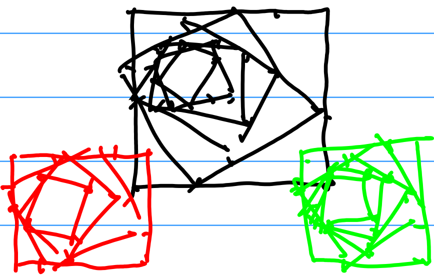
CmpE240

22

a A set of Squares Rotation with one same Color

b Change location/color/size

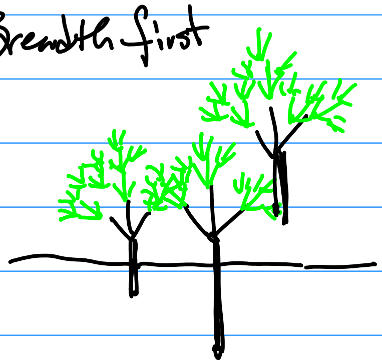
c



Keep the patterns, please don't erease them!

Part II Once Part I is Done Switch to Part I.

a Breadth first

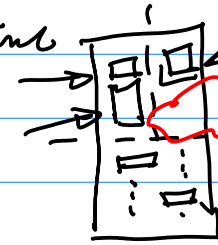


b $L \geq 7$ c Create A patch of Forest Changing Location/size

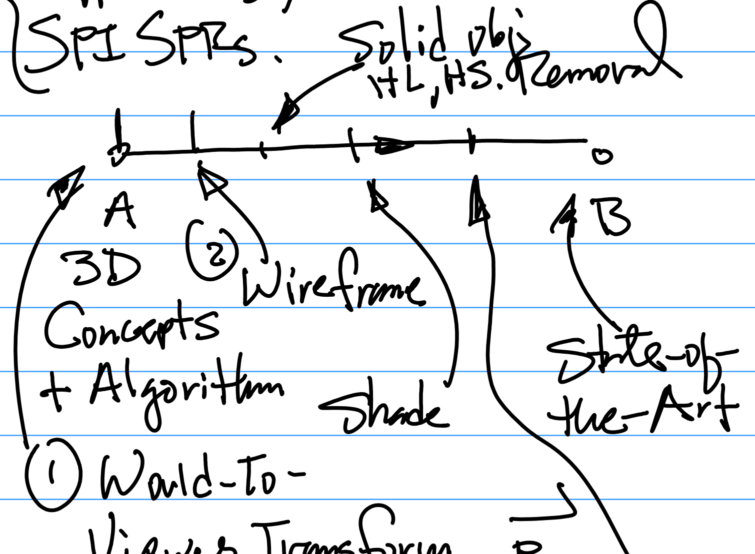
Note: Please Don't Erease the Drawing Till All the trees are constructed.

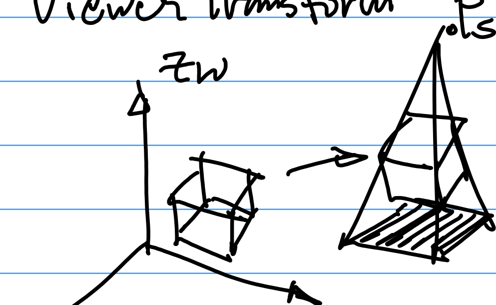
Note: Report Writting.

3D G.E. (Graphics Engine)



GPP SPRs, SPI SPRs.





March 15 (monday)

Note: 1° midterm A week from this Wednesday (March 24th)

2° Smartphone (CAM Capability) A piece of Paper to the Class. Test the Environment

Ref: github: 2018F-114-3D Graphics

Virtual Camera Location

1°

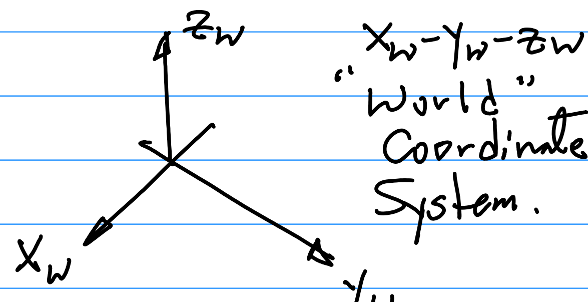


Fig. 1

Right-Hand System,

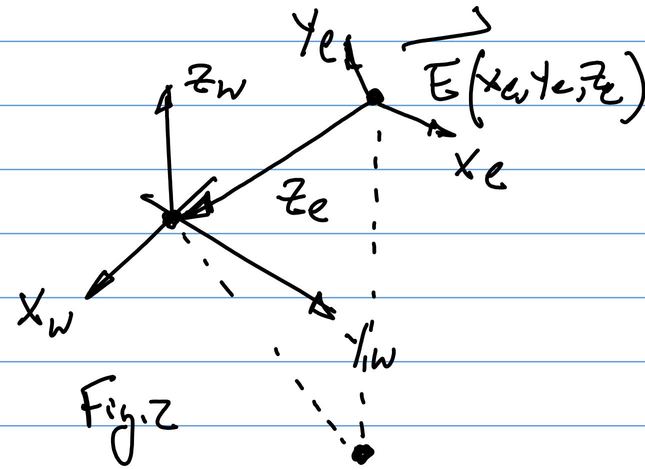


Fig. 2

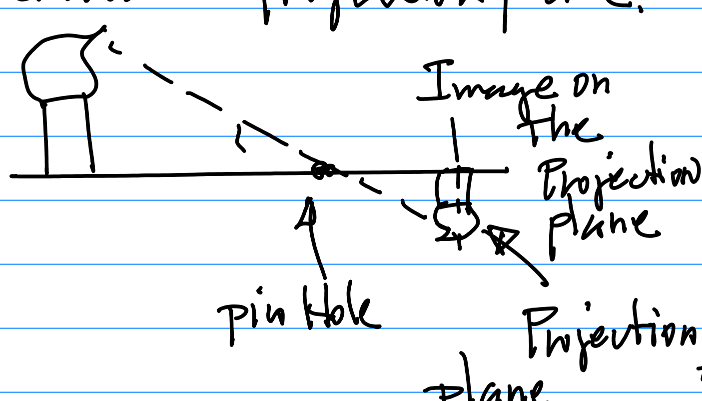
2° Virtual Camera

a. Virtual Enclosure

b. Optic Lens (Pin Hole)

$\phi_d \simeq 0$ Very Small diameter

c. Projection plane, the plane to form projected Image when light passing throngth the lens and Reaches the projection plane.



3. Denote $\vec{E}(x_e, y_e, z_e)$ as

Projection of $\vec{E}(x_e, y_e, z_e)$ on to x_w-y_w plane in the x_w-y_w-z_w World Coordinate System

4. Viewer Coordinate system

Viewer ~ Virtual Camera

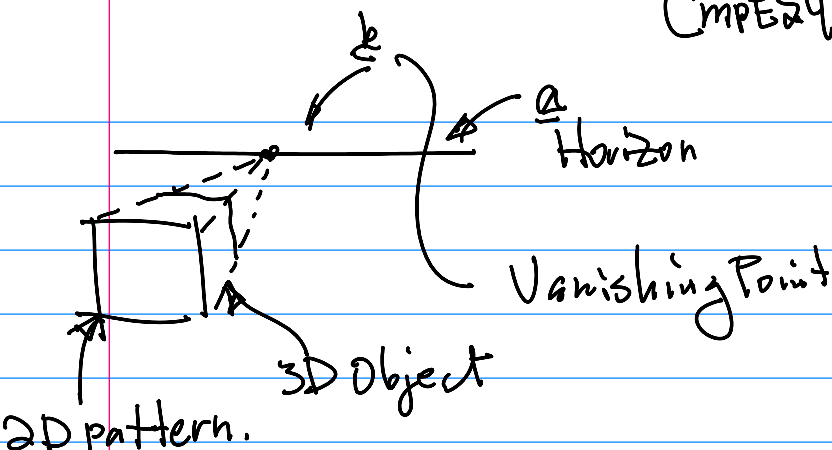
x_e-y_e-z_e Viewer Coordinate System. "Eye"

a. $\vec{E}(x_e, y_e, z_e)$ As the origin.

b. Left-Hand System.

c. z_e-axis points to the origin.

5. Perspective Projection



3D Object formed on 2D plane

7. Transformation Pipeline

To Display 3D object(s) onto 2D LCD Display Screen.

W2V (Work-2-Viewer) Transform

Perspective Projection.

6. Perspective Projection → @ the Virtual Camera in X_w-Y_w-Z_w, in X_e-Y_e-Z_e.

Objects, $\vec{E}$ in X_w-Y_w-Z_w → Viewer Coordinate System X_e-Y_e-Z_e

Projection Plane form Perspective Projection

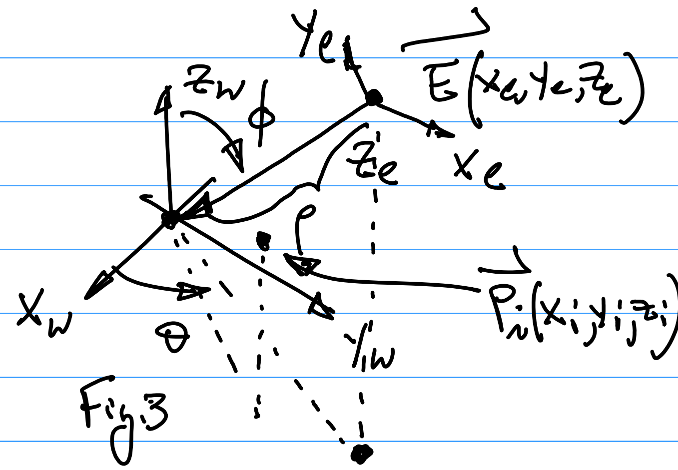


Fig.3

3 parameters:

a. theta θ Angle

b. Vector $\vec{E}$ to $\vec{D}$, " roh", Distance ρ

Mathematical Formulation

1° Formula: Transformation Pipeline
- a. World-to-Viewer Transform
- b. Perspective Projection

2° Foundation
- a. Translation
- b. Rotations
  - ~ wrt X_w And
  - " Y_w
  - " Z_w
  - wrt Arbitrary axis

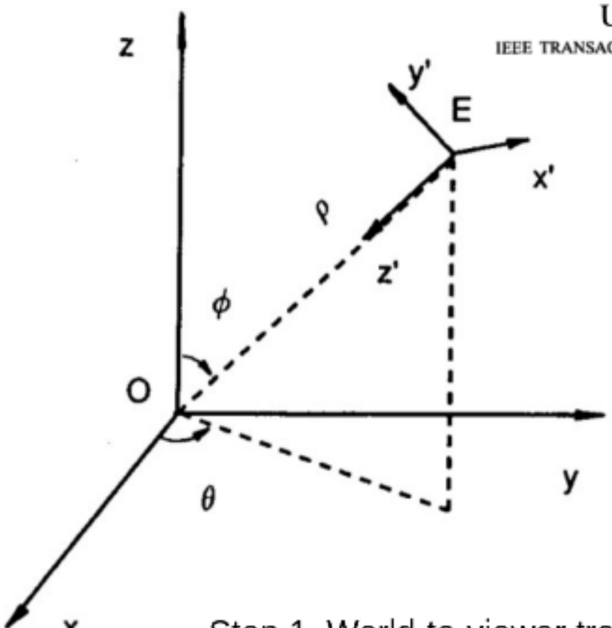
$$\rho \triangleq \sqrt{x_e^2 + y_e^2 + z_e^2} \quad \cdots (1)$$

c. Angle Z_w and Z_e ϕ.

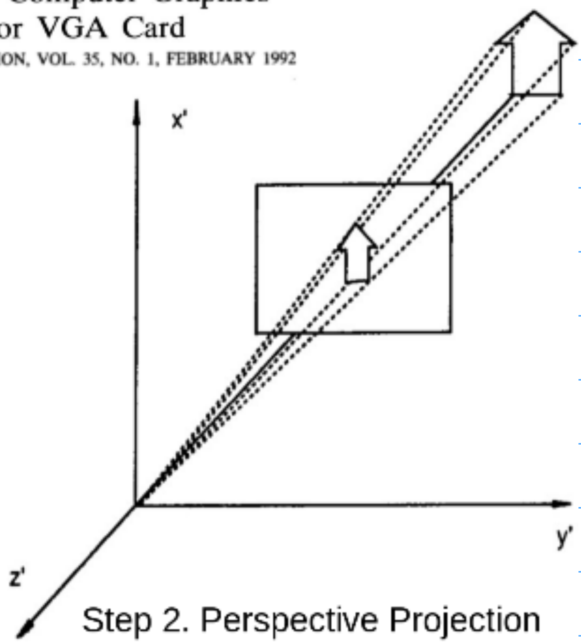
World_2_Viewer

3D Transformation Pipeline Technique

Reference: H. Li Three-Dimensional Computer Graphics Using EGA or VGA Card
IEEE TRANSACTIONS ON EDUCATION, VOL. 35, NO. 1, FEBRUARY 1992



Step 1. World-to-viewer transform



Step 2. Perspective Projection

$$
\mathbf{T} = \begin{bmatrix} -\sin\theta & \cos\theta & 0 & 0 \\ -\cos\phi\cos\theta & -\cos\phi\sin\theta & \sin\phi & 0 \\ -\sin\phi\cos\theta & -\sin\phi\cos\theta & -\cos\phi & \rho \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

$$
x_p = x_e\left(\frac{D}{z_e}\right)
$$

$$
y_p = y_e\left(\frac{D}{z_e}\right)
$$

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Transform, map $\vec{P}_i$ from the World-coordinate to Viewer Coordinate.

$$\begin{pmatrix} x_i' \\ y_i' \\ z_i' \\ 1 \end{pmatrix} = T \begin{pmatrix} x_i \\ y_i \\ z_i \\ 1 \end{pmatrix} \quad \cdots (2)$$

After $X_e - Y_e - Z_e$ Before $X_w - Y_w - Z_w$

World to Viewer Transform.

$$\begin{pmatrix} \sin\theta & \cos\theta & 0 & 0 \\ \cos\theta & \sin\theta & \text{''} & \text{''} \\ \cos\theta & \cos\theta & \text{''} & \text{''} \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Part I. "θ"

$$\begin{pmatrix} 0 & 0 & 0 & 0 \\ \cos\phi & \cos\phi & \sin\phi & \text{''} \\ \sin\phi & \sin\phi & \cos\phi & \text{''} \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Part II "ϕ"

$$\begin{pmatrix} - & & & \\ - & - & & \\ - & - & - & \rho \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Part III "_"

$\underline{\rho}$

March 17 (Wed)

Topics: 1° Hardware Architecture 2° Software SPRs Init & Config.

Example: 2D & 3D G.E.
SPI I/F LCD Display to work with LPC1769.

GPIO (GPP) SPI
A set of b ~

- System Configuration { Per. Cont. / PWR / CLK / multiplexing
- * Configuration of the Peripheral Cont.

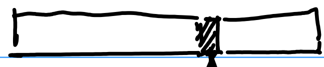
Compare to Rotation Matrix

$$\begin{pmatrix} \cos\alpha & -\sin\alpha & 0 \\ \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

RTOS
Peripheral Controller { GPP / SPI

SPI's SPR.

1. Naming Convention
   LPC_SC → PCONP
2. Power Up the Selected Peripheral Controller By Setting the Corresponding.



"1"

Bitwise "OR"

$|= (1<<10)$

$\&= \sim(3<<20)$

"AND"

"11"

Negation, "00"

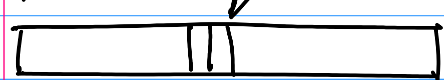
$|= (1<<20)$

"OR"

"01"

Clear

2 Bits



Set 2 bits as "01"

$\&= \sim((3<<18)|(3<<16)|(3<<14));$

"AND"

Nega.

"11"

Total 6 bits << 18

clear 6 bits

$|= ((2<<18)|(2<<16)|(2<<14)|)$

"OR"

Set

"10"

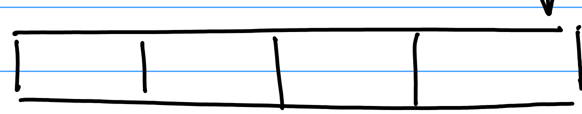
Note: $\begin{cases} CR\phi \\ CR1 \end{cases}$

LPC_SSP1 → CRϕ

Control Register

Table 371

CRϕ



TechSpec.

1° 8 bit Transfer.

CRϕ[3:ϕ] = 0111 = 0X7

2° SPI

CRϕ[5:4] = 00 (SPI)

3° Clock f_{SPI}

a. $\underbrace{CR\phi[15:8]}_{8\ bits}$ $255 = 2^8$

b.

$$f_{SPI} = \frac{PCLK}{(SCR+1)\,CPSDVSR} \quad \cdots (1)$$

[0, 255]

mauch2and.

Today's Topics:

1° Midterm Review

2° SPRs CRϕ, CR1 for SPI I/F

Ref:

1° CPU Datasheet.

PP 431-433.

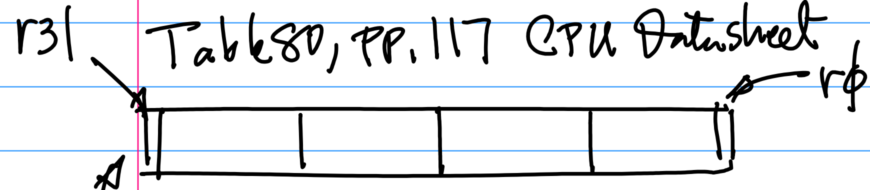
2° Sample code SPI init (Draw a Line)

CMPE240

Example: SSP.C Source Code Walk-Through. 151-208

line 162-165 PINSEL0

Table 80, PP. 117 CPU Datasheet



PINSEL0[31:30] = 10

Table 81. PINSEL1

= 0x2

10 from CPU Datasheet

PINSEL1[1:0], PINSEL1[3:2], PINSEL1[5:4] → SSP1

SSEL0, MOSI0, MISO0

line 173

CR = 0x0707 → Tech Spec.

$\underbrace{\ldots}_{\text{16 upper Bits all zeros.}}$ 0000 0111 0000 0111

From Datasheet PP431

8 bit Transfer

CR0[15:8] SCR Clock

CR[5:4] = 00 SPI

$$f_{SPI} = \frac{PCLK}{(SCR+1) * DVR}$$

CR0

CR0[15:8] = 0x7

CR1[2] = 0 for "Master"

$$f_{SPI} = \frac{1 \times 10^6}{(7+1) * DVR}$$

To find f_{SPI}.

$2^8 = 256$, SCR ∈ [0, 255]

PP. 433. CPSDVSR ∈ [2, 254]

Midterm Review

1° Video ON, Mandatory.

a. Submission to CANVAS
15 min. File Uploading
No Late Submission After the Deadline
paper will be disqualified

b. If CANVAS Disrupted, then E-mail Submission

c. file in "zip"

FirstName + 4 Digits SID + CMPE242 mid.zip

2° 3 Questions ±

Hardware { CPU Block Diagram, memory map, SFRs.

CKT, SCH Design

Software: Coding

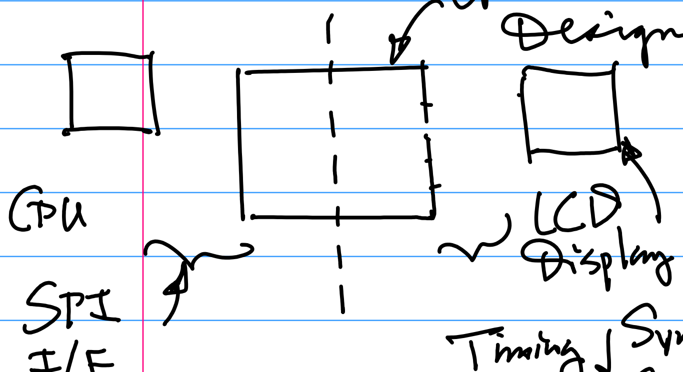
CmpE240

28

SPB ⟷ Binary Pattern
Coding — for Init & Config
Debugging Purpose ⟷ Tech Spec.

Algorithm:
2D vector Graphics.
G.E.

a. LPC CPU — LPC Driver.
LPC Deriver Design



MOSI
MISO
SCK
SSELn

Timing { Sync F, Sync H, Sync D }

$\overline{CS}$

b. Virtual v.s. physical Display Transform.

c. $\vec{P} = \vec{P_i} + \lambda(\vec{P_{i+1}} - \vec{P_i})$

Screen Saver. { i. Rotation! No w/o Rotation matrix
ii. 2D Transforms }

Composition of 2D Transform. { R_{3x3}, T_{3x3} } → Tree.

Preprocess + R_{3x3} + Post ~

Formula: One Page Formula Sheet; is allowed, However, No Example, or Verbal Explanation is Not Allowed, Submission of the formula Page is required with your mid-term paper.

No multiple choice question.

SCH: Requires All the pins needed in the design to have Label; wire: "Arrow" to indicate direction.

Block Diagram: wire(s), Label(s) direction (Arrow)

CPU Datasheet will be provided

C Code program will be provided for Answering questions, or for Redesign.

Calculator is allowed;

CMPE240

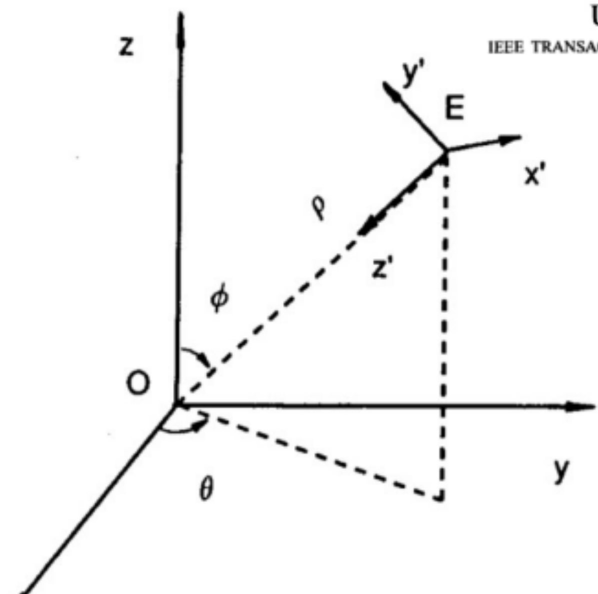
April 5 (Monday)

1° Midterm Key on github, "Key" To search.

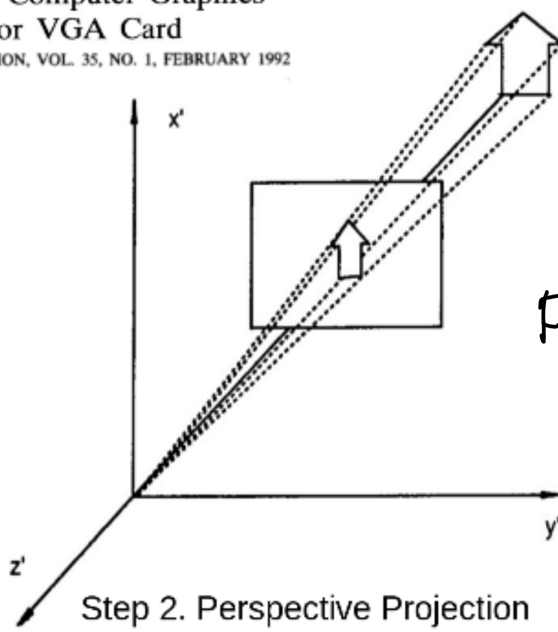
3D Transformation Pipeline Technique

Reference: H. Li Three-Dimensional Computer Graphics Using EGA or VGA Card

IEEE TRANSACTIONS ON EDUCATION, VOL. 35, NO. 1, FEBRUARY 1992



Step 1. World-to-viewer transform



Step 2. Perspective Projection

Fig 1.

$$\boxed{\mathbf{T} = \begin{bmatrix} -\sin\theta & \cos\theta & 0 & 0 \\ -\cos\phi\cos\theta & -\cos\phi\sin\theta & \sin\phi & 0 \\ -\sin\phi\cos\theta & -\sin\phi\cos\theta & -\cos\phi & \rho \\ 0 & 0 & 0 & 1 \end{bmatrix}} \quad \ldots(1)$$

$$\boxed{\begin{aligned} x_p &= x_e\left(\frac{D}{z_e}\right) \\ y_p &= y_e\left(\frac{D}{z_e}\right) \end{aligned}} \quad \ldots(2)$$

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Today's Topics: 3D G.E.

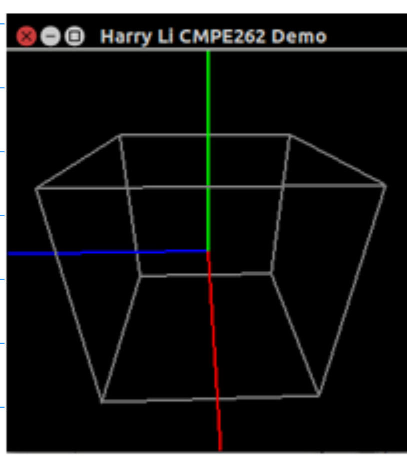


Fig 2a

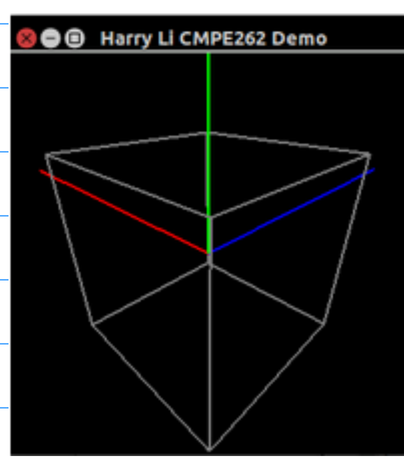
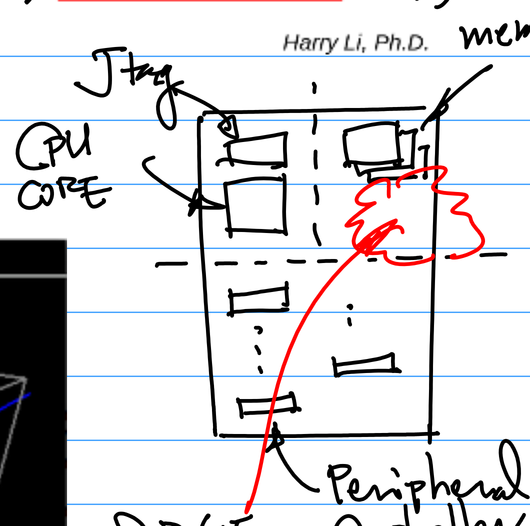


Fig 2b



2D G.E.
3D G.E. → GPU

from github. Key "111a, 111b, ..."

Note: 2D G.E. { Vector Graphics / Transformation / Primitive Graphics { a D.D.A., b line, c Arc/circle etc. } Transistor/Gate Level.

Example: 3D Wireframe Model

First, X_w-Y_w-Z_w World Coordinate System.

a Right System, r-g-b for X_w, Y_w, Z_w axis

b Transformation Pipeline

{ 1st World-2-Viewer

$T_{4\times4}: (x_w, y_w, z_w) \to (x_v, y_v, z_v)$ ...(3)

2nd Perspective Projection

$P: (x_v, y_v, z_v) \to (x_p, y_p)$ ...(3b) }

Second. Design of Dataset, e.g. 4 Vertices for X_w-Y_w-Z_w Axis

$\vec{P}(x,y,z)$ 3D pt. in X_w-Y_w-Z_w

Step 1. $\vec{P}(x,y,z) \in \mathbb{R}^3$

for the Origin $\vec{P}_0(x_0, y_0, z_0) = (0,0,0)$ ...(4)

$\vec{P}_x(x_x, y_x, z_x) = (100, 0, 0)$, ...(4-1)

$\vec{P}_y(x_y, y_y, z_y) = (0, 100, 0)$, and ..(4-2)

$\vec{P}_z(x_z, y_z, z_z) = (0, 0, 100)$ ...(4-3)

#define X_w_axis ~

⋮

#define Z_w_axis ~

Now, Implementation (Drawing r-g-b axis) ← April 12 (M)

Homework: Draw r-g-b axis on your LPC Display. Bring your Program/Board to the Next Class.

Step 2. World_2_Viewer

$T_{4\times4}: (x_w, y_w, z_w) \in \mathbb{R}^3 \to (x_v, y_v, z_v) \in \mathbb{R}^3$

$$\begin{pmatrix} x_v \\ y_v \\ z_v \\ 1 \end{pmatrix} = T_{4\times4} \begin{pmatrix} x_w \\ y_w \\ z_w \\ 1 \end{pmatrix} \quad \cdots (5)$$

"After" "Before"

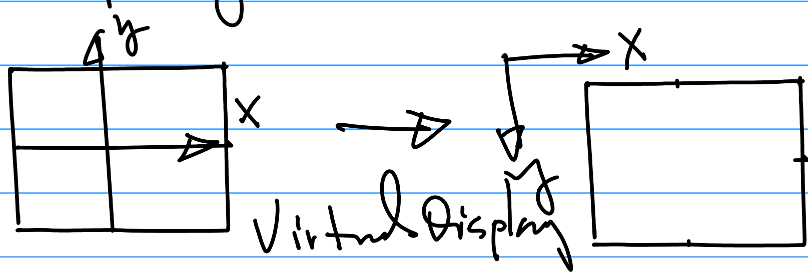
Now, find the X_w-axis in Viewer Coordinate

Step 3. Perspective Projection

$P : (X_e, Y_e, Z_e) \in \mathbb{R}^3 \rightarrow (X''_i, Y''_i) \in \mathbb{R}^2$

Coordinate on your LPC1769 Display Device.

Note:
(X''_i, y''_i) is defined on 2D Virtual Display Coordinate. Need to perform Virtual to Physical Transformation in order to plot your result.



$$\begin{cases} X_p = \dfrac{D}{Z_v} X_v & \ldots (a1) \\ y_p = \dfrac{D}{Z_v} \cdot y_v & \ldots (a2) \end{cases}$$

$(X_v, y_v, Z_v) \in \mathbb{R}^3$ Virtual Cam

focal Length

(X_p, y_p) On your 2D Display

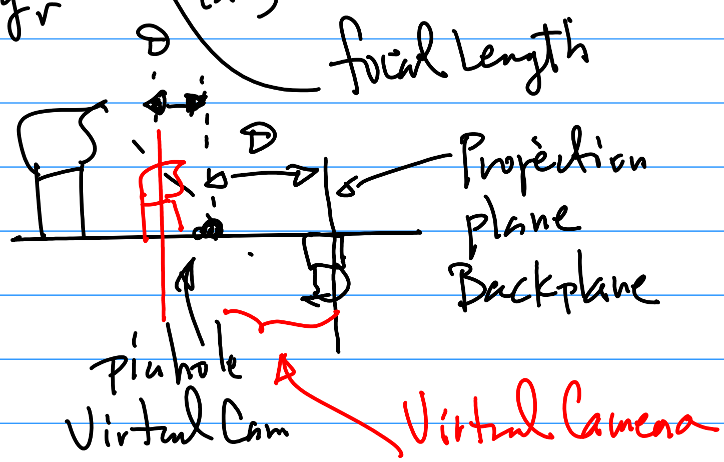
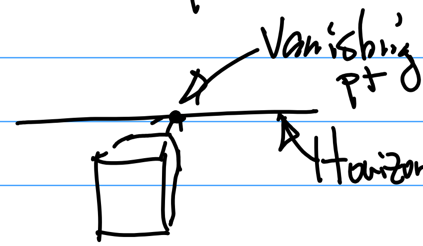


Fig 1.

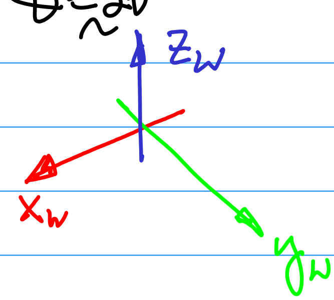
Back projection plane: the only light that can reach the projection plane is the light passing through the "pin hole". (plane is at the Back) projection

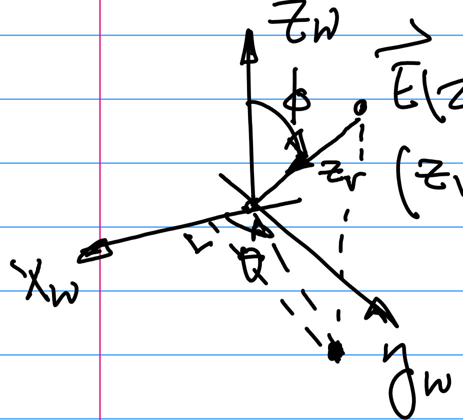
Frontal projection plane: move the back projection plane to the outside of the virtual camera.

D: Distance from the projection plane to the "pin hole".



In Homework, D=20





$\vec{E}(200, 200, 200) = (x_e, y_e, z_e)$
$(z_r \Rightarrow z_e)$

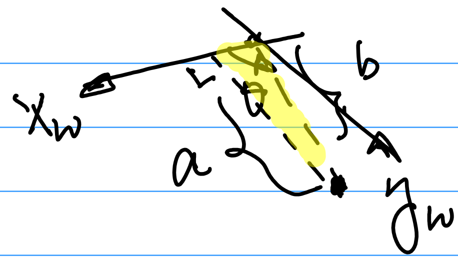


Fig 1.

$\sin\theta = \frac{a}{b}$

a. Vector Passing Through $\vec{E}$, Perpendicular to X_w-Y_w plane, So form an intersection pt.

b. Vector Passing through the intersection pt on X_w-Y_w, perpendicular to X_w axis.

$a = y_e = 200$
$b = \sqrt{x_e^2 + y_e^2} = 200\sqrt{2}$

$\therefore \sin\theta = \frac{200}{200\sqrt{2}} = \sqrt{2}/2$

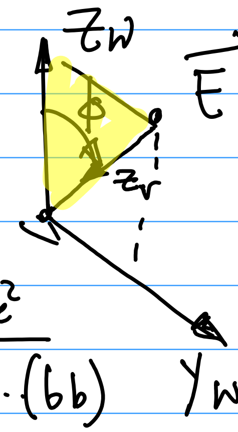
$\cos\theta = \frac{x_e}{b} = \frac{200}{200\sqrt{2}} = \sqrt{2}/2$

for ϕ (phi)

Note: Angle θ (Theta) on X_w-Y_w plane
{ wrt Positive X_w-axis, And
Counter Clockwise Direction.

$\cos\phi = \frac{z_e}{\rho}$ ...(5b)

$\rho = \sqrt{x_e^2 + y_e^2 + z_e^2}$ ...(6)
"rho"



Note: Angle ϕ (phi) on z_r-z_w plane.

$\sin\phi = \frac{\sqrt{x_e^2 + y_e^2}}{\rho}$ ..(6b)

Now, find each entry on $T_{4\times4}$ matrix, So World-2-Viewer Transform Can be Performed.

April 7 (Wed)

Note: x_v-y_v-z_v Left Hand System

for Angle θ (Theta)

$\sin\theta$ and $\cos\theta$

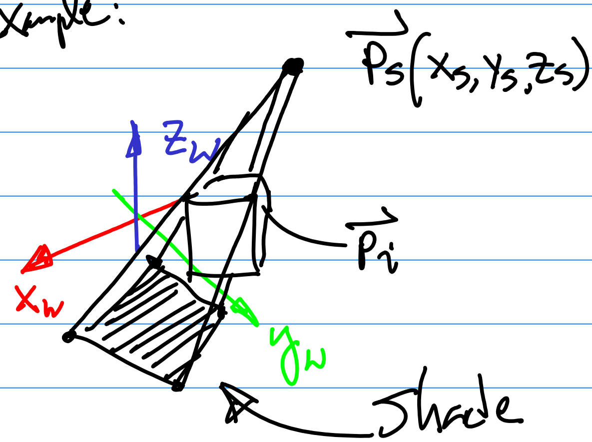
$\cos\phi = \frac{z_e}{\rho} = \frac{200}{\sqrt{200^2 + 200^2 + 200^2}}$
$= \frac{200}{200\sqrt{3}} = \sqrt{3}/3$

Similarly

$$\sin\phi = \sqrt{x_c^2+y_c^2}/\rho = \frac{\cancel{20}\sqrt{2}}{\cancel{20}\sqrt{3}} = \sqrt{2/3}$$

Consider "Shade" Calculation.

Example:



1. X_w-Y_w-Z_w.

April 12 (Monday)

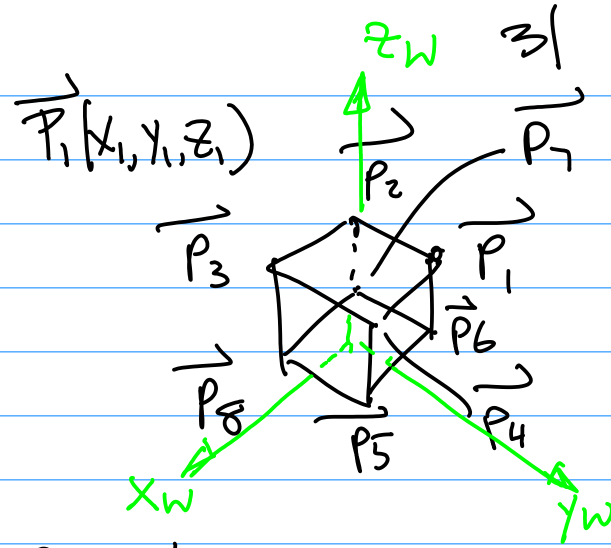
Note: 1° Homework Submission (E-mail)
X_w-Y_w-Z_w Drawing.
Source code — Photo
(Exported Project) By Wednesday.

2° Bring your Prototype Board to Each Session for Inspection, Show & Tell.

Discussion on 3D Shade Computation

Conditions for this discussion

1° Define $\{\vec{P_i}(x_i, y_i, z_i) \mid i = 1, 2, \cdots, 8\}$



One side of the cube overlapped with Z_w-axis size of 100.

$\vec{P_1}(0, 100, 110)$

$\vec{P_2}(0, 0, 110)$, $\vec{P_3}(100, 0, 110)$

$\vec{P_4}(100, 100, 110)$

Note: $\vec{P_1}, \vec{P_2}, \cdots$, are arranged Counter clockwise

$\vec{P_5}(100, 100, 10)$, $\vec{P_6}(0, 100, 10)$

$\vec{P_7}(0, 0, 10)$, $\vec{P_8}(100, 0, 10)$

2. Point Light Source

$\vec{P_s}(100, 100, 200)$

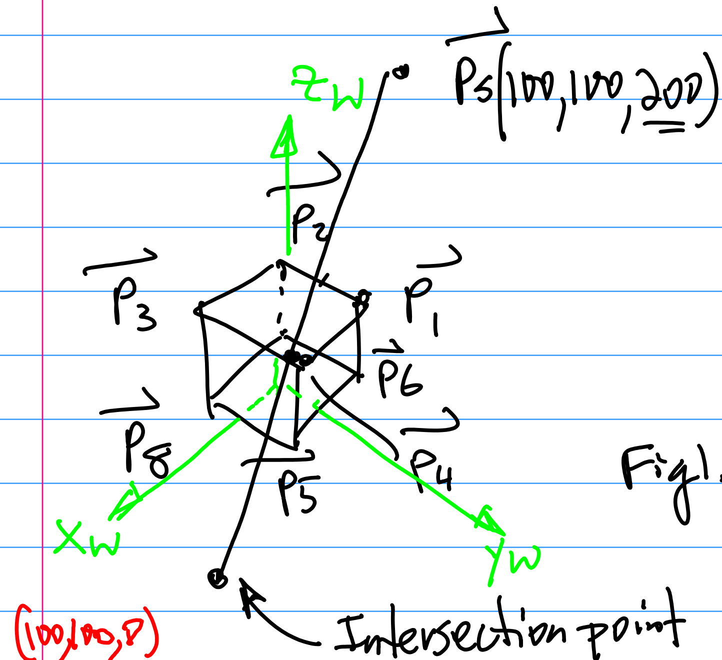


Fig1.

3. Ray Equation, Connecting $\vec{P_3}$ to $\vec{P_4}$,

$$\vec{R} = \vec{P_5} + \lambda(\vec{P_i} - \vec{P_5}) \quad \ldots (1)$$

$$\vec{P_i} = \vec{P_4}$$

OR,

$$\vec{P} = \vec{P_5} + \lambda(\vec{P_i} - \vec{P_5}) \quad \ldots (1b)$$

Find intersection point on X_w-Y_w plane.

4. plane Equation

<u>4a</u> Normal Vector $\vec{n}(n_x, n_y, n_z)$ perpendicular to the given plane, X_w-Y_w plane

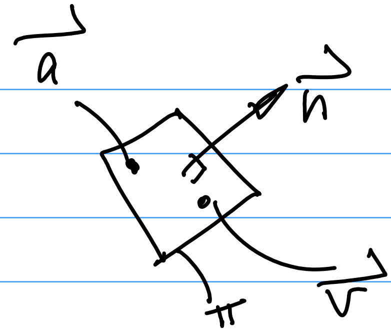


Fig.2

4b. plane π.

An Known, Arbitrary pt on π denoted $\vec{a}(a_x, a_y, a_z)$

An arbitrary point $\vec{v}(v_x, v_y, v_z)$ on π

$$\vec{n} \cdot (\vec{a} - \vec{v}) = 0 \quad \ldots (2)$$

OR

$$\underset{\text{Normal Vector}}{\vec{n}} \cdot \underbrace{(\vec{v} - \vec{a})}_{\text{line segment}} = 0 \quad \ldots (2\text{-}a) \checkmark$$

5. Intersection pt.

$$\begin{cases} \vec{R} = \vec{P_5} + \lambda(\vec{P_i} - \vec{P_5}) & \ldots (3a) \\ \vec{n} \cdot (\vec{v} - \vec{a}) = 0 & \ldots (3b) \end{cases}$$

From (3b),

$$\vec{n} \cdot (\vec{v} - \vec{a}) = 0$$

$\vec{v} = \vec{R}$, $\vec{v} = \vec{P_s} + \lambda(\vec{P_i} - \vec{P_s})$

Sub. $\vec{v} = \vec{R}$ Above into (3b)

$$\vec{n} \cdot (\vec{v} - \vec{a})\Big|_{\vec{v}=\vec{R}} = 0$$

$$\vec{n} \cdot (\vec{R} - \vec{a})\Big|_{\vec{R}=\vec{P_s}+\lambda(\vec{P_i}-\vec{P_s})} = 0$$

$$\vec{n} \cdot \left(\vec{P_s} + \lambda(\vec{P_i} - \vec{P_s}) - \vec{a}\right) = 0$$

$$\vec{n} \cdot \vec{P_s} + \lambda \vec{n} \cdot (\vec{P_i} - \vec{P_s}) - \vec{n} \cdot \vec{a} = 0$$

$$\lambda \vec{n} \cdot (\vec{P_i} - \vec{P_s}) = \vec{n} \cdot \vec{a} - \vec{n} \cdot \vec{P_s}$$

$$\lambda = \frac{\vec{n} \cdot (\vec{a} - \vec{P_s})}{\vec{n} \cdot (\vec{P_i} - \vec{P_s})} \quad \ldots (4)$$

---

from Eqn (3a), Ray Eqn.

with λ we can find the intersection Point.

In C/C++ Coding.

$$\lambda = \frac{\vec{n} \cdot (\vec{a} - \vec{P_s})}{\vec{n} \cdot (\vec{P_i} - \vec{P_s})} = \frac{(n_x, n_y, n_z) \cdot (a_x - x_s, a_y - y_s, a_z - z_s)}{(n_x, n_y, n_z) \cdot (x_i - x_s, y_i - y_s, z_i - z_s)}$$

$$= \frac{n_x(a_x - x_s) + n_y(a_y - y_s) + n_z \cdot (a_z - z_s)}{n_x(x_i - x_s) + n_y(y_i - y_s) + n_z(z_i - z_s)} \quad \ldots (4a)$$

Example: Compute the shade by finding intersection pt formed by $\vec{P_s}$ and $\vec{P_4}$.

Sol: From Eqn (3a), we have

$$\vec{R} = \vec{P_s} + \lambda(\vec{P_4} - \vec{P_s})$$

$$= (x_s, y_s, z_s) + \lambda(x_4 - x_s, y_4 - y_s, z_4 - z_s)$$

from Eqn (4), where

$$\vec{n}(n_x, n_y, n_z) = (0, 0, 1)$$

$$\vec{a}(a_x, a_y, a_z) = (0, 0, 0)$$

Hence,

$$\lambda = \frac{0 \cdot (a_x - x_s) + 0 \cdot (a_y - y_s) + 1 \cdot (a_z - z_s)}{0 \cdot (x_4 - x_s) + 0 \cdot (y_4 - y_s) + 1 \cdot (z_4 - z_s)}$$

$$= \frac{a_z - z_s}{z_4 - z_s} = \frac{0 - 200}{110 - 200} = \frac{20\cancel{0}}{9\cancel{0}}$$

$$= 20/9$$

Therefore, Sub λ Back to the Ray Eqn.

$$\vec{R} = \vec{P_5} + \lambda(\vec{P_4} - \vec{P_5})\Big|_{\lambda = 20/9}$$

$$= (100, 100, 200) + \frac{20}{9}(x_4 - x_5, y_4 - y_5, z_4 - z_5)$$

$$= (100, 100, 200) + \frac{20}{9}(100 - 100, 100 - 100, 110 - 200)$$

$$= (100, 100, 200) + \frac{20}{9} \cdot (0, 0, -90)$$

$$= (100, 100, 200) + (0, 0, -\frac{20}{9} \times 90)$$

$$= (100, 100, 200) + (0, 0, -200) = (100, 100, 0)$$

Note: 1° Finish Last Homework, then Expand to a Cube. (Display it).

2° Compute/Implement this Algorithm, to Calculate (Hand) Each of Every 4 pts of top Surface of the Cube.

Note: Homework Submission Extended to 18th Sunday, 11:59pm.

a e-mail ; b Subject: First Name + SID(4 Digits) + CMPE240 + HW2

April 14 (Th).

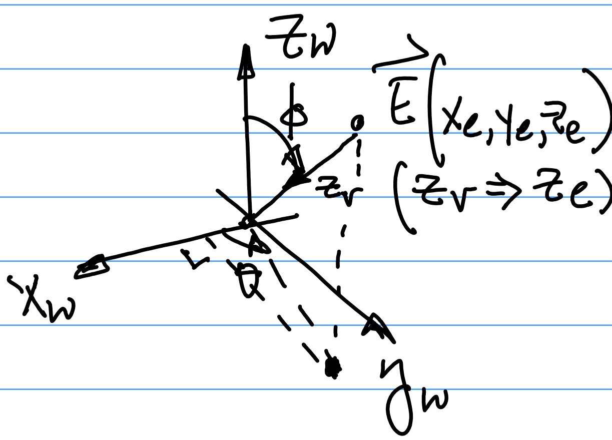
See the figure Next page

```
float Xe = 200.0f;
float Ye = 200.0f;
float Ze = 200.0f;
float Rho = sqrt(pow(Xe,2) + pow(Ye,2) + pow(Ze,2));
float D_focal = 20.0f;
```

```
//define the x-y-z world coordinate
world.X[0] = 0.0;    world.Y[0] =  0.0;   world.Z[0] =  0.0;    // origin
world.X[1] = 50.0;   world.Y[1] =  0.0;   world.Z[1] =  0.0;    // x-axis
world.X[2] = 0.0;    world.Y[2] =  50.0;  world.Z[2] =  0.0;    // y-axis
world.X[3] = 0.0;    world.Y[3] =  0.0;   world.Z[3] =  50.0;   // y-axis
```

for X_w-Y_w-Z_w World-Coordinate System

```
typedef struct {
    float X[UpperBD];
    float Y[UpperBD];
    float Z[UpperBD];
} pworld;
```



for X_v-Y_v-Z_v Viewer (Virtual Camera)

```
typedef struct {
    float X[UpperBD];
    float Y[UpperBD];
    float Z[UpperBD];
} pviewer;
```

for Perspective Projection

```
typedef struct{
    float X[UpperBD];
    float Y[UpperBD];
} pperspective;
```

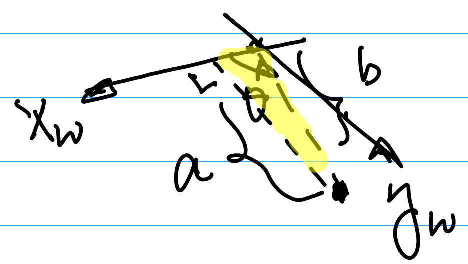
Declaration of Each Coordinate System

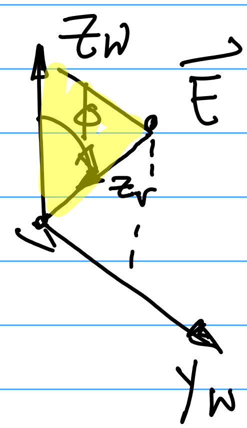
```
pworld  world;
pviewer viewer;
pperspective perspective;
```

Initialization, By Defining 4 vectors (pts) $\vec{P_1}, \vec{P_2}, \vec{P_3}, \vec{P_4}$ for X_w, Y_w, Z_w axis

```
//define the x-y-z world coordinate
world.X[0] = 0.0;    world.Y[0] =  0.0;   world.Z[0] =  0.0;    // origin
world.X[1] = 50.0;   world.Y[1] =  0.0;   world.Z[1] =  0.0;    // x-axis
world.X[2] = 0.0;    world.Y[2] =  50.0;  world.Z[2] =  0.0;    // y-axis
world.X[3] = 0.0;    world.Y[3] =  0.0;   world.Z[3] =  50.0;   // y-axis
```

From PP.31. Fig. Below



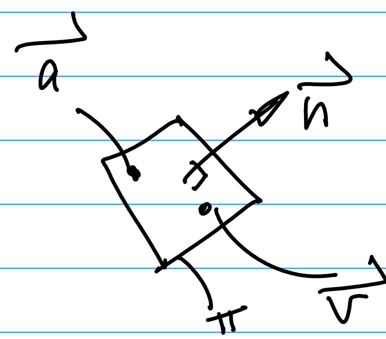


We defines $\sin\theta$, $\cos\theta$ for $T_{4\times4}$

World-To-Viewer Transform.

```
float sPheta = Ye / sqrt(pow(Xe,2) + pow(Ye,2));
float cPheta = Xe / sqrt(pow(Xe,2) + pow(Ye,2));
float sPhi = sqrt(pow(Xe,2) + pow(Ye,2)) / Rho;
float cPhi = Ze / Rho;
```

From PP. 32



Define plane Equation By

a. Normal Vector $\vec{n}(n_x, n_y, n_z) = (0,0,1)$

b. Arbitrary pt $\vec{a} = (0,0,0)$

Then a Point Light Source $\vec{P_s}(x_s, y_s, z_s)$

```
world.X[45] = -200.0; world.Y[45] = 50.0; world.Z[45] = 200.0; // Ps (point source)
world.X[46] = 0; world.Y[46] = 0; world.Z[46] = 0; // arbitrary vector A on x-y plane
world.X[47] = 0; world.Y[47] = 0; world.Z[47] = 1; // normal vector for x-y
```

Now, the Implement for Computing World-to-Viewer By $T_{4\times4}$

```
for(int i = 0; i <= UpperBD; i++)
{
    viewer.X[i] = -sPheta * world.X[i] + cPheta * world.Y[i];
    viewer.Y[i] = -cPheta * cPhi * world.X[i]
    - cPhi * sPheta * world.Y[i]
    + sPhi * world.Z[i];
    viewer.Z[i] = -sPhi * cPheta * world.X[i]
    - sPhi * cPheta * world.Y[i]
    -cPheta * world.Z[i] + Rho;
}
```

from TP,29, $T_{4\times4}$

$$\mathbf{T} = \begin{bmatrix} -\sin\theta & \cos\theta & 0 & 0 \\ -\cos\phi\cos\theta & -\cos\phi\sin\theta & \sin\phi & 0 \\ -\sin\phi\cos\theta & -\sin\phi\cos\theta & -\cos\phi & \rho \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\begin{pmatrix} X_v \\ Y_v \\ Z_v \\ 1 \end{pmatrix} = T_{4\times4} \begin{pmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{pmatrix}$$

World-to-Viewer Transform

"After" "Before"

Now, Perspective Projection from TP,29

```
perspective.X[i] = D_focal * viewer.X[i] / viewer.Z[i] ;
perspective.Y[i] = D_focal * viewer.Y[i] / viewer.Z[i] ;
```

$$x_p = x_e\left(\frac{D}{z_e}\right)$$

$$y_p = y_e\left(\frac{D}{z_e}\right)$$

For Intersection Computation
a find λ in X_w-Y_w-Z_w,
b find intersection pt(s) in X_w-Y_w-Z_w
c Then Transformation pipeline then Done!

Then, Compute Virtual Display (2D) to Physical Display! Then plot the points!

Diffuse Reflection.

Background/Basic Concepts

1. Objective: To generate realistic Looking 3D Graphics

Lighting Models — After Trans. Pipeline

$$\vec{I}(x,y) = (r(x,y), g(x,y), b(x,y)) \quad \cdots(1)$$

Primitive Colors.

Graphics (Vector) Graphics

r,g,b : 8 bit Resolution.

$r,g,b \in [0,255]$, for 15 bits, or 16 bit r,g,b. is Common.

2. Color Space

April 19 (Monday)

Diffuse Reflection

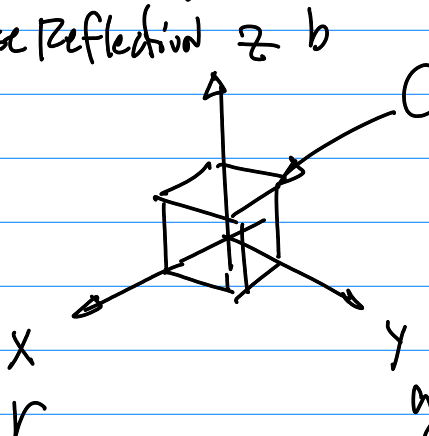
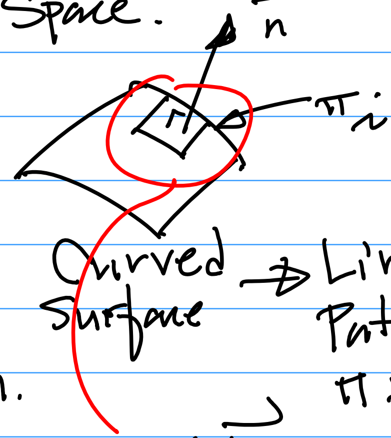


Fig 1.

Note: in r-g-b Color Space,
(255,0,0) : Brightest Red
(0,255,0) : Brightest Green, etc.

line connecting (0,0,0) to (1,1,1) : gray, (0,0,0) Black, (1,1,1) Brightest White

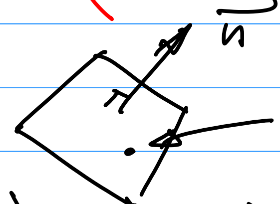
3. Color Contribution to Each pixel on a Surface of a given Object in 3D Space.



Fibza

Curved Surface → Linear Patches π_i

Fig 2b



$$\vec{I}(x,y,z) = \vec{I}_1(x,y,z) + \vec{I}_2(x,y,z) + \vec{I}_3(x,y,z) \quad \cdots(2)$$

3D Space in $X_w - Y_w - Z_w$

$\vec{I}_1(x,y,z)$: Diffuse Reflection

Diffuse Reflection (Ref. on github) :

Fig 2c

Diffuse Reflection: ~ that reflects incoming light uniformly in all different directions.

4. Reflectivity for all 3 Different light models (I_1, I_2, I_3)

Define $\vec{R} = (r_r, r_g, r_b)$ ...(3)

$0 \leq r_r, r_g, r_b \leq 1$

$r_r = r_g = r_b = 0$ Black

$r_r = r_g = r_b = 1$ white

$r_r = 0, \ r_g = 0.75, \ r_b = 0$: Green

Physical Characteristics of the given Surface

Now, Specular Reflection

I_2 : Reflection Produces high light, it is a function of E position.

I_3 : Ambient light, from indirect light Source, Can be Simulated by adding Constant values to r, g, b.

Example: Diffuse Reflection model.

Step 1. $\vec{I}(x,y,z)$ Color on a pt. of a Surface in 3D Space.

$\vec{I}(x,y,z) = (\vec{I_r}(x,y,z), I_g(x,y,z), \vec{I_b}(x,y,z))$

Simplify the discussion by focusing on One primitive Color

$\vec{I_r}(x,y,z)$

Energy of Photons from the Source reaching the pt. is inversive Proportional to the squared distance

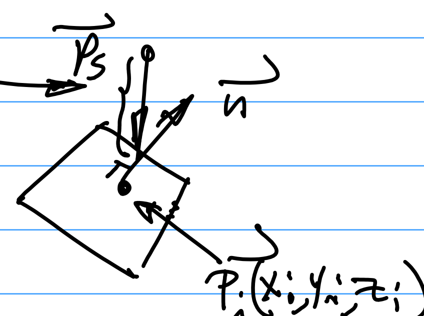
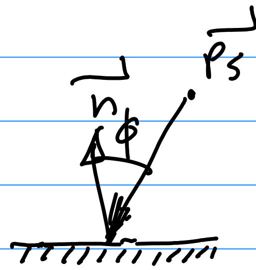


Fig 3

$\| \vec{P_s} - \vec{P_i} \|^2 = \| \vec{r} \|^2$ ...(4)

Ray Equation $\vec{r}$

$\vec{I_r}(x,y,z) \sim \frac{1}{\|r\|^2}$ ...(5)



ϕ. phi: Angle of the incoming light

$\phi = 0$, Strongest incoming light $\rightarrow$ Normalize it "1"

$\phi = \pi/2$ photons miss the pt. on the Surface $\rightarrow$ Normalized it. "0"

Cosϕ Rule. Dot Product

$$\vec{n} \cdot (-\vec{P_s}) = \|\vec{n}\| \|-\vec{P_s}\| \cos\phi \quad \ldots (5)$$

$$\cos\phi = \frac{\vec{n} \cdot (-\vec{P_s})}{\|\vec{n}\| \|-\vec{P_s}\|} = -\frac{\vec{n} \cdot \vec{P_s}}{\|\vec{n}\| \|\vec{P_s}\|} \quad \ldots (6)$$

define $-\vec{P_s}$ as Ray Vector

$$\vec{r} \stackrel{\Delta}{=} \vec{P_i} - \vec{P_s} \quad \ldots (7)$$

Hence

$$\cos\phi = \frac{\vec{n} \cdot \vec{r}}{\|\vec{n}\| \|\vec{r}\|} \quad \ldots (8)$$

$$\vec{I_r}(x,y,z) \sim \cos\phi \left(= \frac{\vec{n} \cdot \vec{r}}{\|\vec{n}\| \|\vec{r}\|} \right) \quad \ldots (9)$$

$$\vec{I_r}(x,y,z) \sim K_r \quad \ldots (10)$$ Reflectivity for r

Preparation for

From Eqn (5), (9), (10)

$$\vec{I_r}(x,y,z) = K_r \frac{\vec{n} \cdot \vec{r}}{\|\vec{n}\| \|\vec{r}\|} \frac{1}{\|r\|^2} \quad \ldots (11)$$

where

$$\|\vec{r}\|^2 = \|\vec{P_i} - \vec{P_s}\|^2 = (x_i - x_s)^2 + (y_i - y_s)^2 + (z_i - z_s)^2$$

CmpE240

April 21 (Wed)

Lab (Project) 3D GE, (Diffuse Reflection) Due 2 weeks, May 9th Sunday 11:59 pm.

a. 2018F-115-Rubrics

b. 2018F-116, C++ Sample code

c. 2018F-117 DDA

d. 2018F-118 Interpolation

Example: Design/Implementation for Project on Diffuse Reflection.

(See github to find Ref. 2018S~Diff)

Step 1. Define Data Points (Vertices $\vec{P}_i(x_i, y_i, z_i)$ in the World Coordinate System)

$\{\vec{P}_i(x_i, y_i, z_i) \mid i = 1, 2, \ldots 8\}$ for a Cube,

Only interested in Top Surface

$\{\vec{P}_i(x_i, y_i, z_i) \mid i = 1, 2, \cdots, 4\}$

Cube with Side of 100, And elevated by 10.

Only Consider Diffuse Reflection on the top Surface formed by $\{\vec{P}_1, \vec{P}_2, \vec{P}_3, \vec{P}_4\}$

$\vec{P}_1(0, 100, 110)$, $\vec{P}_2(0, 0, 110)$

$\vec{P}_3(100, 0, 110)$, $\vec{P}_4(100, 100, 110)$

Step 2. Define Point Light Source $\vec{P}_5(200, 200, 200)$, white and Reflectivity

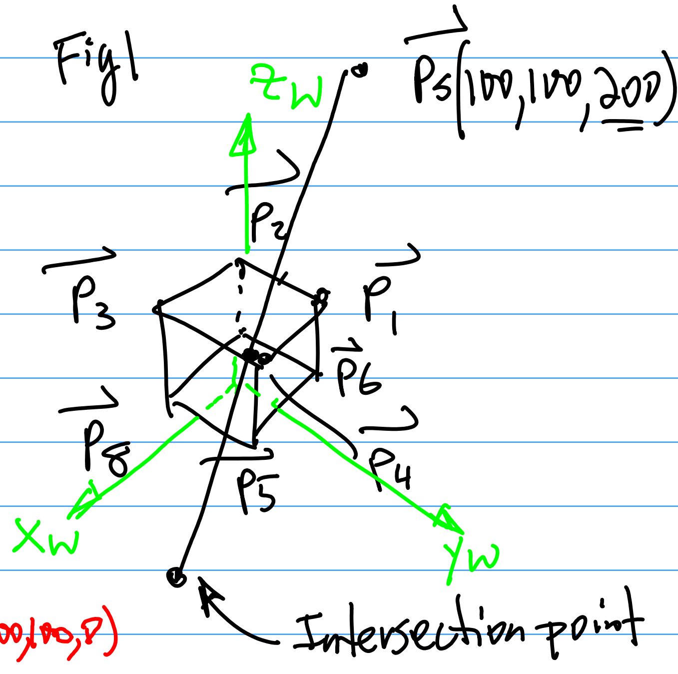
$\vec{K}(K_r, K_g, K_b) = (0.8, 0, 0)$

For Red

Question:

Do we have to perform Transformation Pipeline Computations in order to compute Diffuse Reflection? No

Fig 1



$$\vec{I_r}(x,y,z) = K_r \frac{\vec{n}\cdot\vec{r}}{\|\vec{n}\|\|\vec{r}\|} \frac{1}{\|r\|^2} \quad \cdots (1)$$

Since $\vec{P_s}(200,200,200)$,

$$\vec{r} \triangleq \vec{P_i} - \vec{P_s}\Big|_{i=4} = \vec{P_4} - \vec{P_s}$$

$$= (x_4-x_s, y_4-y_s, z_4-z_s) \quad \cdots (2)$$

$$\|r\|^2 = \left(\sqrt{(x_4-x_s)^2+(y_4-y_s)^2+(z_4-z_s)^2}\right)^2$$

$$= (x_4-x_s)^2+(y_4-y_s)^2+(z_4-z_s)^2$$

$$= 100^2+100^2+90^2$$

And $\cos\phi$

$$\vec{n}(n_x, n_y, n_z) = (0,0,1)$$

$$\vec{n}\cdot\vec{r} = (0,0,1)\cdot(r_x, r_y, r_z)$$

$$= (0,0,1)\cdot(x_4-x_s, y_4-y_s, z_4-z_s)$$

$$= 0\cdot(x_4-x_s)+0\cdot(y_4-y_s)+1\cdot(z_4-z_s)$$

$$= z_4-z_s$$

$$\|\vec{n}\|\|\vec{r}\| = \sqrt{n_x^2+n_y^2+n_z^2}\cdot\sqrt{r_x^2+r_y^2+r_z^2}$$

$$= \sqrt{0^2+0^2+1^2}\cdot\sqrt{(x_4-x_s)^2+(y_4-y_s)^2+(z_4-z_s)^2}$$

$$= 1\cdot\sqrt{(x_4-x_s)^2+(y_4-y_s)^2+(z_4-z_s)^2}$$

$$\frac{\vec{n}\cdot\vec{r}}{\|\vec{n}\|\|\vec{r}\|} = \frac{z_4-z_s}{\sqrt{(x_4-x_s)^2+(y_4-y_s)^2+(z_4-z_s)^2}}$$

$$= \frac{110-200}{\sqrt{100^2+100^2+90^2}}$$

No! Positive Value Only

Change Eqn (2) from $\vec{P_i}-\vec{P_s}$ to $\vec{P_s}-\vec{P_i}$!

Therefore, we have

$$\frac{200-110}{\sqrt{100^2+100^2+90^2}}$$

So, we have Diffuse Reflection @ pt. 4 $\vec{P_4}$

$$I_{diff} = K_d \frac{200-110}{\sqrt{100^2+100^2+90^2}} \cdot \frac{1}{100^2+100^2+90^2}$$

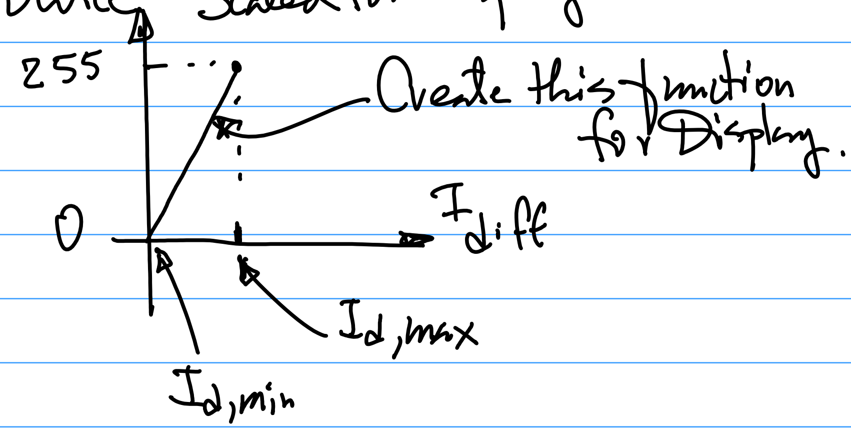
0.8

$$I_{diff} = 0.8 \frac{200-110}{\sqrt{100^2+100^2+90^2}} \frac{1}{(100^2+100^2+90^2)}$$

Note:

1° I_{diff} Computed is <u>Very</u> Small! You Need Scaling factor to Scale it up for the dynamic Range of your Hardware (LCD) Display Device

Scaled for Display



Add Offset 20 to I_{diff}. So it is more visible.

Question: How to Expand the Computation to the Rest of the points on the top Surface?