CMPE240

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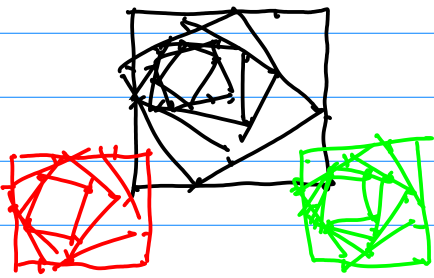
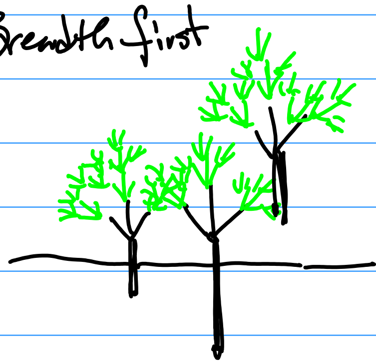
a A set of Squares Rotation
with One Same Color
b Change location/color/size
c



Keep the patterns, please
don't erase them!

Part II Once Part I is Done
Switch to Part I.
a Breadth first



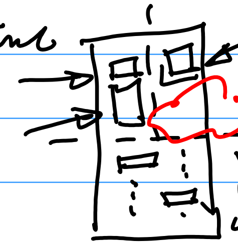
b $L \geq 7$ c Create A patch of Forest
Changing Location/size

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

Note: Report Writting.

3D G.E. (Graphics Engine)

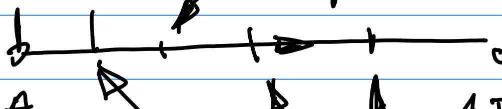
CPU Architecture
Jtag
CortexM3



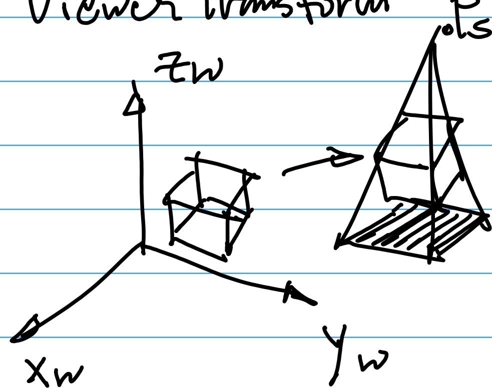
mem. Contrl
3D G.E.
Peripheral Controllers.

{ GPP SPRs,
SPI SPRs.

Solid obj
HL, HS. Removal



A
B
3D
Concepts
+ Algorithm
(2) Wireframe
Shade
State-of-the-Art
(1) World-To-
Viewer Transform



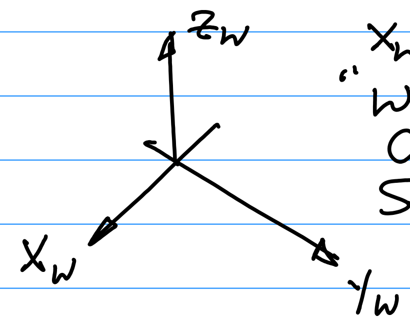
Lighting model.
Diffuse
Reflection

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°



X_w-Y_w-Z_w "World" Coordinate System.

Fig. 1

Right-Hand System,

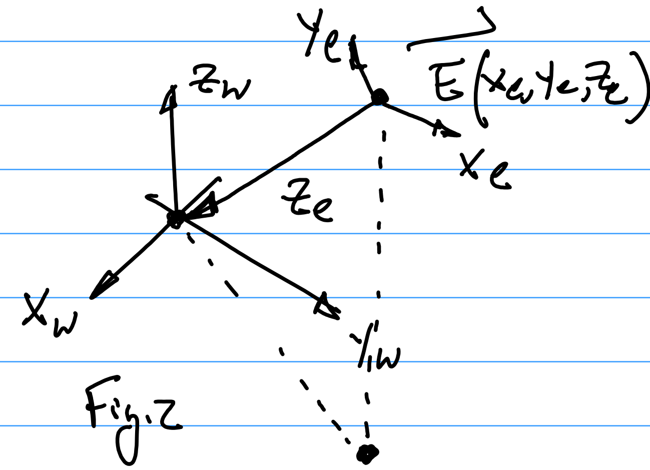


Fig. 2

Projection of $\vec{E}(x_e, y_e, z_e)$ onto X_w-Y_w plane in the X_w-Y_w-Z_w World Coordinate System

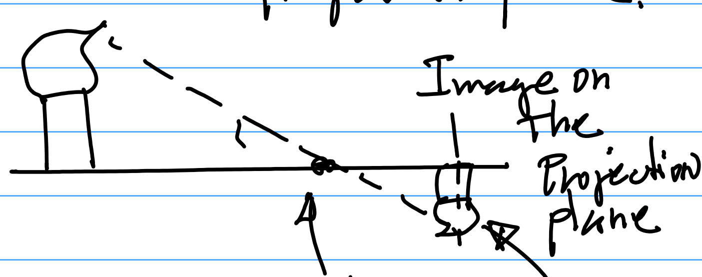
2° Virtual Camera

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 throughth the lens and Reaches the projection plane.



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

4. Viewer Coordinate system

Viewer ~ Virtual Camera

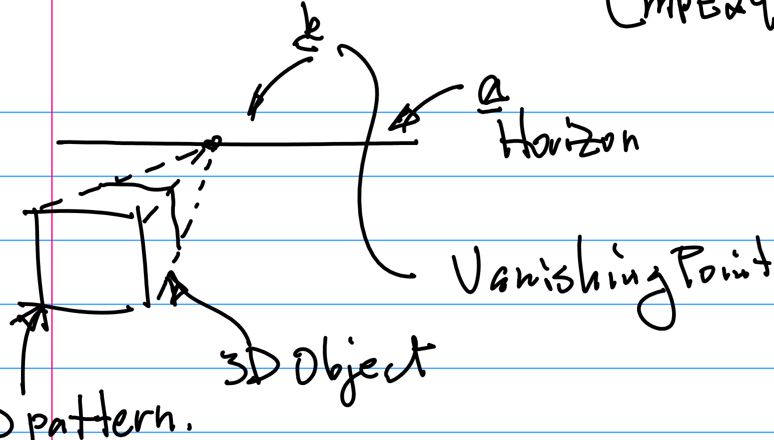
X_e-Y_e-Z_e Viewer Coordinate System.

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) on to 2D LCD Display Screen.

- W2V (World-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

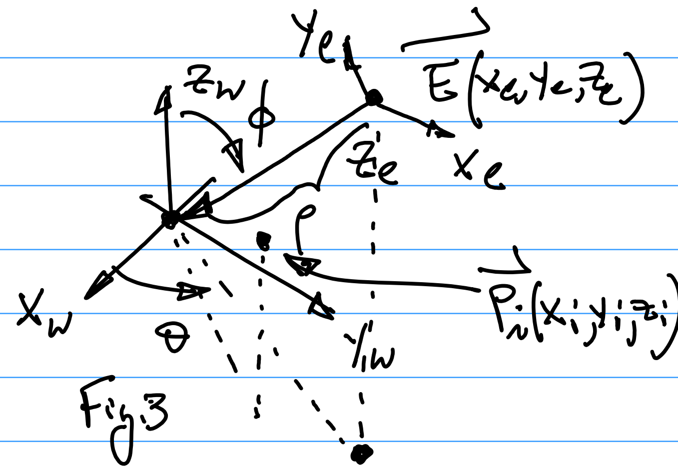


Fig.3

3 parameters:

a. theta θ Angle

b. Vector $\vec{E}$ to $\vec{O}$, "rol", Distance ρ

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

c. Angle Z_w and Z_e ϕ.

Mathematical Formulation

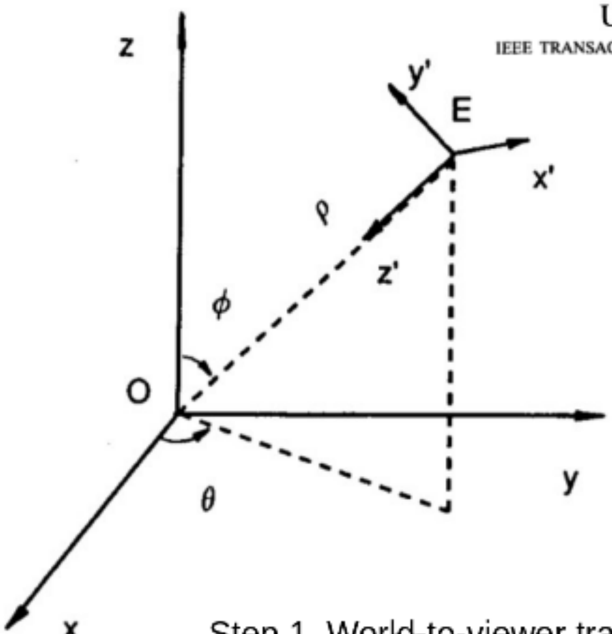
1° Formula: Transformation Pipeline
- a. World-to-Viewer Transform
- b. Perspective Projection

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

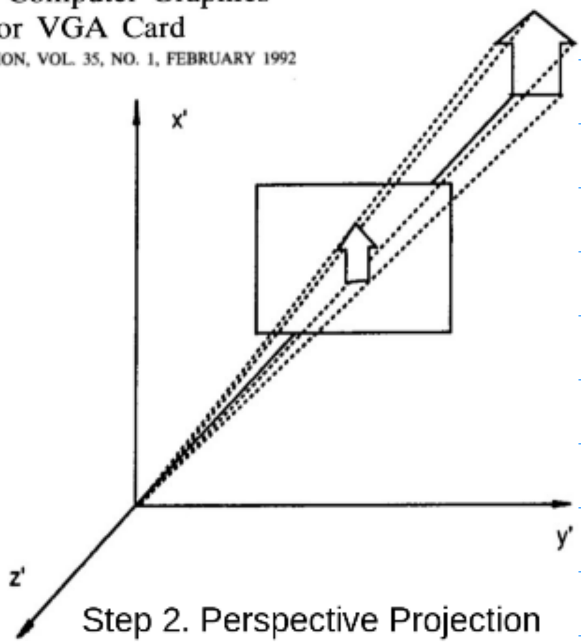
World_2_Viewer

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.

$$\begin{pmatrix} x_i' \\ y_i' \\ z_i' \\ 1 \end{pmatrix} = \underset{\text{World to Viewer Transform.}}{T} \begin{pmatrix} x_i \\ y_i \\ z_i \\ 1 \end{pmatrix} \quad \ldots (2)$$

After x_e-y_e-z_e Before x_w-y_w-z_w

$$\begin{pmatrix} \sin\theta & \cos\theta & 0 & 0 \\ \cos\theta & \sin\theta & \text{"} & \text{"} \\ \cos\theta & \cos\theta & \text{"} & \text{"} \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad \text{Part I. "}\theta\text{"}$$

$$\begin{pmatrix} 0 & 0 & 0 & 0 \\ \cos\phi & \cos\phi & \sin\phi & \text{"} \\ \sin\phi & \sin\phi & \cos\phi & \text{"} \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad \text{Part II "}\phi\text{"}$$

$$\begin{pmatrix} - & & & \\ - & - & & \\ - & - & - & \rho \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad \text{Part III "\_"}$$

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 6 ~

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

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.

CmpE240

Bitwise "OR"

|= (1<<10)

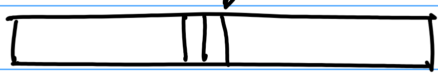
&= ~(3<<20)

"AND" Negation, "11" "00"

|= (1<<20)

"OR" "01"

Clear 2 Bits



Set 2 bits as "01"

&=~((3<<18)|(3<<16)|(3<<14));

"AND" Nega. "11" Total 6 bits <<18

clear 6 bits

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

"OR" "10"

Set

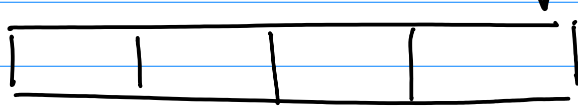
Note: { CR0, CR1 }

LPC_SSP1 -> CR0

Control Register

Table 371

CR0



Tech Spec.

1° 8 bit Transfer.

CR0[3:0] = 0111 = 0X7

2° SPI

CR0[5:4] = 00 (SPI)

3° Clock f_{SPI}

a CR0[15:8] 8 bits 255 = 2^8

b

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

SCR: [0, 255]

mauch22nd.

Today's Topics:

1° Midterm Review

2° SPRs CR0, 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

r31 Table 80, pp. 117 CPU Datasheet r0

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.

.... 0000 0111 0000 0111

16 upper Bits all zeros.

From Datasheet PP431

8 bit Transfer

CR0[15:8] SCR

CR[5:4] = 00 SPI

Clock

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

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, SPRs.

CKT, SCH Design

Software: Coding

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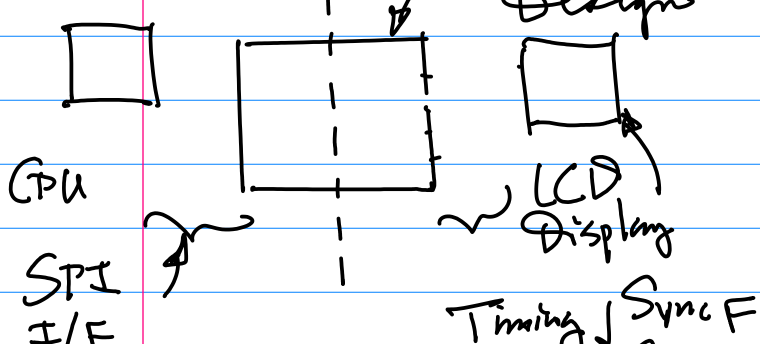
SPB → Binary Pattern
Coding — for Init & Config
Debugging Purpose
→ Tech Spec.

Algorithm:
2D Vector Graphics.
G.E.

a LPC CPU LPC Driver.
LPC Deriver Design



Timing { Sync F, $Sync_H$, $Sync_D$

MOSI
MISO
SCK
SSELn

$\overline{CS}$

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 midterm 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

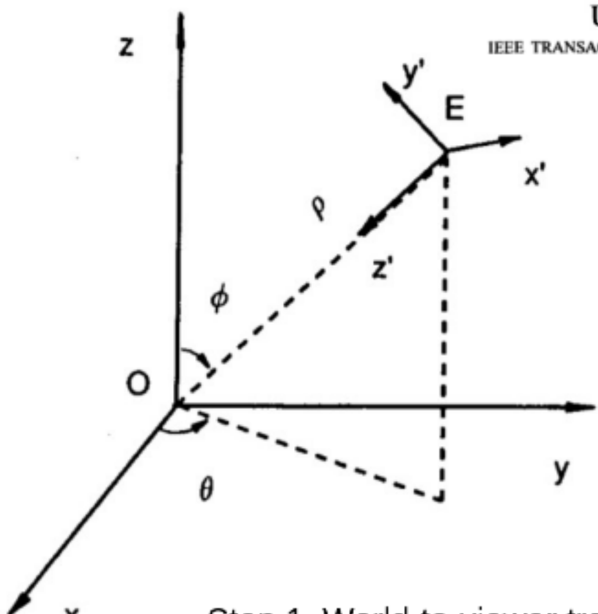
April 5 (Monday)

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

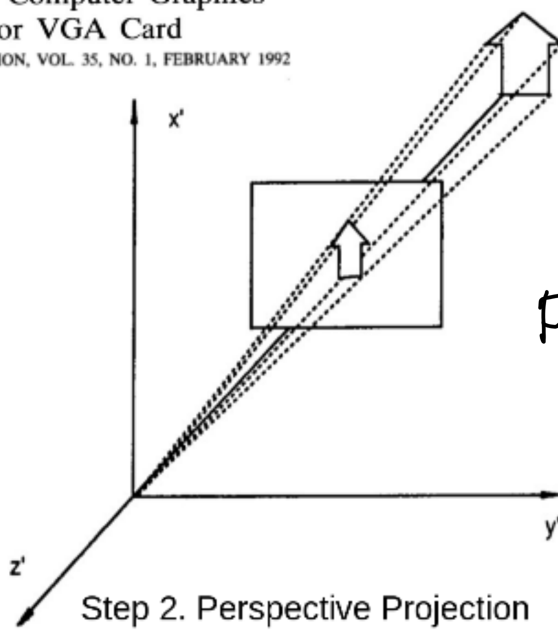
3D Transformation Pipeline Technique

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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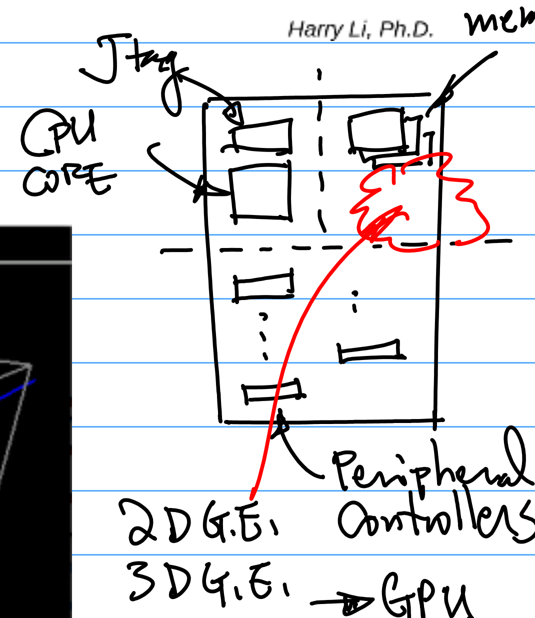
Today's Topics: 3D G.E.



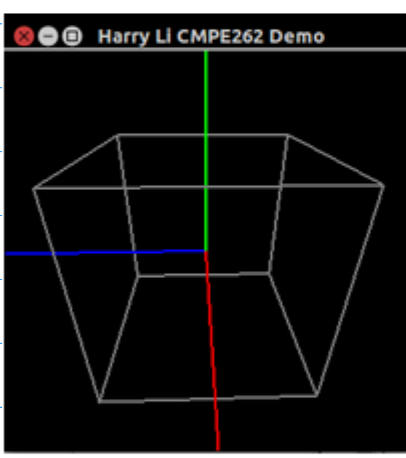


Fig 2a

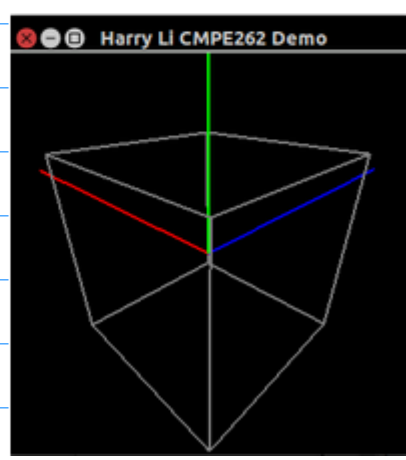


Fig 2b

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

Note: 2D G.E. $\begin{cases} \text{Vector Graphics} \\ \text{Transformation} \\ \text{Primitive Graphics} \end{cases}$ $\begin{cases} \underline{a} \text{ D.D.A.} \\ \underline{b} \text{ line} \\ \underline{c} \text{ Arc/circle etc.} \end{cases}$ Transistor/Gate Level.

Example: 3D Wireframe Model

First, X_w-Y_w-Z_w World Coordinate System.

$\underline{a}$ Right System, r-g-b for X_w, Y_w, Z_w axis

$\underline{b}$ Transformation Pipeline

$\underline{1st}$ World-2-Viewer

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

$\underline{2nd}$ Perspective Projection

$$P: (X_v, Y_v, Z_v) \to (x_p, y_p) \quad \cdots (3b)$$

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 $\vec{P}_0(x_0, y_0, z_0) = (0, 0, 0) \cdots (4)$

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

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

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

#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

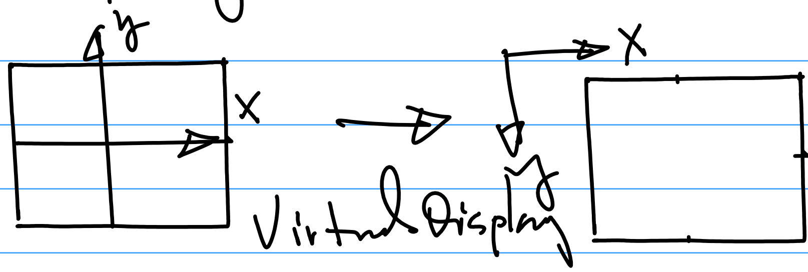
CmpE240

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.



$$\begin{cases} x_p = \dfrac{D}{z_v} x_v & \text{..(a1)} \\ y_p = \dfrac{D}{z_v} \cdot y_v & \text{... (a2)} \end{cases}$$

$(x_v, y_v, z_v) \in \mathbb{R}^3$ Virtual Cam

focal Length

(x_p, y_p) On your 2D Display

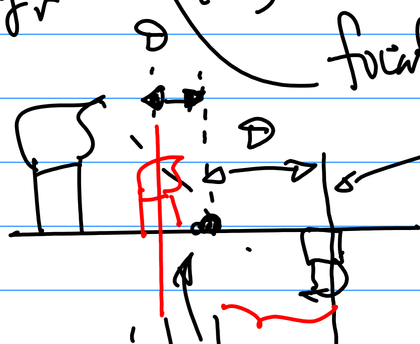
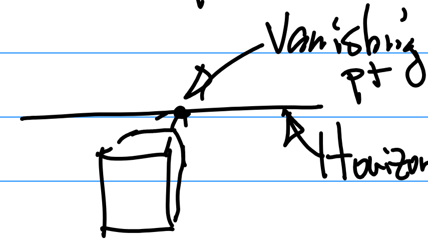


Fig 1.

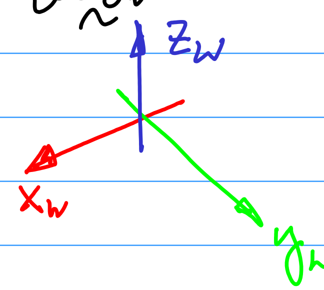
Back projection plane: the only light that can reach the projection plane is the light passing through the "pin hole". (plane is at the Back) projection

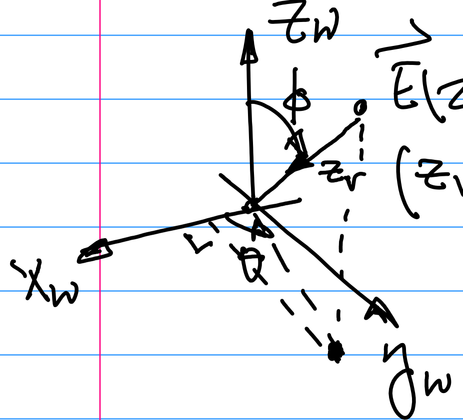
Frontal projection plane: move the back projection plane to the outside of the virtual Camera.

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



In Homework, D = 20





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

$(z_v \Rightarrow z_e)$

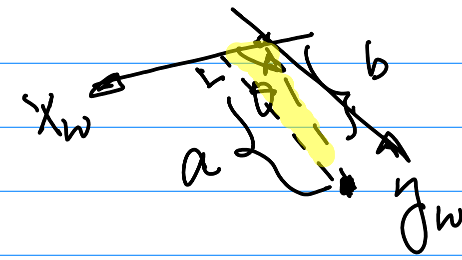


Fig 1.

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

$a = y_e = 200$

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

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

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

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.

Note: Angle θ (Theta) on X_w-Y_w plane

{ wrt Positive X_w-axis, And Counter Clockwise Direction

Note: Angle ϕ (phi) on z_v-z_w plane.

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

for Angle θ (Theta)

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

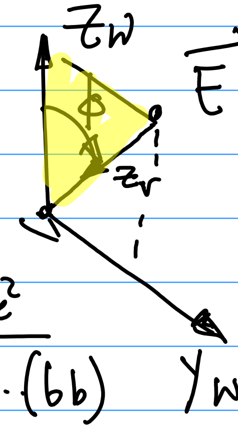
for ϕ (phi)

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

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

"rho"

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



April 7 (Wed)

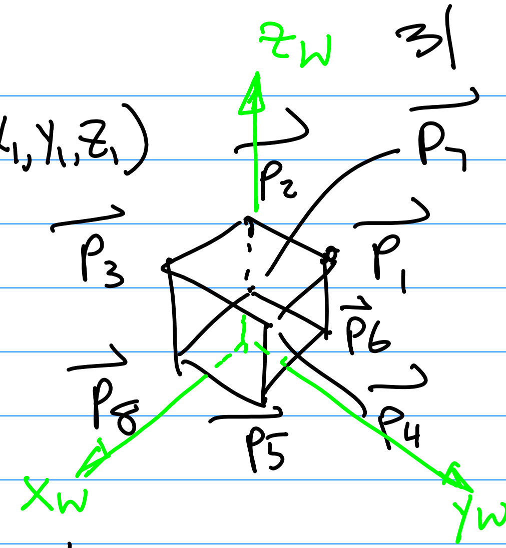
Note: x_v-y_v-z_v Left Hand System

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

$= \frac{200}{200\sqrt{3}} = \sqrt{3}/3$

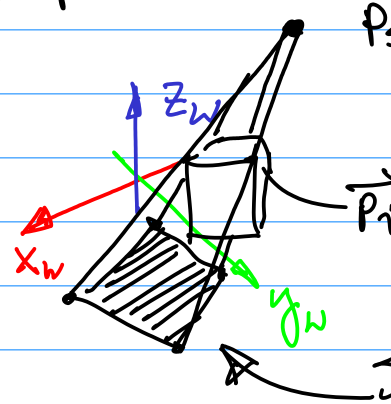
Similarly

$$\sin\phi = \sqrt{x_c^2 + y_c^2}/\rho = \frac{\cancel{2}\cancel{0}\sqrt{2}}{\cancel{2}\cancel{0}\sqrt{3}} = \sqrt{2/3}$$



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

$\vec{P}_s(100, 100, 200)$

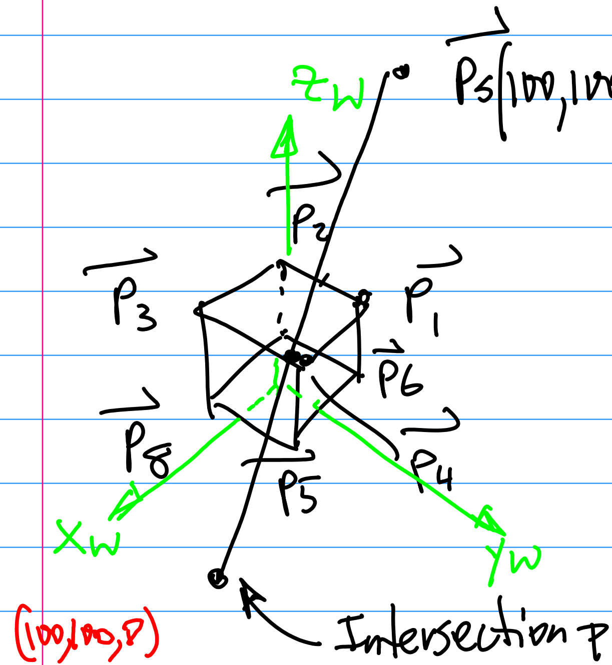


Fig 1.

3. Ray Equation, Connecting $\vec{P_5}$ 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

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

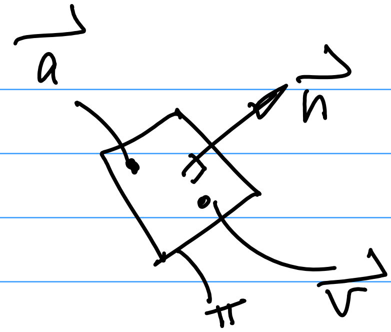


Fig. 2

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).

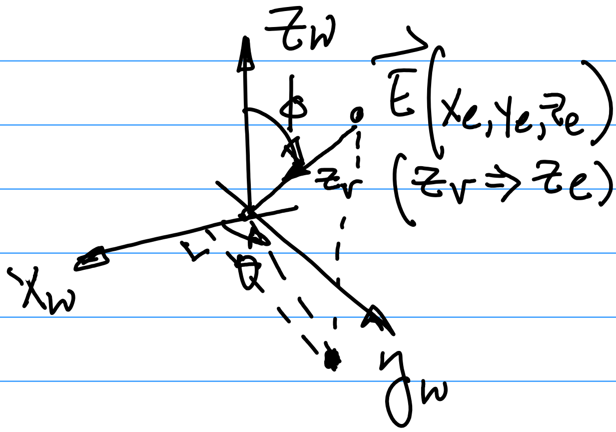
See the figure Next page

```
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;
```

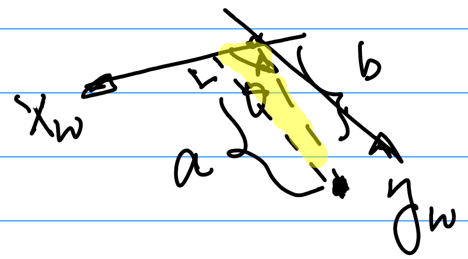
Declaration of Each Coordinate System

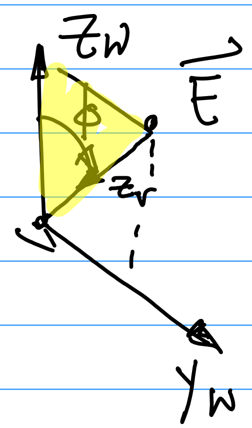
```
pworld  world;
pviewer viewer;
pperspective perspective;
```

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



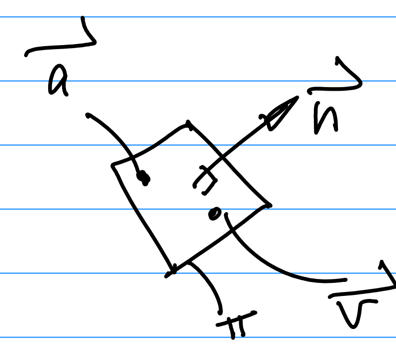


We defines $\sin\theta$, $\cos\theta$ for $T_{4\times4}$

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 $\vec{Ps}(x_s, y_s, z_s)$

```
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, $T_{4\times4}$

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

$$\underbrace{\begin{pmatrix} X_v \\ Y_v \\ Z_v \\ 1 \end{pmatrix}}_{\text{"After"}} = T_{4\times4} \underbrace{\begin{pmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{pmatrix}}_{\text{"Before"}}$$

World-to-Viewer Transform

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] ;
```

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

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, Computer 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

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

Graphics (Vector) Graphics

Primitive Colors.

r, g, b : 8 bit Resolution.

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

2. ColorSpace