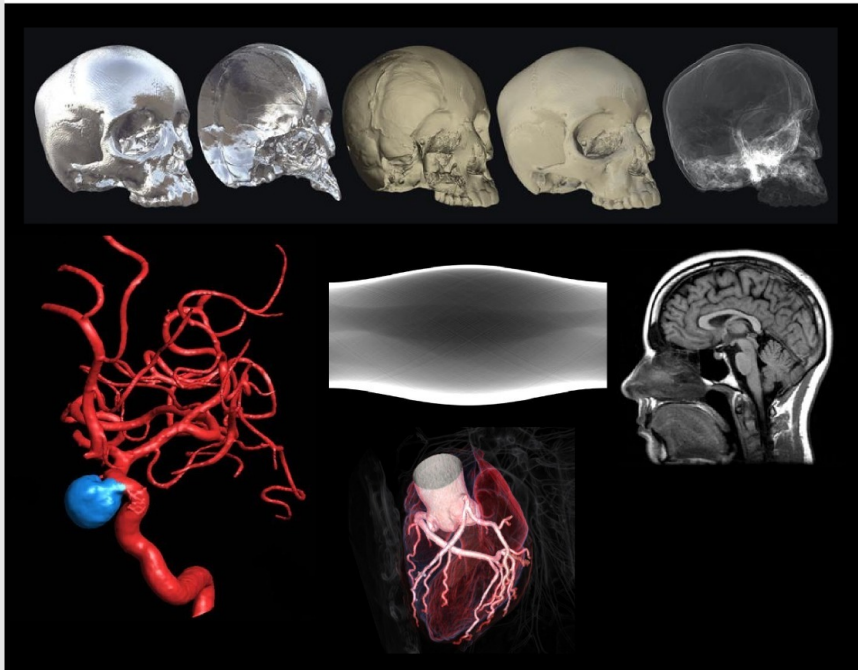
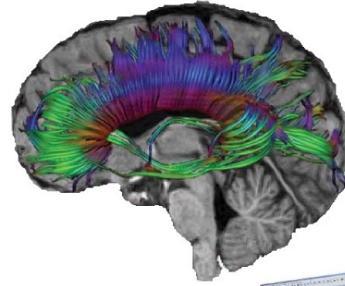
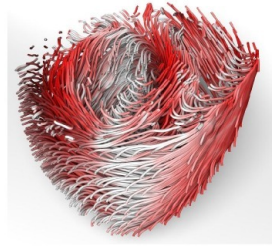
Simulation: calcul numérique



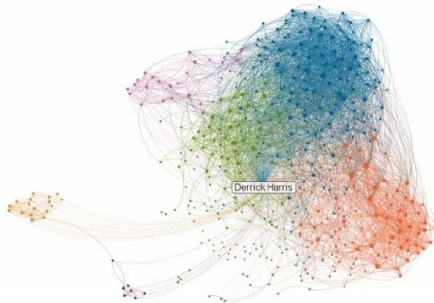
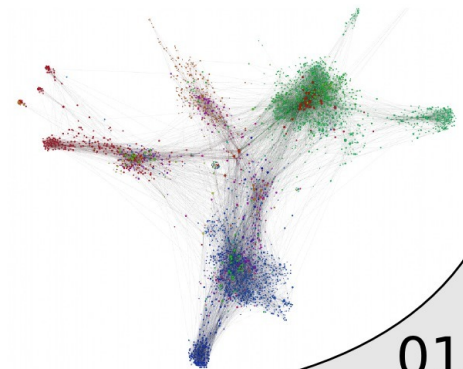
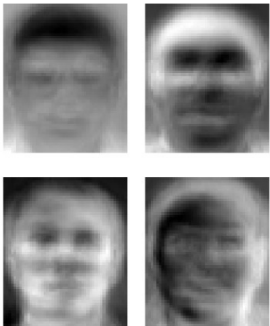
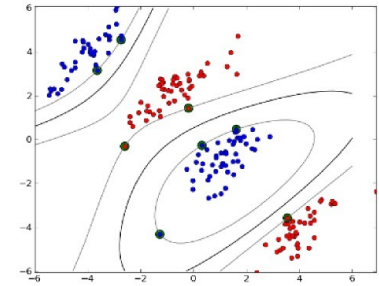
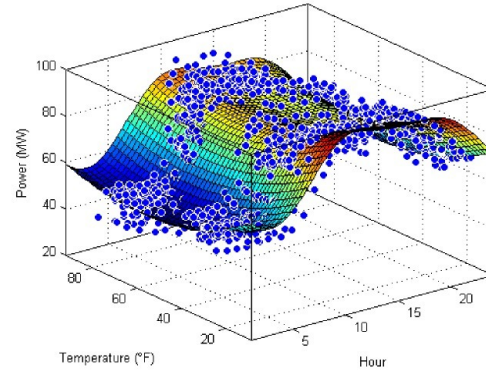
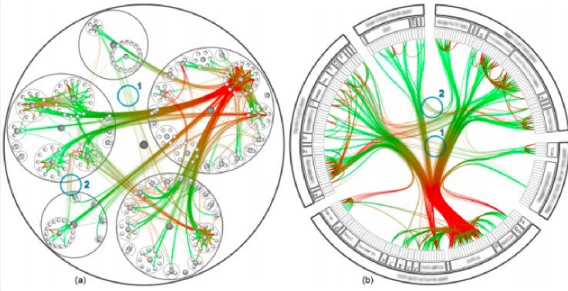
Simulation: Visu scientifique



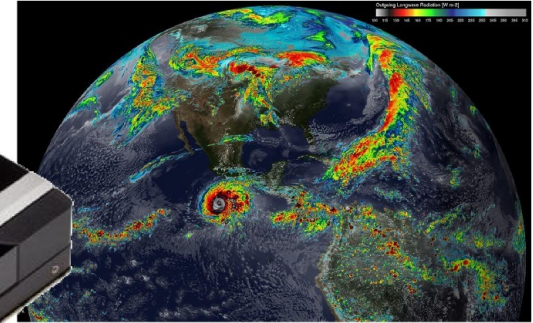
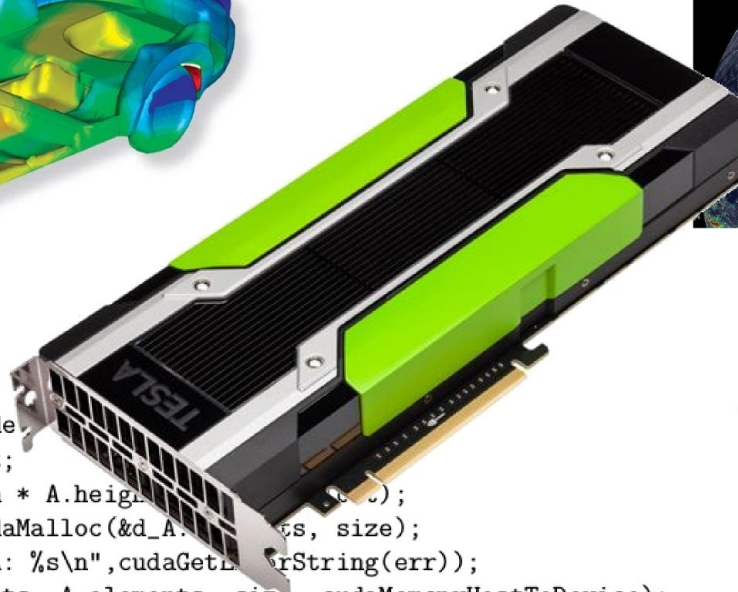
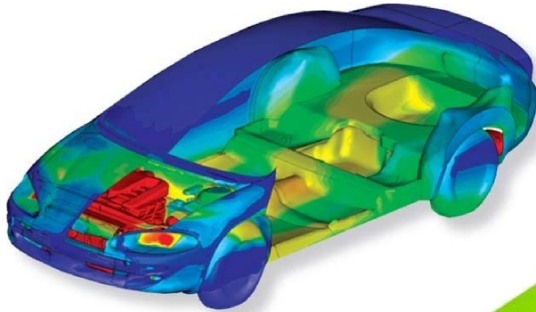
Simulation: Imagerie médicale



Analyse de données: Big Data

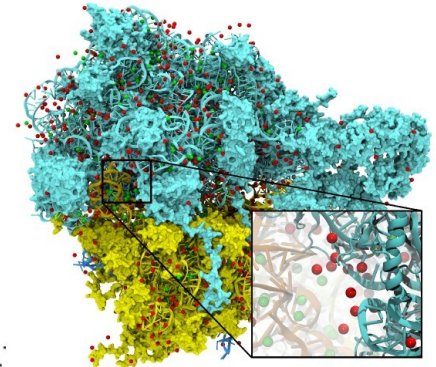
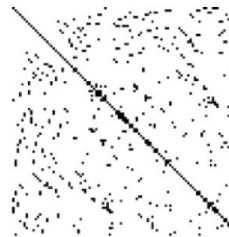


Analyse de données: GPGPU



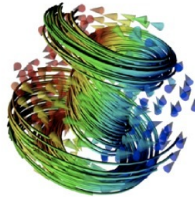
```
Matrix d_A;  
d_A.width = d_A.stride;  
d_A.height = A.height;  
size_t size = A.width * A.height * sizeof(float);  
cudaError_t err = cudaMalloc(&d_A.elements, size);  
printf("CUDA malloc A: %s\n", cudaGetErrorString(err));  
cudaMemcpy(d_A.elements, A.elements, size, cudaMemcpyHostToDevice);
```

```
Matrix d_B;  
d_B.width = d_B.stride = B.width;  
d_B.height = B.height;  
size = B.width * B.height * sizeof(float);  
err = cudaMalloc(&d_B.elements, size);  
printf("CUDA malloc B: %s\n", cudaGetErrorString(err));
```



Simulation, Calcul, Analyse de données

Types de métiers



Calcul numérique
Domaine physique/médicale
Analyse de données
Programmation efficace
Visualisation scientifique
(champs scalaires/vecteurs, ...)
Grands jeux de données
GPU



Stages/Anciens CPE

Imagerie du cerveau
(*Scient. Comp. II*)

Visu. dents 3D
(*Michigan Univ.*)

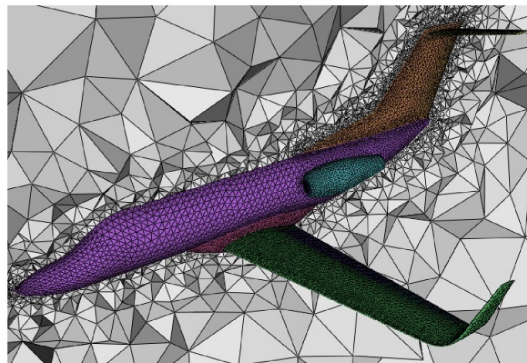
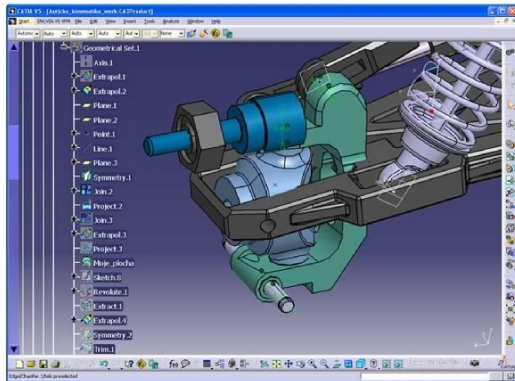
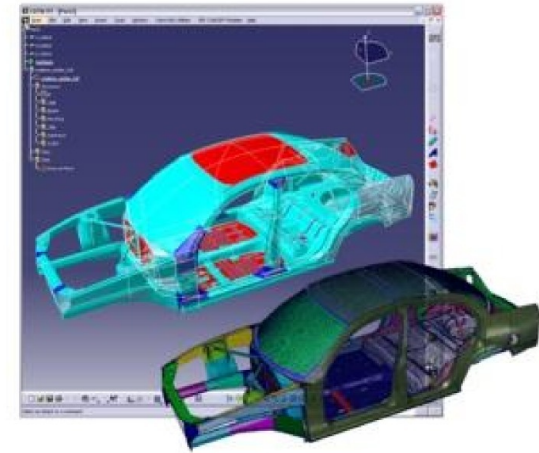
Visu 3D.
(*GE Healthcare*)

Recallage
(*Michelin*)

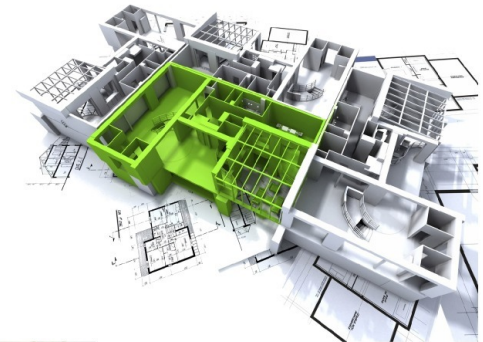
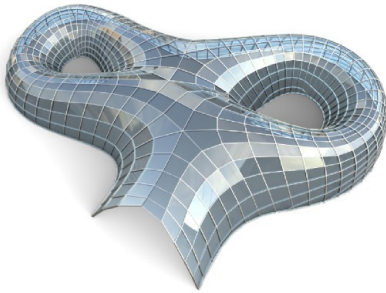
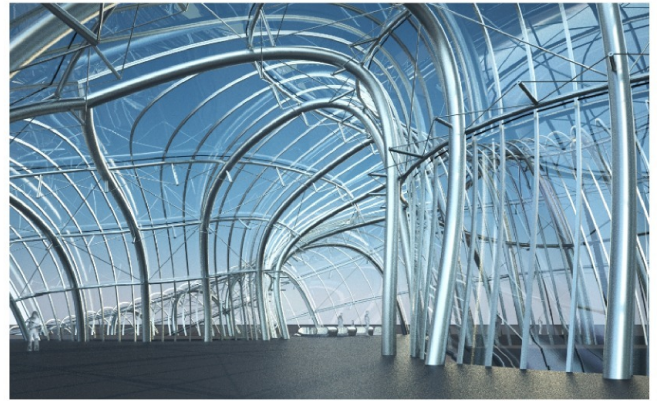
Data analysis
(*L'Oreal*)

Simulation cheveux
(*LIRIS*)

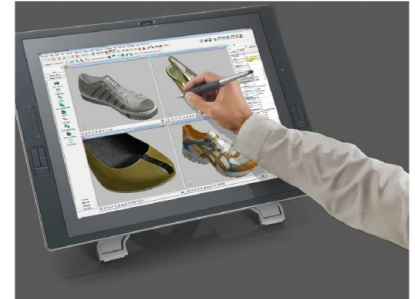
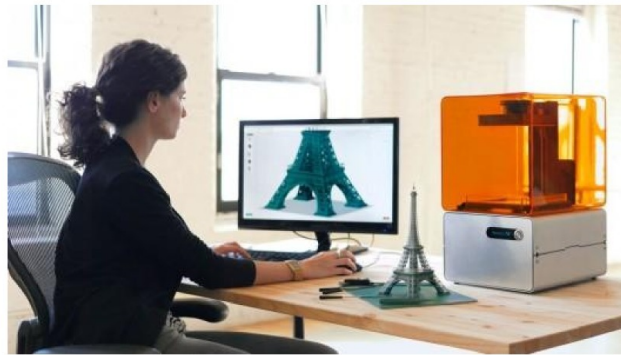
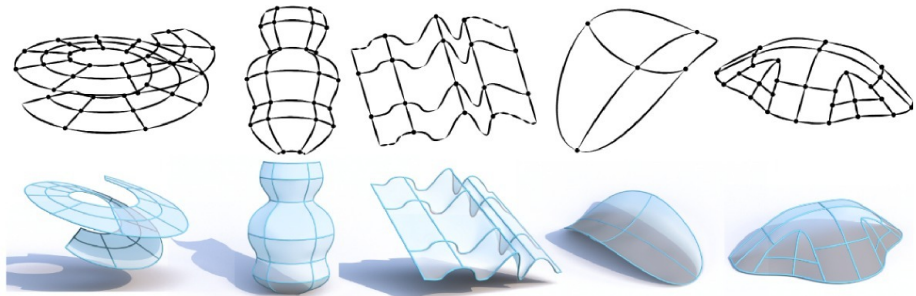
Design: CAO



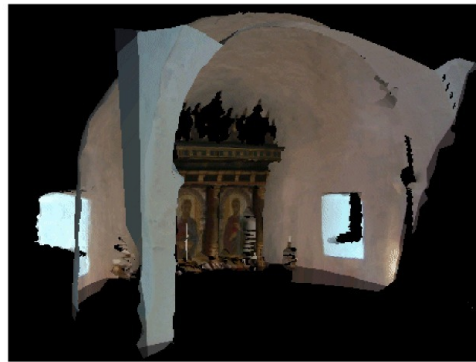
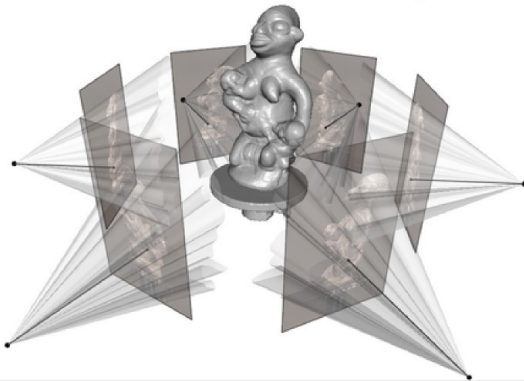
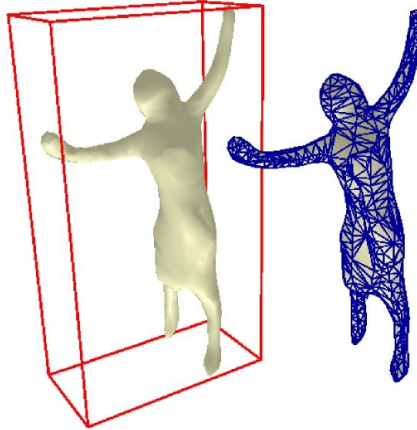
Design: Architecture



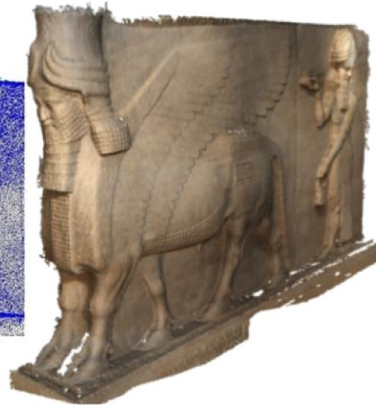
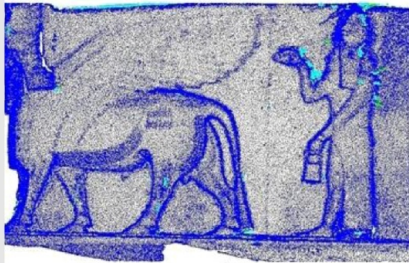
Design: Prototypage



Design: Reconstruction 3D



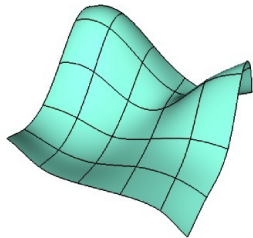
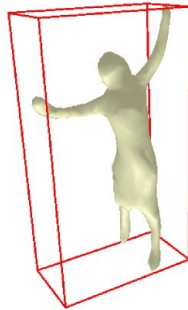
Design: Patrimoine



Design

Types de métiers

Maillage
Capteurs
Reconstruction
Interaction, IHM
Mécanique
Courbes & Surfaces

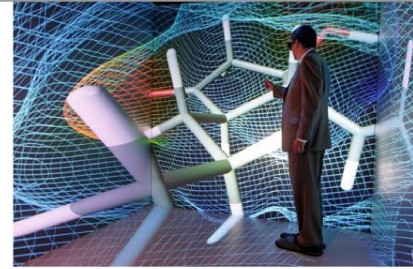


Stages/Anciens CPE

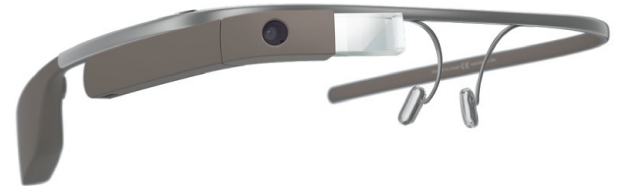
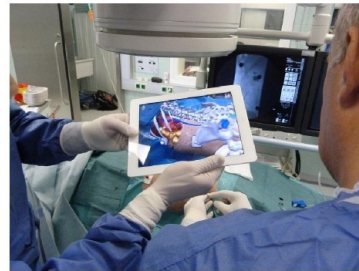
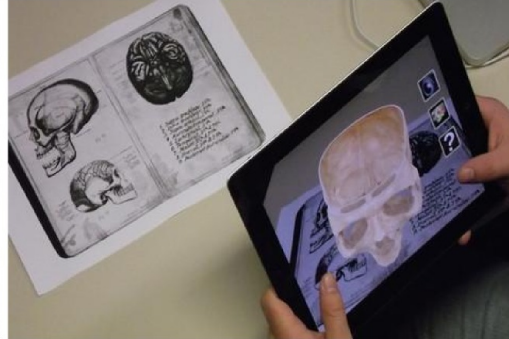
Reconstruction 3D
(Kagoshima Univ.)
Sculpture virtuelle
(LIRIS)
Scène 3D
(Technodigit)
Capteur vidéo 3D
(Thales)
Gestion collisions
(Delcam)
Modélisation 3D
(Rauscher)
Vision lunette 3D
(Rodenstock)



Interaction: Réalité virtuelle (VR)



Interaction: Réalité augmentée



Interaction

Types de métiers

Reconstruction 3D
Simulation rapide
IHM
Capteurs
Dev. smartphone



Stages/Anciens CPE

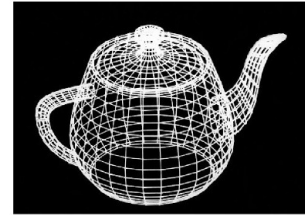
Realité augmentée médicale
(Kitware)
Réalité augmentée ville
(Wikitude)
Logiciel d'esquisse
(Dassault)
Ville virtuelle
(LIRIS)
A350 air system modeling
(Airbus)
Réalité augmentée Android
(CEA)

Historique

Historique

1ere 3D (années 70-80)

Supercalculateurs



80-90

*Architecture dédiée
(3D "cablée")*



Fin 90

Cartes vidéo 3D



Historique

Début 2000 Apparition des cartes graphiques

Programmation 3D possible sur un PC standard
Langage proche de l'assembleur



Geforce 256



morrowind

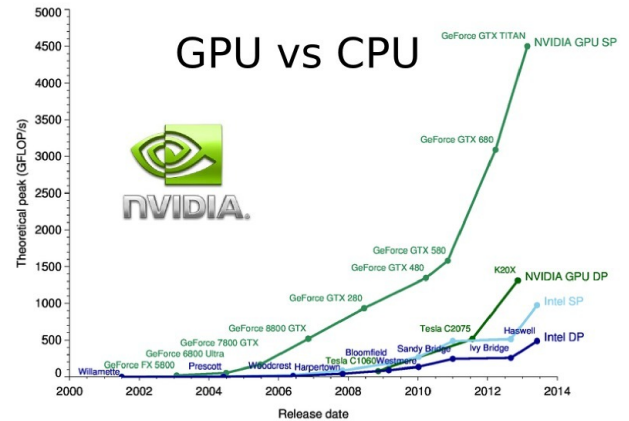


Historique

2014

Language de
programmation
parallèle.

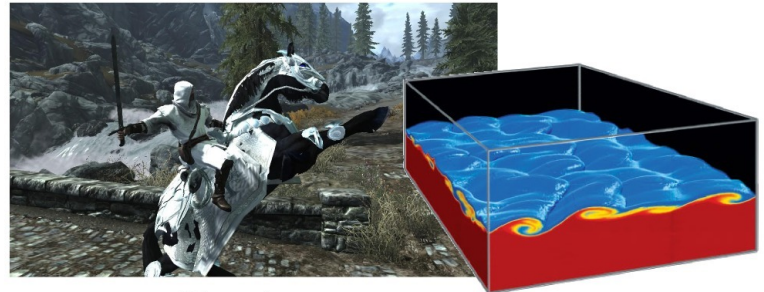
GPGPU



<http://michaelgalloy.com/>



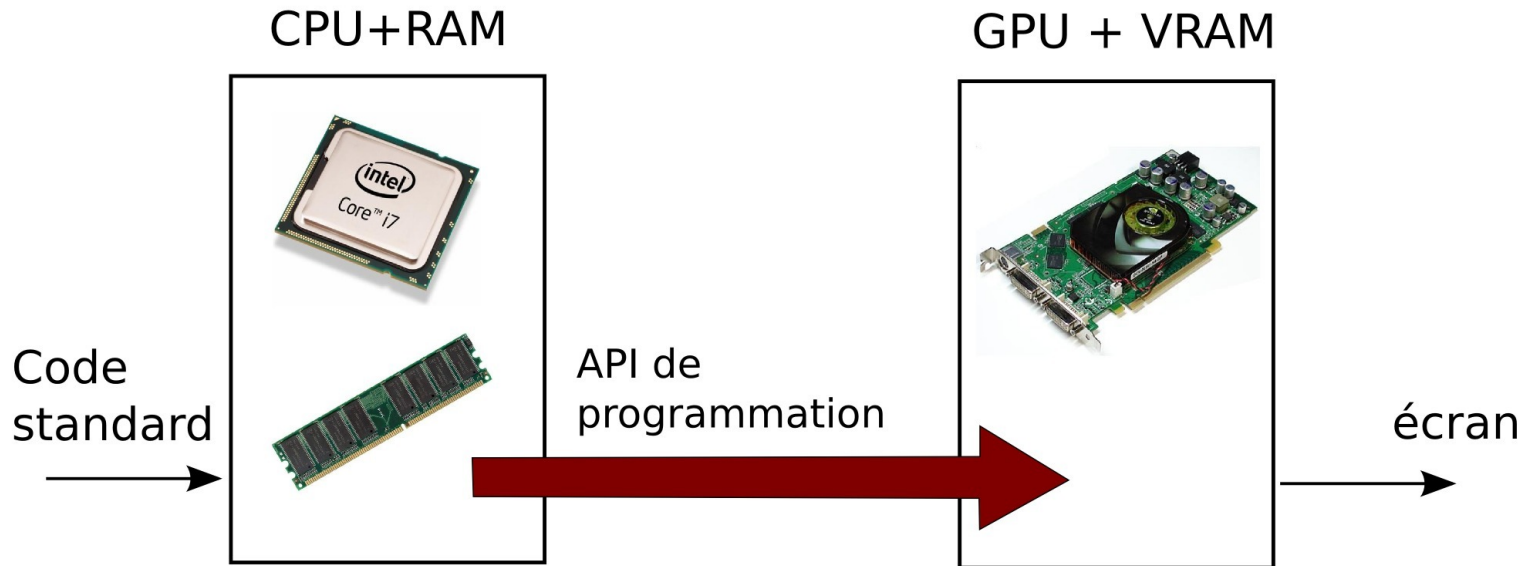
Crytek Engine



Skyrim

OpenGL

Communication avec GPU



2 API principales:

- **OpenGL**
- **Direct3D**

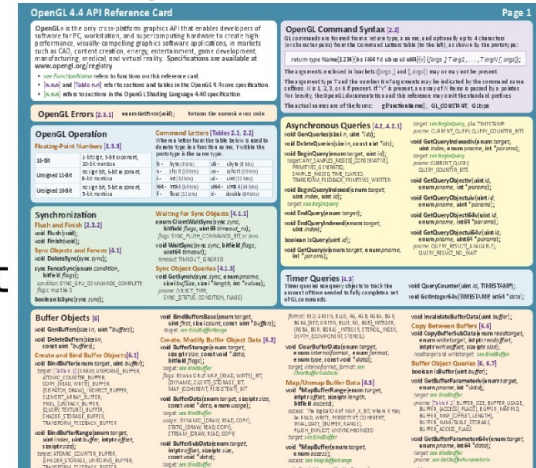
OpenGL

- Un ensemble de **spécifications** (cahier des charges) sous forme d'API pour communiquer avec la carte graphique

- Possède plusieurs implémentations suivant la carte graphique et les drivers

- Version revendeur: NVIDIA, ATI, Intel
- Mesa3D (implémentation logicielle libre)
- OpenGL ES pour Android / iPhone
- Consoles: Wii, PS3, DS

- Bibliothèque de fonctions C
Nombreux wrappers



Sources: David Odin

Programmation 3D

Etape 1:

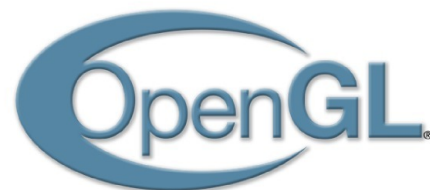
Afficher une fenêtre
(indépendant d'OpenGL)

Etape 2:

Démarrer un contexte
OpenGL dans cette fenêtre

Etape 3:

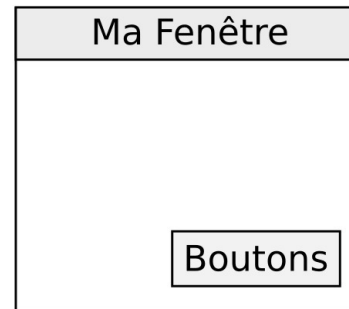
Appeler le code OpenGL
dans une boucle permanente



Programmation 3D

Etape 1:

Afficher une fenêtre
(indépendant d'OpenGL)



Il faut donc un gestionnaire de fenêtres & evenements

Plusieurs choix:

- Glut (simple, léger, limité)
- SDL (spécialisé pour les jeux)
- GLFW (léger, récent)
- GTK (gestionnaire générique fenêtre & évènements)
- Qt (gestionnaire générique, très complet, lourd)
- ...

Utilisation de GLUT

GLUT - The OpenGL Utility Toolkit

Un gestionnaire de fenêtre dédié pour OpenGL

```
//fonction d'affichage
static void display_callback()
{}

int main(int argc, char** argv)
{
    glutInit(&argc, argv); //initialise glut
    glutInitDisplayMode(GLUT_DOUBLE |
                        GLUT_RGB |
                        GLUT_DEPTH); //mode d'affichage
    glutInitWindowSize(800, 800); //taille de la fenetre
    glutCreateWindow("Ma Fenetre"); //creation de la fenetre
    glutDisplayFunc(display_callback); //affichage dans la fenetre
    glewInit(); //initialisation des fonctions de glew
    glutMainLoop(); //boucle permanente

    return 0;
}
```

Pour compiler: g++ pgm.c -lGL -lGLU -lglut -lGLEW

Sous Linux: Installer les packages de **freeglut**, **Glew**

Fonction d'affichage

Pour afficher quelque chose

```
static void display_callback()
{
    glClearColor(0.5, 0.6, 0.9, 1.0);
    glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);
    glutSwapBuffers();
}
```

glNAME : Fonction OpenGL

glClearColor(r,g,b,a) : Couleur d'effacement de l'écran

glClear() : Efface l'écran (+ tampon profondeur)

glutSwapBuffers() : Echange tampon/affichage

↖ fonction liée à glut

Callback GLUT

```
static void display_callback()

{ ... }
static void keyboard_callback(unsigned char key,
                             int x_mouse, int y_mouse)
{
    printf("key %c with mouse at position (%d,%d) \n",
           key, x_mouse, y_mouse);

    if(key=='q')
    {
        puts("Goodbye");
        exit(0);
    }
}

int main(int argc, char** argv)
{
    glutInit(&argc, argv); //initialise glut
    glutInitDisplayMode(GLUT_DOUBLE |
                       GLUT_RGB |
                       GLUT_DEPTH); //mode d'affichage
    glutInitWindowSize(800, 800); //taille de la fenetre
    glutCreateWindow("Ma Fenetre"); //creation de la fenetre

    glutDisplayFunc(display_callback);
    glutKeyboardFunc(keyboard_callback);

    glewInit(); //initialisation des fonctions de glew
    glutMainLoop(); //boucle permanente

    return 0;
}
```

récupération touches
clavier

→ Fonction à appeler

Callback GLUT (mouse)

Récupération des informations du click souris

```
static void mouse_click_callback(int button, int state,  
                                int x, int y)  
{  
    printf("mouse click %d,%d , (x,y)=(%d,%d)\n",button,state,x,y);  
}
```

```
glutMouseFunc(mouse_click_callback);
```

Evènements par "callback" = fonction utilisateur appelée lors d'un évènement

Callback GLUT

Autres évènements possibles:

glutReshapeFunc	(redimensionnement de fenêtre)
glutKeyboardFunc	(appui clavier)
glutSpecialFunc	(touches spéciales du clavier: flèches)
glutMouseFunc	(clic souris)
glutMotionFunc	(déplacement souris)
glutTabletButtonFunc	(appui bouton tablette)
glutIdleFunc	(lorsque rien ne se passe)
glutTimerFunc	(appel au bout d'un temps donné)

<http://www.opengl.org/resources/libraries/glut/spec3/spec3.html>

Appels OpenGL

Principe général

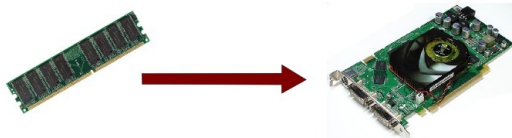
Initialisation

- Définition des données ^{1x}

```
float T[500];  
...  
T[5]=7.5;
```

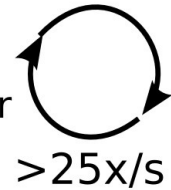
- Envoi des données sur GPU

```
glBufferData(...)
```



Boucle d'affichage

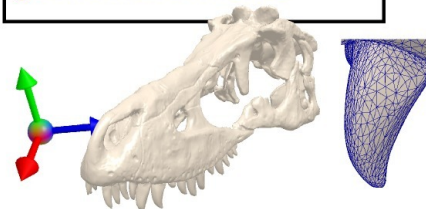
- Pointer vers les données à afficher (sur GPU)



```
glBindBuffer(...)
```

- Demande d'affichage

```
glDrawElements(...)
```



Programme minimaliste

Affichage de triangle

Pgm minimal, triangle

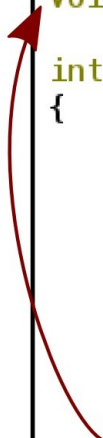
```
//un identifiant de buffer
GLuint vbo=0;

//fonction d'affichage
static void display_callback()
{...}

//fonction d'initialisation
void init() {...}

int main(int argc, char** argv)
{
    glutInit(&argc, argv); //initialise glut
    glutInitDisplayMode(GLUT_DOUBLE |
                        GLUT_RGB |
                        GLUT_DEPTH); //mode d'affichage
    glutInitWindowSize(800, 800); //taille de la fenetre
    glutCreateWindow("Ma Fenetre"); //creation de la fenetre
    glutDisplayFunc(display_callback); //affichage dans la fenetre
    glewInit(); //initialisation des fonctions de glew
    init();
    glutMainLoop(); //boucle permanente

    return 0;
}
```



Pgm minimal, triangle

```
//un identifiant de buffer
GLuint vbo=0;

//fonction d'affichage
static void display_callback()
{...}
```

```
//fonction d'initialisation
void init() {...}
```

```
int main(int argc, char** argv)
```

```
{
    glutInit(&argc, argv); //initialise glut
    glutInitDisplayMode(GLUT_DOUBLE |
        GLUT_RGB |
        GLUT_DEPTH); //mode d'affichage
    glutInitWindowSize(800, 800); //taille de la fenetre
    glutCreateWindow("Ma Fenetre"); //creation de la fenetre
    glutDisplayFunc(display_callback); //affichage dans la fenetre
    glewInit(); //initialise
    init();
    glutMainLoop(); //boucle
    return 0;
}
```

```
//fonction d'initialisation
void init()
```

```
{
```

```
    //les donnees
```

```
    float sommets[]={0,0,0,
                      1,0,0,
                      0,1,0};
```

```
    glGenBuffers(1,&vbo); //creation du VBO
```

```
    glBindBuffer(GL_ARRAY_BUFFER,vbo); //Buffer courant
```

```
    //copie des donnees en VRAM
```

```
    glBufferData(GL_ARRAY_BUFFER,sizeof(sommets),sommets,GL_STATIC_DRAW);
```

```
    glEnable(GL_DEPTH_TEST); //Active gestion de profondeur
```

```
}
```

Position

0	0	0	1	0	0	0	1	0
---	---	---	---	---	---	---	---	---

en RAM

glBufferData()

vbo

0	0	0	1	0	0	0	1	0
---	---	---	---	---	---	---	---	---

sur GPU

Pgm minimal, triangle

```
//un identifiant de buffer
GLuint vbo=0;

//fonction d'affichage
static void display_callback()
{...}

//fonction d'initialisation
void init() {...}

int main(int argc, char** argv)
{
    glutInit(&argc, argv); //initialise glut
    glutInitDisplayMode(GLUT_DOUBLE |
        GLUT_RGB | GLUT_DEPTH); //mode d'affichage
    glutInitWindowSize(800, 800); //taille de la fenetre
    glutCreateWindow("Ma Fenetre"); //creation de la fenetre
    glutDisplayFunc(display_callback); //affichage dans la fenetre
    glewInit(); //initialisation des fonctions de glew
    init();
    glutMainLoop(); //boucle permanente

    return 0;
}
```

```
//fonction d'affichage
static void display_callback()
{
    //couleur du fond
    glClearColor(0.5, 0.6, 0.9, 1.0);
    glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);

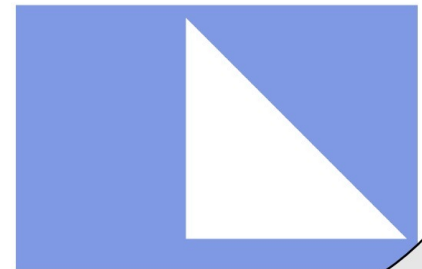
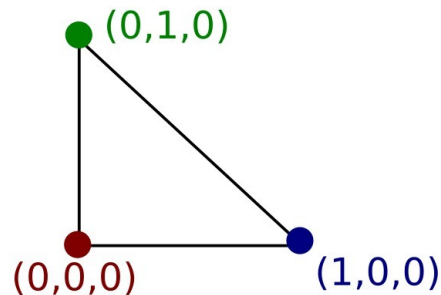
    //affichage
    glEnableClientState(GL_VERTEX_ARRAY); //active donnees
    glBindBuffer(GL_ARRAY_BUFFER, vbo); //buffer courant
    glVertexPointer(3, GL_FLOAT, 0, 0); //buffer de donnees
    glDrawArrays(GL_TRIANGLES, 0, 3); //demande d'affichage

    glutSwapBuffers();
}
```

Buffer courant:
vbo



glDrawArrays() Affiche



Modes affichages

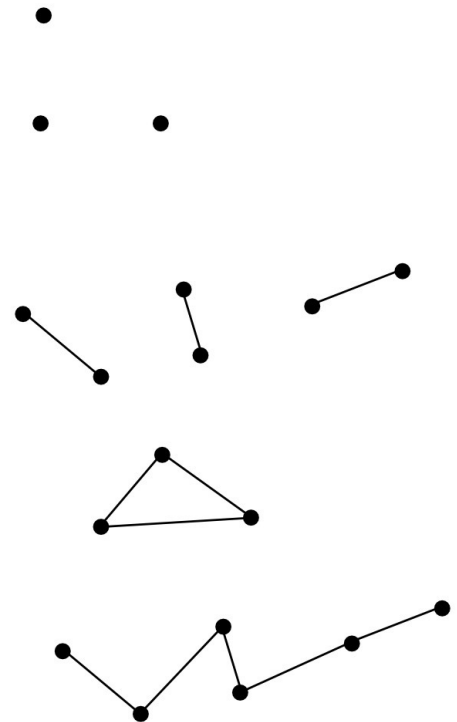
glDrawArrays(GLenum *mode*, GLint *first*, GLsizei *count*);

```
glPointSize(5);  
glDrawArrays(GL_POINTS, 0, N);
```

```
glDrawArrays(GL_LINES, 0, N);
```

```
glDrawArrays(GL_LINES_LOOP, 0, N);
```

```
glDrawArrays(GL_LINES_STRIP, 0, N);
```



Introduction aux Shaders

Notion de shaders

Programme en C, C++, etc
Sur CPU

```
int main()  
{ ...
```

Création des données

Envoie sur GPU

Demande d'affichage

Gestion évènements



Sur GPU

2 programmes de contrôles

Vertex Shader

appelé pour
tous les sommets

projection
position



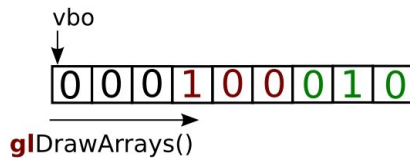
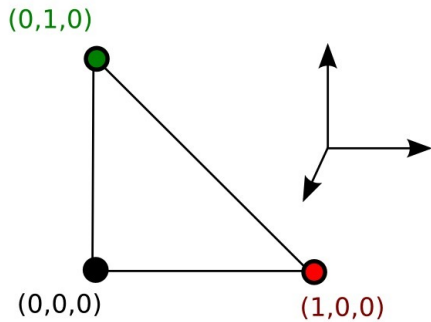
Fragment Shader

appelé pour tous les
"pixels colorés"

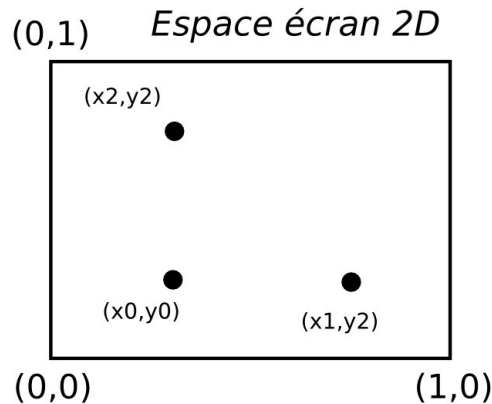
couleurs pixels

But des shaders

Données 3D



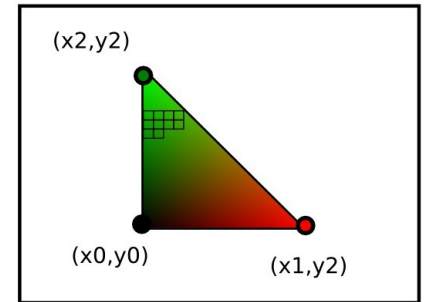
Vertex Shader



entrée:
coordonnées 3D

sortie:
coordonnées 2D
espace écran

Fragment Shader

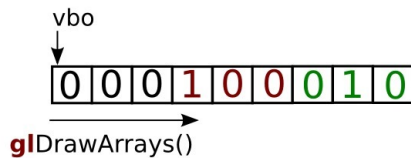
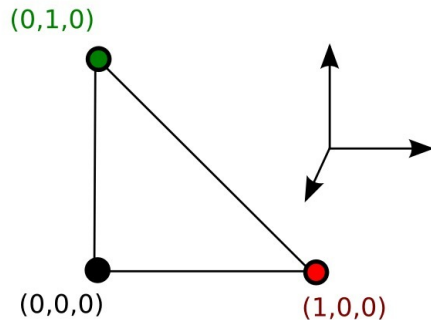


entrée:
coordonnée
fragment courant
+ interpolation
linéaire données

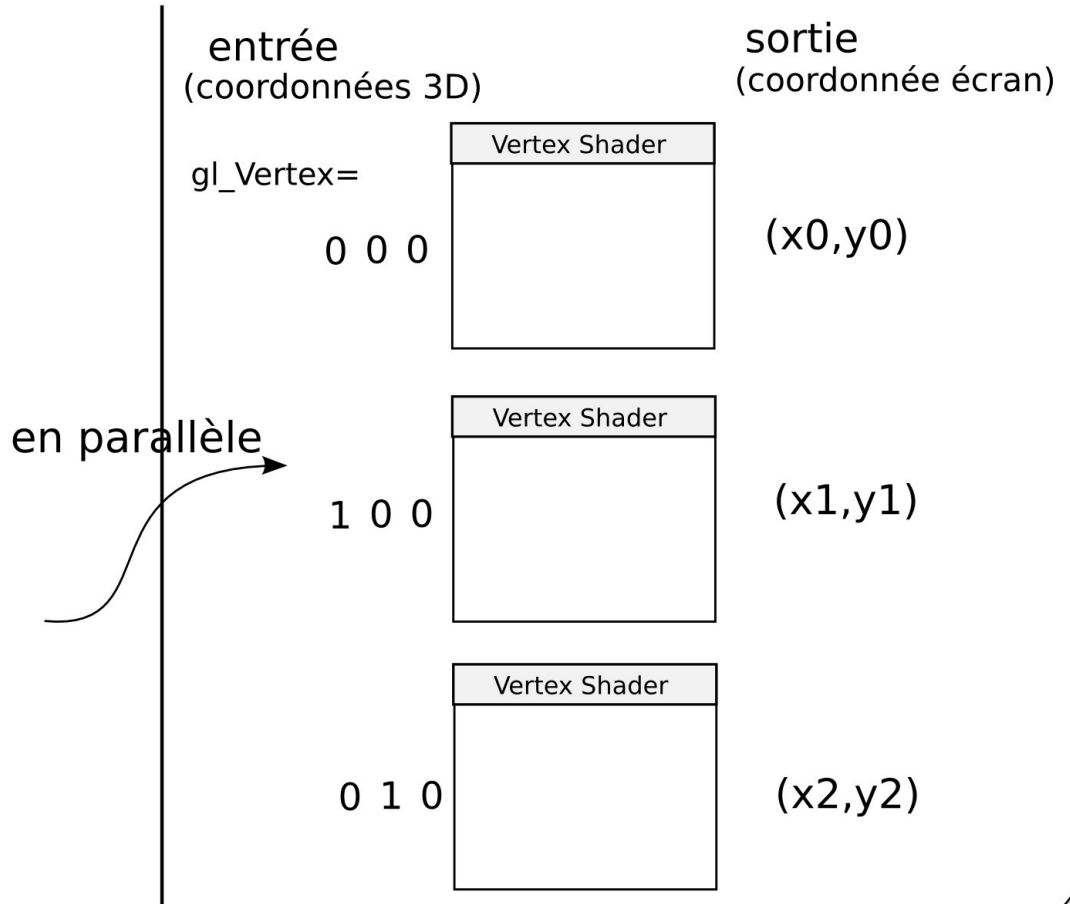
sortie:
couleur du
fragment

Parallélisme

Données

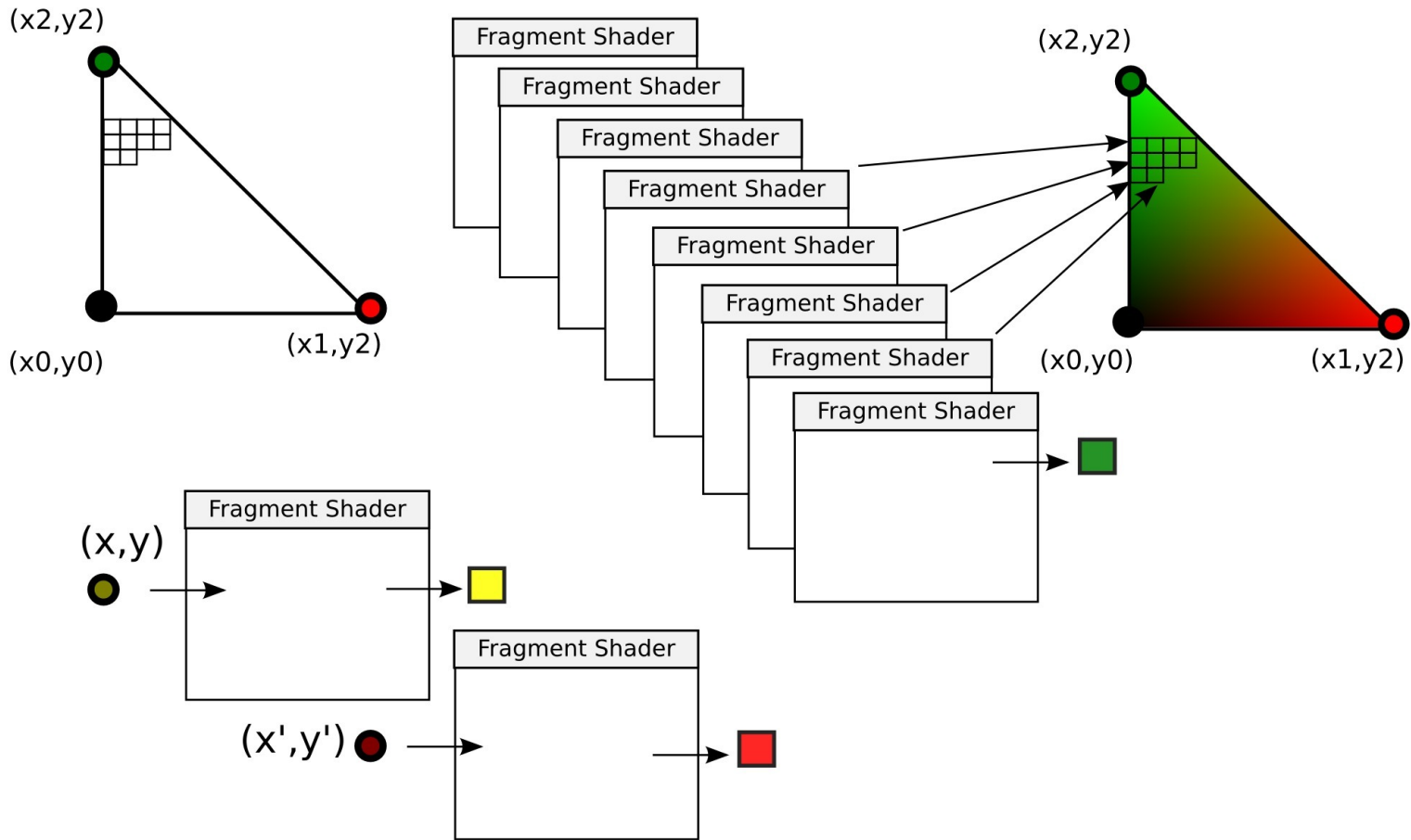


Vertex shader



Parallélisme

Fragment shader



Shaders en pratique

Créez 2 fichiers *textes*:

```
#version 120

//Un Vertex Shader minimaliste
void main (void)
{
    //Coordonnees du sommet
    gl_Position = gl_Vertex;
}
```

shader.vert

```
#version 120

//Un Fragment Shader minimaliste
void main (void)
{
    //couleur du fragment
    gl_FragColor = vec4(1.0f,0.0f,0.0f,1.0f);
}
```

shader.frag

Chargez les fichiers dans le programme principal

```
glCreateProgram();
glCreateShader(...);
glShaderSource(...);
glCompileShader(...);
glAttachShader(...);
glLinkProgram(...);
glUseProgram(...);
```

Shaders en pratique

```
#version 120
```

```
//Un Vertex Shader minimaliste
```

```
void main (void)
```

```
{
```

```
    //Coordonnees du sommet
```

```
    gl_Position = gl_Vertex;
```

```
}
```

Ressemble
à du C

shader.vert

Variable déjà connue
position de sortie des sommets

Variable déjà connue
position d'entrée des sommets

Shaders en pratique

```
#version 120

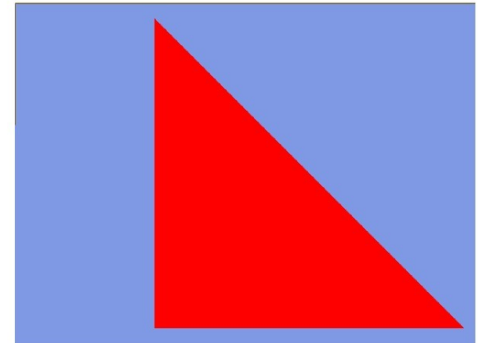
//Un Fragment Shader minimaliste
void main (void)
{
    //couleur du fragment
    gl_FragColor = vec4(1.0f,0.0f,0.0f,1.0f);
}
```

shader.frag

Variable de sortie:
couleur du pixel

Contrôle
de la couleur

Ce n'est pas du C
Ressemble à du C++
=> C'est du GLSL



Notions de GLSL

Langage proche du C, et C++ en plus simple
Possède les éléments de calculs

int

float

vec2(x,y);

vec3(x,y,z);

vec4(x,y,z,w);

vec3 a(1,4,3);

vec2 b=a.xy;

vec2 c=a.zx;

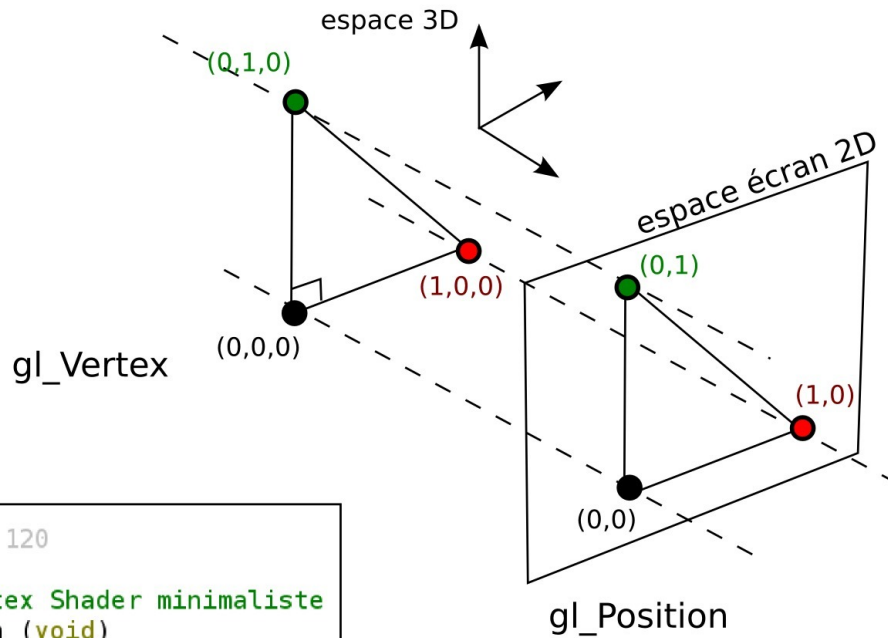
vec2 c=vec2(a.y,4);

mat2();

mat3();

mat4();

Projection

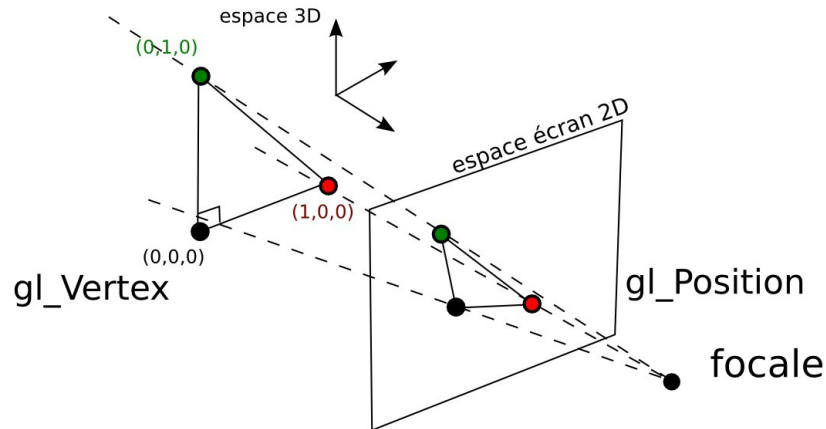
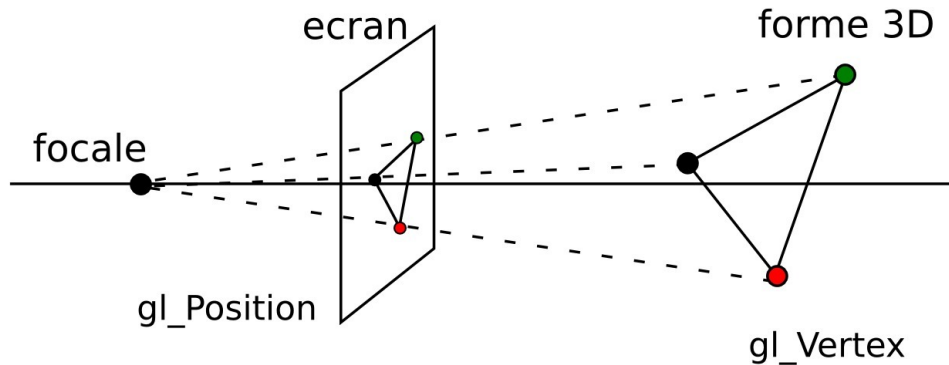


```
#version 120

//Un Vertex Shader minimaliste
void main (void)
{
    //Coordonnees du sommet
    gl_Position = gl_Vertex;
}
```

Projection orthogonale

Projection

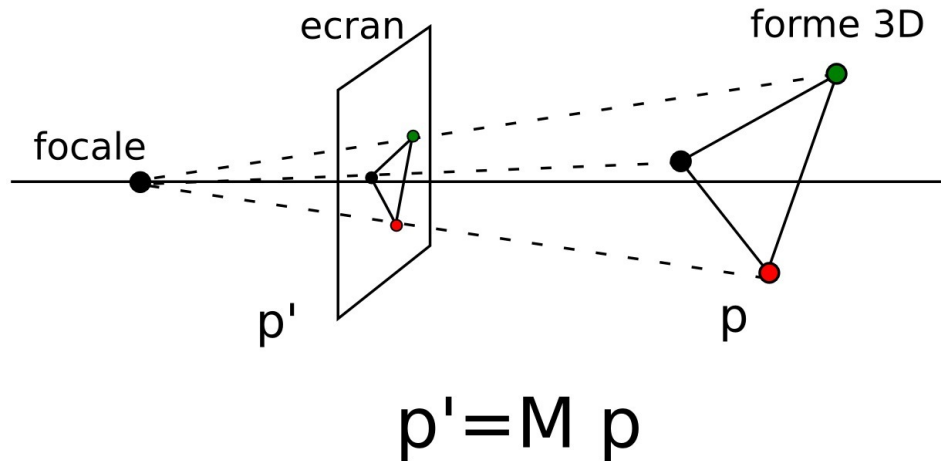


`gl_Position=projection_perspective(gl_Vertex)`

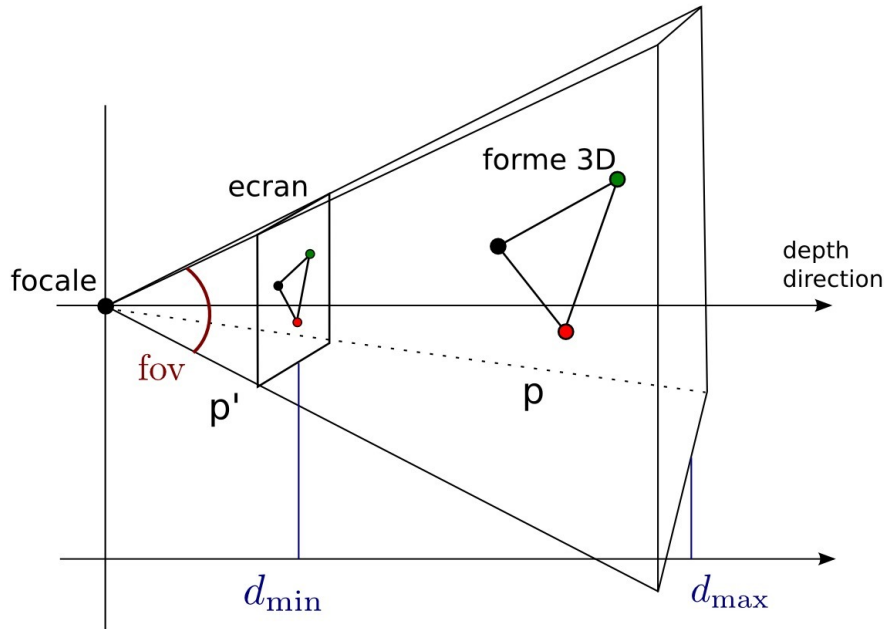
Projection perspective

`gl_Position=projection_perspective(gl_Vertex)`

`projection_perspective` : Matrice de projection 4x4
(voir espace projectif 2nd semestre)



Projection perspective



a: aspect ratio y/x

$$p' = M p$$

$$M = \begin{pmatrix} f_x & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & C & D \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

$$f = \cotan(\text{fov}/2)$$

$$f_x = f/a$$

$$C = \frac{d_{\max} + d_{\min}}{d_{\max} - d_{\min}}$$

$$D = -2 \frac{d_{\max} d_{\min}}{d_{\max} - d_{\min}}$$

Projection perspective

Exemple de vertex shader

```
mat4 projection=mat4(vec4(1.7321f,0.0f,0.0f,0.0f),  
                    vec4(0.0f,1.7321f,0.0f,0.0f),  
                    vec4(0.0f,0.0f,1.1053f,1.0f),  
                    vec4(0.0f,0.0f,-1.0526f,0.0f));  
  
//Un Vertex Shader minimaliste  
void main (void)  
{  
    //Coordonnees du sommet  
    vec4 p=projection*gl_Vertex;  
  
    //position dans l'espace ecran  
    gl_Position = p;  
}
```

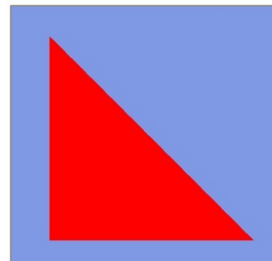
attention:
vecteurs colonnes

fov=60 degrés

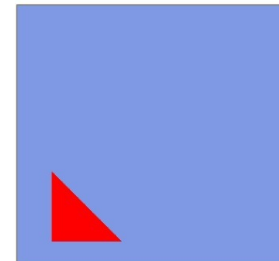
a=1

d_min=0.5

d_max=10



z=2



z=6

Passage d'arguments uniform

Il est possible de passer des paramètres du CPU vers les shaders

display_callback()

```
float valeur_a_passer=rotation_x/360.0;  
glUniform1f (get_uni_loc(shader_program_id, "valeur"), valeur_a_passer);
```

shader.frag()

```
uniform float valeur;  
  
//Un Fragment Shader minimaliste  
void main (void)  
{  
    //couleur du fragment  
    gl_FragColor = vec4(valeur,valeur,0,1);  
}
```

uniform:

paramètre ayant la même valeur pour l'ensemble des shaders.

Passage d'arguments uniform

Utilisation: - Interaction clavier, souris
- Temps

```
glUniform1f (get_uni_loc(shader, string), value);  
    1u  
    2f  
    3d  
    Matrix4fv  
    ...
```

Rem. fonctions OpenGL

L'API d'OpenGL est en C: 1 nom par types d'arguments

```
gl[NOM]f(...);  
gl[NOM]i(...);  
gl[NOM]u(...);  
gl[NOM]d(...);  
gl[NOM]vf(...);
```

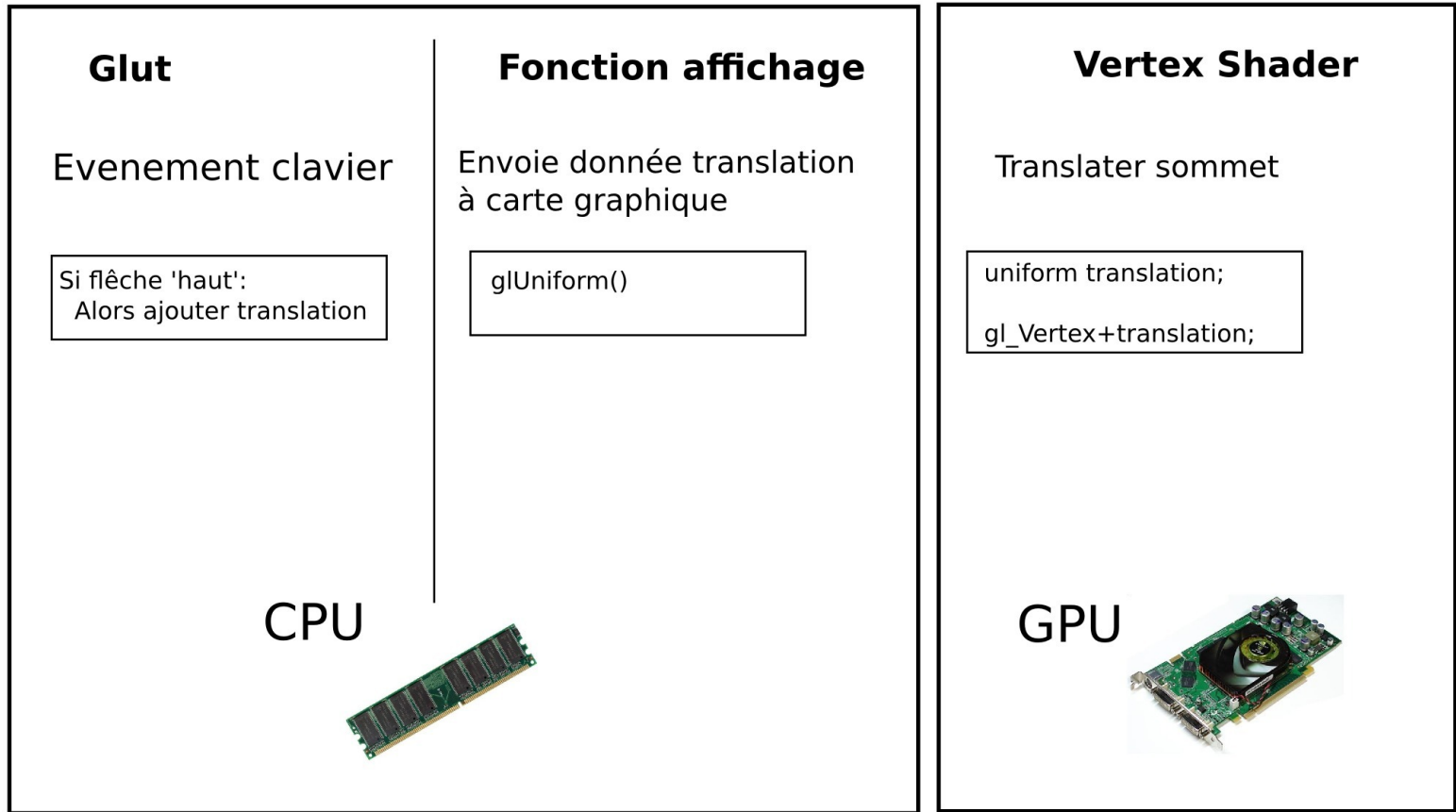
```
gl[NOM]3f(...);  
gl[NOM]2u(...);
```

ex.

```
glUniform1f(...)  
glUniform2u(...)
```

Interaction

Possibilité de déplacer un objet dans le vertex shader



Interaction

Possibilité de déplacer un objet dans le vertex shader

```
static void special_callback(int key, int, int)
{
    float dL=0.01f;
    switch (key)
    {
        case GLUT_KEY_UP:
            translation_y+=dL;
            break;
        case GLUT_KEY_DOWN:
            translation_y-=dL;
            break;
        case GLUT_KEY_LEFT:
            translation_x-=dL;
            break;
        case GLUT_KEY_RIGHT:
            translation_x+=dL;
            break;
    }

    //reactualisation de l'affichage
    glutPostRedisplay();
}
```

Gestion
clavier

Vertex Shader

```
#version 120

uniform vec4 translation;

//Un Vertex Shader minimaliste
void main (void)
{
    //Coordonnees du sommet
    vec4 p=gl_Vertex+translation;
    gl_Position = p;
}
```

```
glUniform4f(get_uni_loc(shader_program_id,"translation"),
            translation_x,
            translation_y,
            translation_z,0.0f);
glDrawArrays(GL_TRIANGLES, 0, 3);
```

Affichage

Interaction

Rotation possible également

```
glUniformMatrix4fv(get_uni_loc(shader_program_id, "rotation"),  
                    1, false, pointeur(rotation));  
glUniform4f(get_uni_loc(shader_program_id, "translation"),  
             translation_x, translation_y, translation_z, 0.0f);
```

```
uniform vec4 translation;  
uniform mat4 rotation;  
  
//Un Vertex Shader minimaliste  
void main (void)  
{  
    //Coordonnees du sommet  
    vec4 p=rotation*gl_Vertex+translation;  
  
    //position dans l'espace ecran  
    gl_Position = p;  
}
```

Interaction

Il est possible d'appliquer différentes rotation/translation à différents objets

Principe:

Envoie donnée uniform (translation1/rotation1) depuis le pgm principal
Demande affichage objet 1

Envoie donnée uniform (translation2/rotation2) depuis le pgm principal
Demande affichage objet 2

...

Interaction

Une translation/rotation appliquée à un objet et pas aux autres
=> Déformation d'un objet

Une translation/rotation appliquée à tous les objets
=> Déplacement de la caméra

Il n'y a aucune différence entre déplacer la 'caméra'
et déplacer tous les objets de la scène.

$$p' = \text{rotation} * p + \text{translation}$$

Vertex shader + déformation

```
#version 120

uniform vec4 translation;
uniform mat4 rotation;
uniform mat4 projection;

//Un Vertex Shader minimaliste
void main (void)
{
    //Coordonnees du sommet
    vec4 p=rotation*gl_Vertex+translation;
    p=projection*p;

    //position dans l'espace ecran
    gl_Position = p;
}
```

recu du programme principal



Passage d'arguments varying

```
#version 120
```

```
varying vec4 position3d;
```

```
//Un Vertex Shader minimaliste  
void main (void)  
{  
    //Projection du sommet  
    gl_Position = ftransform();  
    position3d=gl_Vertex;  
}
```

interpolation

```
#version 120
```

```
varying vec4 position3d;
```

```
//Un Fragment Shader minimaliste  
void main (void)  
{  
    //couleur du fragment  
    gl_FragColor = position3d;  
}
```



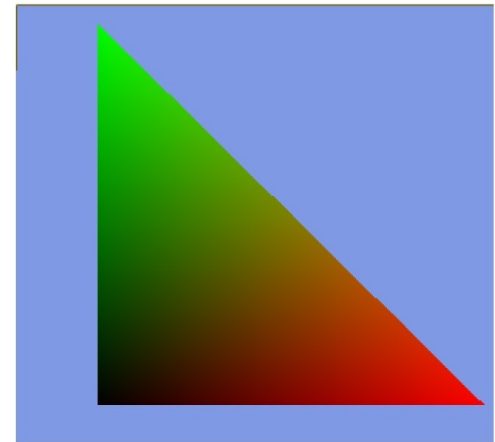
(0,1,0)



(0,0,0)



(1,0,0)



Passage d'arguments varying

```
#version 120
```

```
varying vec4 position3d;
```

```
//Un Vertex Shader minimaliste  
void main (void)  
{  
    //Projection du sommet  
    gl_Position = ftransform();  
    position3d=gl_Vertex;  
}
```

interpolation

```
#version 120
```

```
varying vec4 position3d;
```

```
//Un Fragment Shader minimaliste  
void main (void)  
{  
    //couleur du fragment  
    gl_FragColor = position3d;  
}
```

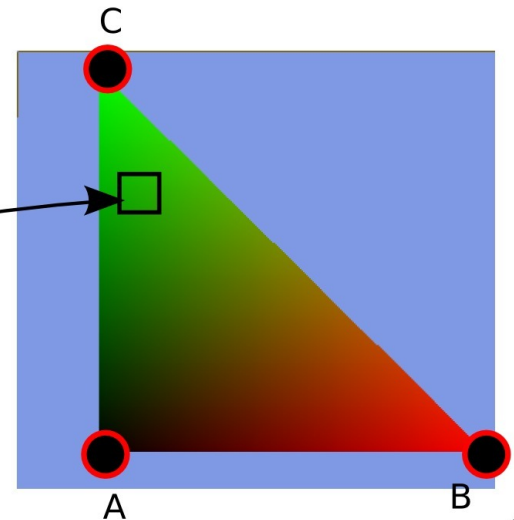
Interpolation barycentrique (linéaire)
réalisée automatiquement par la carte graphique:

$$\text{position}_{3d} = \alpha A + \beta B + \gamma C$$

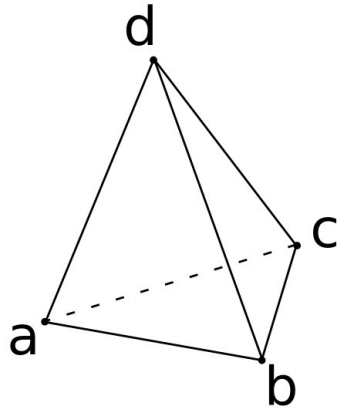
$$\alpha + \beta + \gamma = 1$$

$$(\alpha, \beta, \gamma) \in [0, 1]^3$$

*pour tous
les fragments*



Maillages

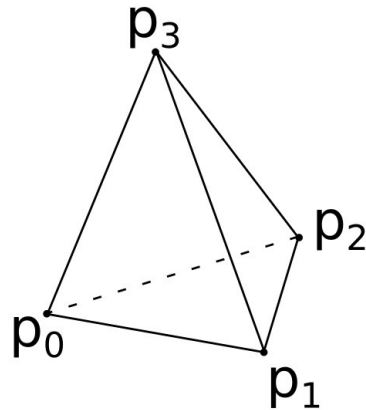


```
float vertex[] =  
{xa, ya, za , xb, yb, zb , xd, yd, zd,  
  xb, yb, zb , xc, yc, zc , xd, yd, zd,  
  xc, yc, zc , xd, yd, zd , xa, ya, za,  
  xa, ya, za , xb, yb, zb , xc, yc, zc} ;  
  
glBufferData(...)
```

Répétition:

- perte de place
- modification complexe

Maillages, format indexé



Séparation:
géométrie 3D / connectivité

```
float vertex[] =  
{p0x, p0y, p0z , p1x, p1y, p1z ,  
  p2x, p2y, p2z , p3x, p3y, p3z};  
  
float indices[] =  
{0,1,3 , 1,2,3 , 0,3,2 , 0,2,1};
```

2 Types de buffers sur le GPU

Buffer de géométrie

p0x p0y p0z p1x ...

float

Buffer d'indices

0 1 3 1 2 3 0 ...

unsigned int

+ Coordonnées écrites une seule fois

Format indexé

Initialisation

```
vec3 p0(0,0,0);
vec3 p1(1,0,0);
vec3 p2(0,1,0);
vec3 p3(0,0,1);
vec3 vertex[]={p0,p1,p2,p3};

triangle_index triangle0(0,1,2);
triangle_index triangle1(0,1,3);
triangle_index triangle2(0,2,3);
triangle_index triangle3(3,1,2);
triangle_index index[]={triangle0,triangle1,triangle2,triangle3};

glGenBuffers(1,&vbo);
glBindBuffer(GL_ARRAY_BUFFER,vbo);
glBufferData(GL_ARRAY_BUFFER,sizeof(vertex),vertex,GL_STATIC_DRAW);

glGenBuffers(1,&vboi);
glBindBuffer(GL_ELEMENT_ARRAY_BUFFER,vboi);
glBufferData(GL_ELEMENT_ARRAY_BUFFER,sizeof(index),index,GL_STATIC_DRAW);
```

Affichage

```
glDrawElements(GL_TRIANGLES, 4*3, GL_UNSIGNED_INT, 0);
```

Entrelacement de données

On souhaite envoyer au GPU:

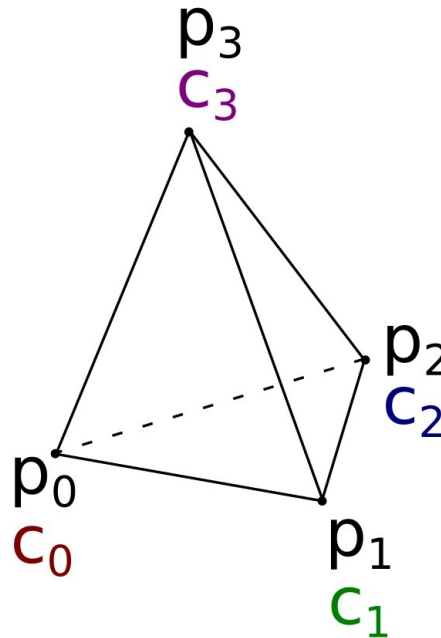
4 Sommets

- géométrie (x,y,z)
- couleur (r,g,b)

donnees:

[p0,c0,p1,c1,p2,c2,p3,c3]

↑ ↑
3 floats 3 floats



Entrelacement de données

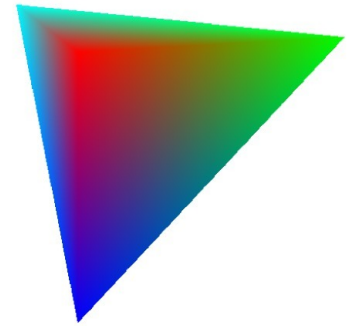
```
vec3 p0(0,0,0); vec3 c0(1,0,0);
vec3 p1(1,0,0); vec3 c1(0,1,0);
vec3 p2(0,1,0); vec3 c2(0,0,1);
vec3 p3(0,0,1); vec3 c3(0,1,1);
vec3 vertex[]={p0,c0 , p1,c1 , p2,c2 , p3,c3};

triangle_index triangle0(0,1,2); triangle_index triangle1(0,1,3);
triangle_index triangle2(0,2,3); triangle_index triangle3(3,1,2);
triangle_index index[]={triangle0,triangle1,triangle2,triangle3};

glGenBuffers(1,&vbo);
glBindBuffer(GL_ARRAY_BUFFER,vbo);
glBufferData(GL_ARRAY_BUFFER,sizeof(vertex),vertex,GL_STATIC_DRAW);

glGenBuffers(1,&vboi);
glBindBuffer(GL_ELEMENT_ARRAY_BUFFER,vboi);
glBufferData(GL_ELEMENT_ARRAY_BUFFER,sizeof(index),index,GL_STATIC_DRAW);
```

Init



```
glEnableClientState(GL_VERTEX_ARRAY);
glVertexPointer(3, GL_FLOAT, 2*3*sizeof(float), 0);

glEnableClientState(GL_COLOR_ARRAY);
long int offset_couleur=3*sizeof(float);
glColorPointer(3,GL_FLOAT,2*3*sizeof(float),(GLubyte*)offset_couleur);

glDrawElements(GL_TRIANGLES, 4*3, GL_UNSIGNED_INT, 0);
```

Display

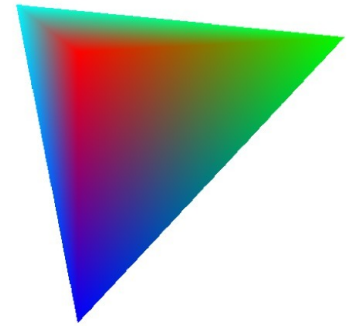
Entrelacement de données

```
vec3 p0(0,0,0); vec3 c0(1,0,0);  
vec3 p1(1,0,0); vec3 c1(0,1,0);  
vec3 p2(0,1,0); vec3 c2(0,0,1);  
vec3 p3(0,0,1); vec3 c3(0,1,1);  
vec3 vertex[]={p0,c0 , p1,c1 , p2,c2 , p3,c3};  
  
triangle_index triangle0(0,1,2); triangle_index triangle1(0,1,3);  
triangle_index triangle2(0,2,3); triangle_index triangle3(3,1,2);  
triangle_index index[]={triangle0,triangle1,triangle2,triangle3};  
  
glGenBuffers(1,&vbo);  
glBindBuffer(GL_ARRAY_BUFFER,vbo);  
glBufferData(GL_ARRAY_BUFFER,sizeof(vertex),vertex,GL_STATIC_DRAW);  
  
glGenBuffers(1,&vboi);  
glBindBuffer(GL_ELEMENT_ARRAY_BUFFER,vboi);  
glBufferData(GL_ELEMENT_ARRAY_BUFFER,sizeof(index),index,GL_STATIC_DRAW);
```

Init

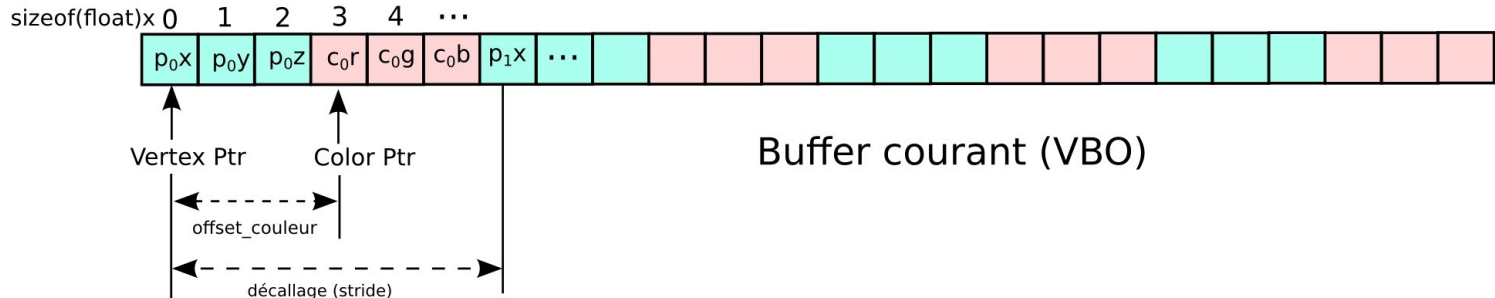
```
glEnableClientState(GL_VERTEX_ARRAY);  
glVertexPointer(3, GL_FLOAT, 2*sizeof(float), 0);  
  
glEnableClientState(GL_COLOR_ARRAY);  
long int offset_couleur=3*sizeof(float);  
glColorPointer(3,GL_FLOAT,2*sizeof(float),(GLubyte*)offset_couleur);  
  
glDrawElements(GL_TRIANGLES, 4*3, GL_UNSIGNED_INT, 0);
```

Display



 position (float)

 couleur (float)

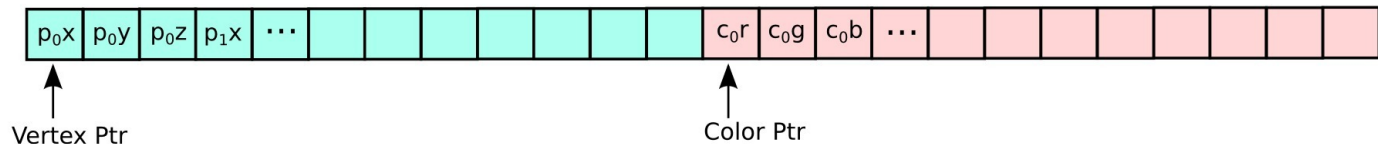


Autre possibilité

```
vec3 p0(0,0,0); vec3 c0(1,0,0);  
vec3 p1(1,0,0); vec3 c1(0,1,0);  
vec3 p2(0,1,0); vec3 c2(0,0,1);  
vec3 p3(0,0,1); vec3 c3(0,1,1);  
vec3 vertex[]={p0,p1,p2,p3 , c0,c1,c2,c3};
```

```
glEnableClientState(GL_VERTEX_ARRAY);  
glVertexPointer(3, GL_FLOAT, 0, 0);  
  
glEnableClientState(GL_COLOR_ARRAY);  
long int offset_couleur=4*3*sizeof(float);  
glColorPointer(3,GL_FLOAT,0,(GLubyte*)offset_couleur);  
  
glDrawElements(GL_TRIANGLES, 4*3, GL_UNSIGNED_INT, 0);
```

VBO Courant



Autre possibilité

Init

```
vec3 p0(0,0,0); vec3 c0(1,0,0);
vec3 p1(1,0,0); vec3 c1(0,1,0);
vec3 p2(0,1,0); vec3 c2(0,0,1);
vec3 p3(0,0,1); vec3 c3(0,1,1);
vec3 vertex[]={p0,p1,p2,p3};
vec3 color[] ={c0,c1,c2,c3};

triangle_index triangle0(0,1,2); triangle_index triangle1(0,1,3);
triangle_index triangle2(0,2,3); triangle_index triangle3(3,1,2);
triangle_index index[]={triangle0,triangle1,triangle2,triangle3};

glGenBuffers(1,&vbo_position);
glBindBuffer(GL_ARRAY_BUFFER,vbo_position);
glBufferData(GL_ARRAY_BUFFER,sizeof(vertex),vertex,GL_STATIC_DRAW);

glGenBuffers(1,&vbo_couleur);
glBindBuffer(GL_ARRAY_BUFFER,vbo_couleur);
glBufferData(GL_ARRAY_BUFFER,sizeof(color),color,GL_STATIC_DRAW);

glGenBuffers(1,&vboi);
glBindBuffer(GL_ELEMENT_ARRAY_BUFFER,vboi);
glBufferData(GL_ELEMENT_ARRAY_BUFFER,sizeof(index),index,GL_STATIC_DRAW);
```

Display

```
glEnableClientState(GL_VERTEX_ARRAY);
glBindBuffer(GL_ARRAY_BUFFER,vbo_position);
glVertexPointer(3, GL_FLOAT, 0, 0);

glEnableClientState(GL_COLOR_ARRAY);
glBindBuffer(GL_ARRAY_BUFFER,vbo_couleur);
glColorPointer(3,GL_FLOAT,0,0);

glDrawElements(GL_TRIANGLES, 4*3, GL_UNSIGNED_INT, 0);
```

Autre possibilité

```
vec3 p0(0,0,0); vec3 c0(1,0,0);
vec3 p1(1,0,0); vec3 c1(0,1,0);
vec3 p2(0,1,0); vec3 c2(0,0,1);
vec3 p3(0,0,1); vec3 c3(0,1,1);
vec3 vertex[]={p0,p1,p2,p3};
vec3 color[]={c0,c1,c2,c3};

triangle_index triangle0(0,1,2); triangle_index triangle1(0,1,3);
triangle_index triangle2(0,2,3); triangle_index triangle3(3,1,2);
triangle_index index[]={triangle0,triangle1,triangle2,triangle3};

glGenBuffers(1,&vbo_position);
glBindBuffer(GL_ARRAY_BUFFER,vbo_position);
glBufferData(GL_ARRAY_BUFFER,sizeof(vertex),vertex,GL_STATIC_DRAW);

glGenBuffers(1,&vbo_couleur);
glBindBuffer(GL_ARRAY_BUFFER,vbo_couleur);
glBufferData(GL_ARRAY_BUFFER,sizeof(color),color,GL_STATIC_DRAW);

glGenBuffers(1,&vboi);
glBindBuffer(GL_ELEMENT_ARRAY_BUFFER,vboi);
glBufferData(GL_ELEMENT_ARRAY_BUFFER,sizeof(index),index,GL_STATIC_DRAW);
```

Init

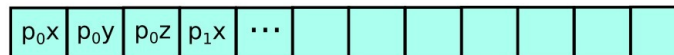
```
glEnableClientState(GL_VERTEX_ARRAY);
glBindBuffer(GL_ARRAY_BUFFER,vbo_position);
glVertexPointer(3, GL_FLOAT, 0, 0);

glEnableClientState(GL_COLOR_ARRAY);
glBindBuffer(GL_ARRAY_BUFFER,vbo_couleur);
glColorPointer(3,GL_FLOAT,0,0);

glDrawElements(GL_TRIANGLES, 4*3, GL_UNSIGNED_INT, 0);
```

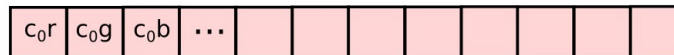
Display

VBO position



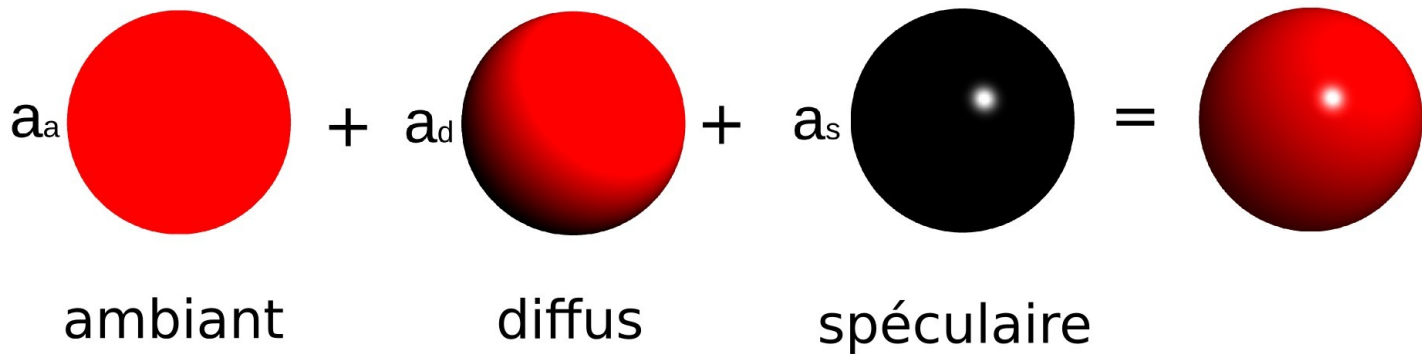
Vertex Ptr
↑

VBO couleur



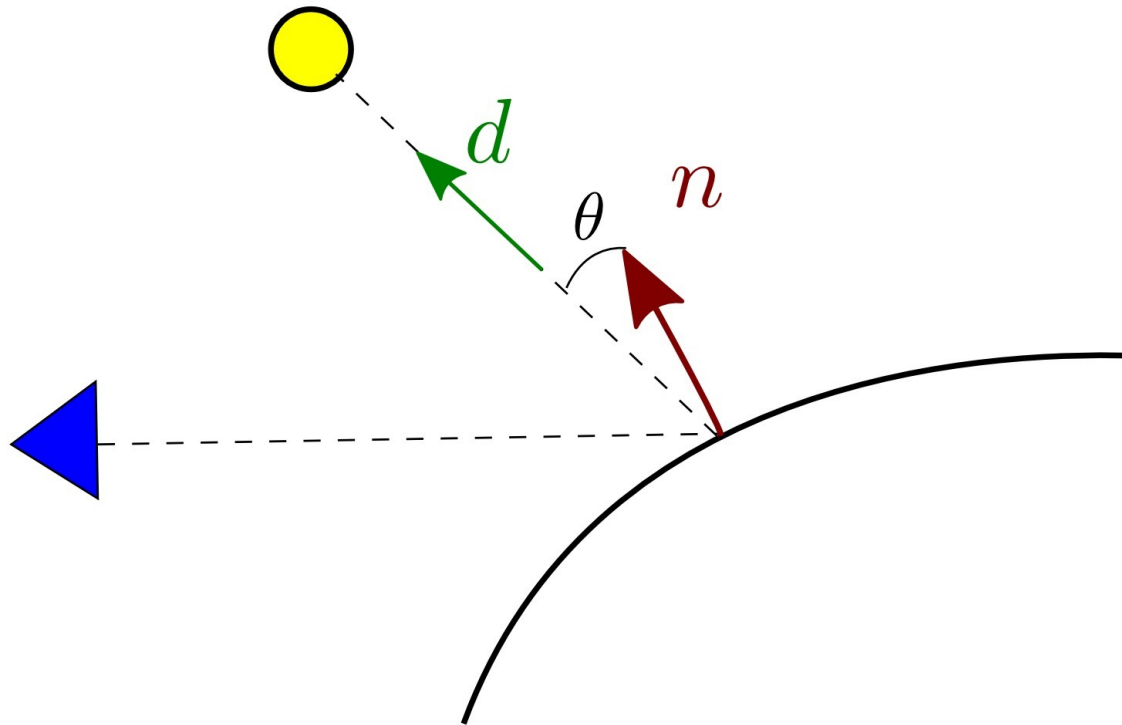
Color Ptr
↑

Illumination



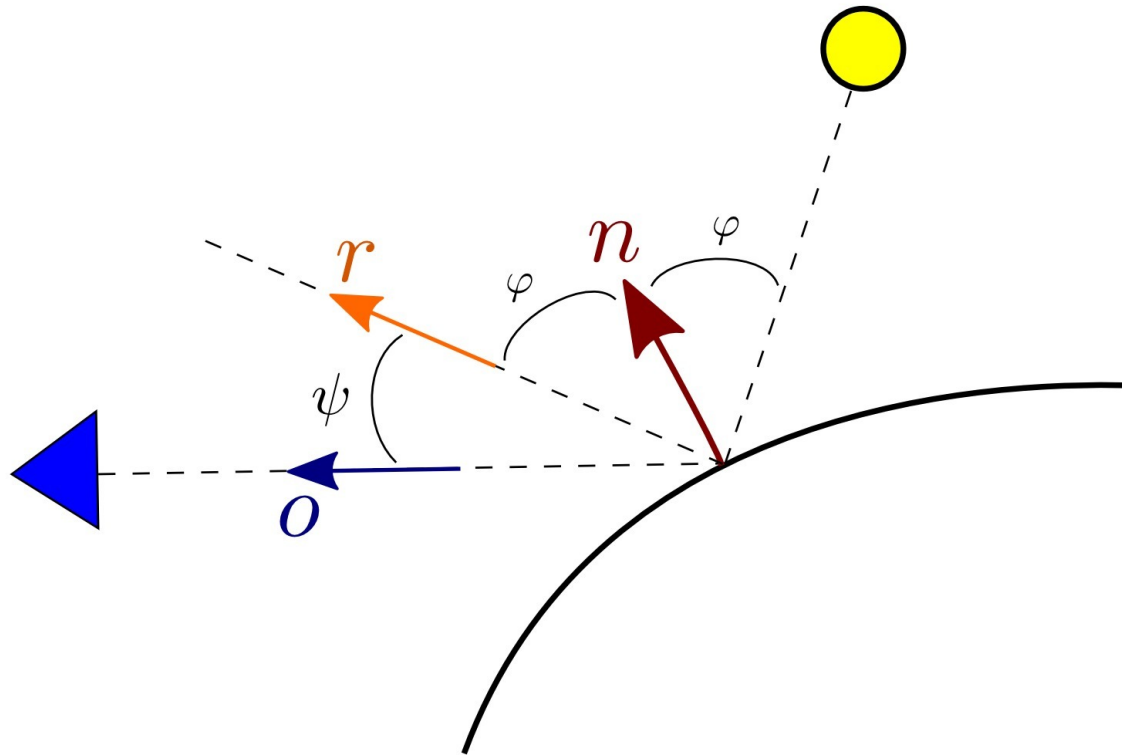
Illumination

Coefficient diffus $c_d = \cos(\theta)$

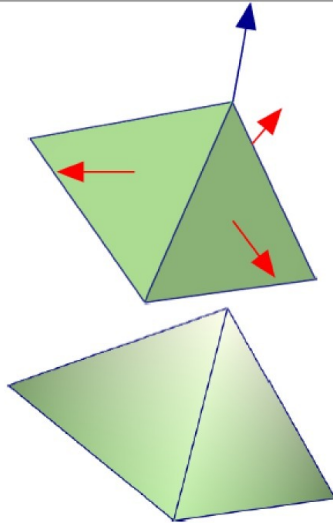


Illumination

Coefficient spéculaire $c_s = \cos(\psi)^n$



Normale par sommet/triangle

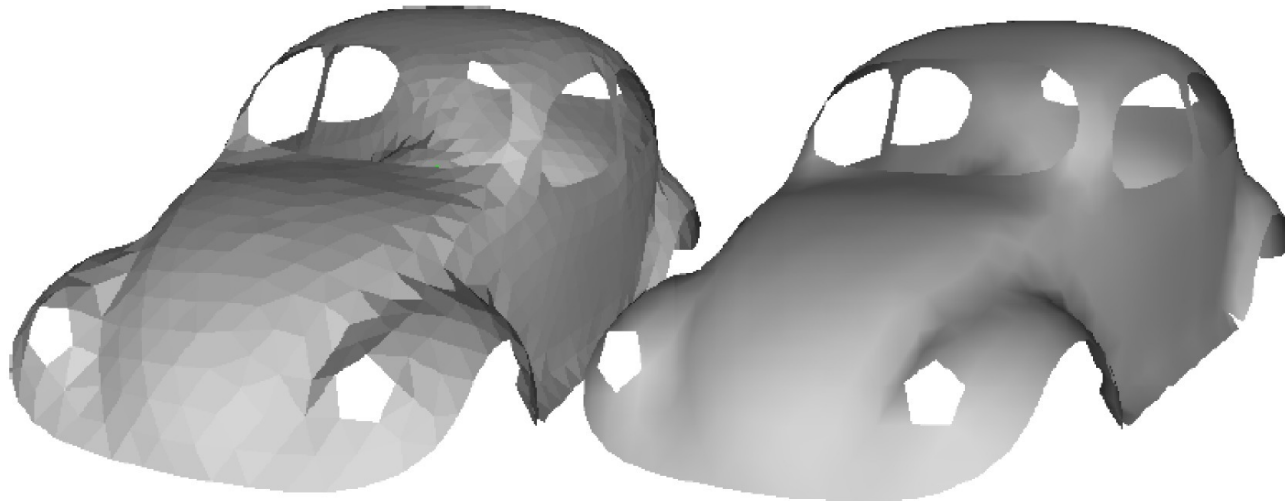


$$\mathbf{n}_k = \frac{\sum_{i \in \mathcal{V}(k)} \mathbf{n}_i}{\left\| \sum_{i \in \mathcal{V}(k)} \mathbf{n}_i \right\|}$$

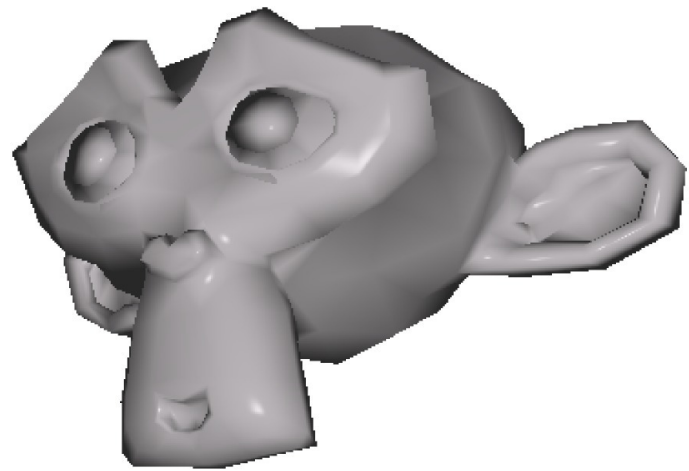
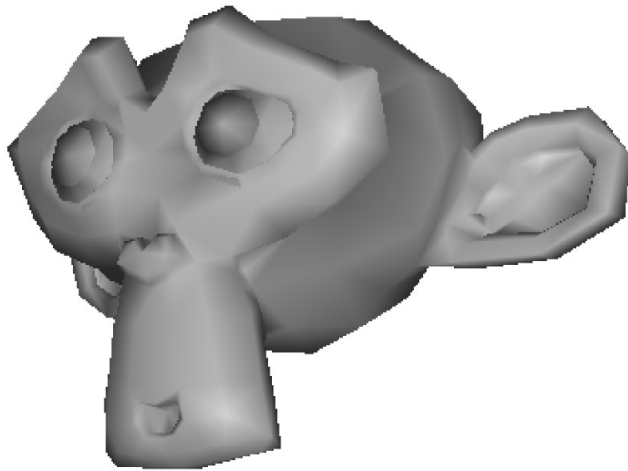
k : indice sommet

i : indice face

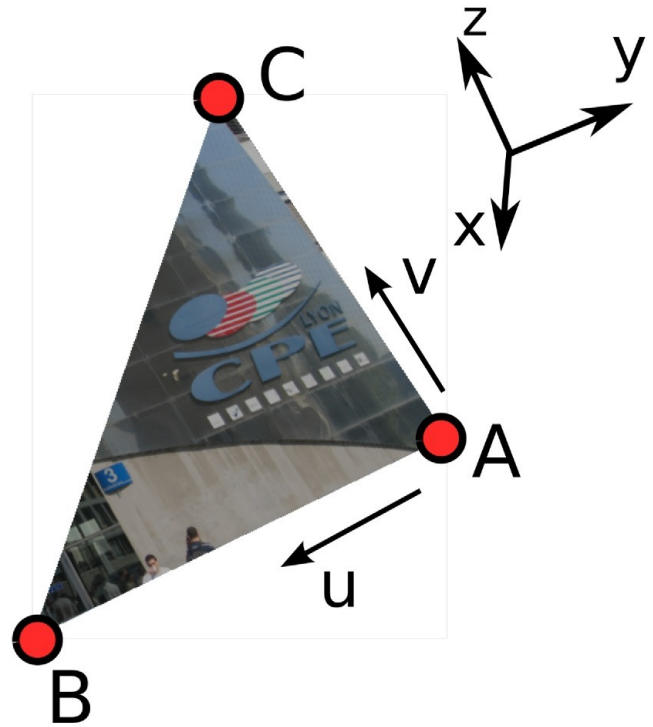
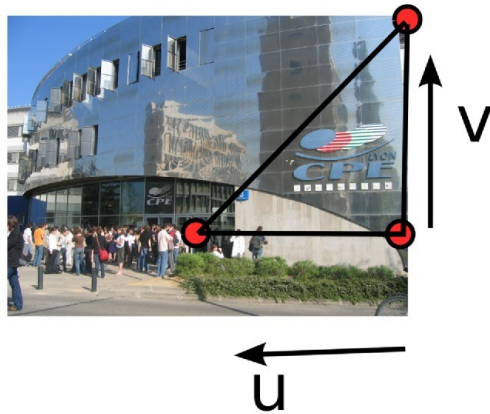
$\mathcal{V}(k)$: faces voisines du sommet k



Illumination Phong/Gouraud



Textures



Format de fichiers

OFF

8 6 12

0 0 0

1 0 0

0 1 0

0 0 1

1 1 0

1 0 1

0 1 1

1 1 1

4 0 1 4 2

4 1 5 7 4

4 3 6 7 5

4 2 6 3 0

4 2 4 7 6

4 0 3 5 1

.off

v 0 0 0

v 1 0 0

v 0 1 0

v 0 0 1

v 1 1 0

v 1 0 1

v 0 1 1

v 1 1 1

f 1 2 5 3

f 2 6 8 5

f 4 7 8 6

f 3 7 4 1

f 3 5 8 7

f 1 4 6 2

.obj

