Sept. 7.

Note: 1° LPC1769 from 2022S Semester, Waiting List. CANVAS. Scott.

2° LPC1768 pin-to-pin Compatable. (Mbed)

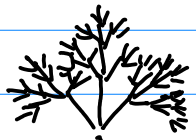
a. Step1. MCUXpresso IDE 1768 Binary Code.

Step2. "Firmware" Upload the binary file to the Flash. Need a prob

Step3. Interactive Debugging.

3° LPC11C24 Dig-Key in Stock. LPC1114 Site

GPP/SPI, FLASH (ON-Chip) 1/8 of the size Comparing to LPC1768/9



Homework (0 pt)

1. Form A Team By Wednesday. 4-Person

2. Select/Finalize your target platform. By the end of the week.

Example: Register File

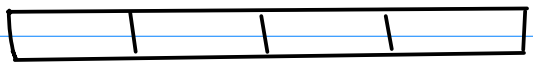
Special Purpose Registers

General Purpose Register

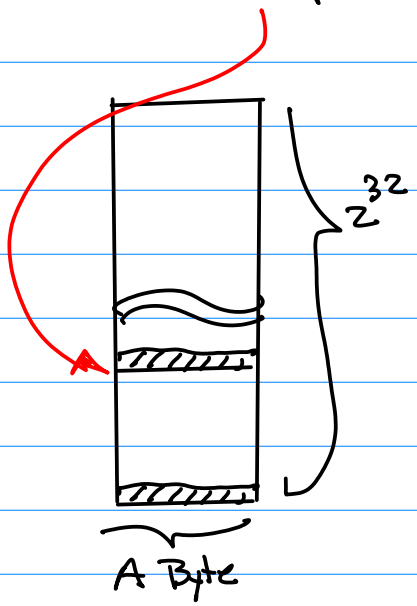
GPx CON

Root

Prefix 3 Letters for Port "x", x=0, 1, 2, 3



GPx CON its address is 32 Bits, it maps to the memory map.



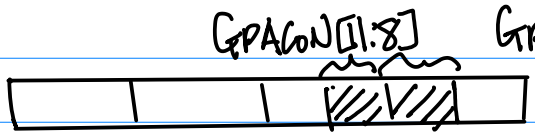
Note: The Task of Init & Config Can be realized by using HLL (High Level Language), C/C++, to deposit A Binary Pattern to that memory Location (Addr. is a Pointer)

CmpE240

Sept. 7

For Example for Samsung ARM-11.

Consider:
Power up Address + Power Process.
Booting.



GPx_{CON} its address is 32 Bits, it maps to the memory map.

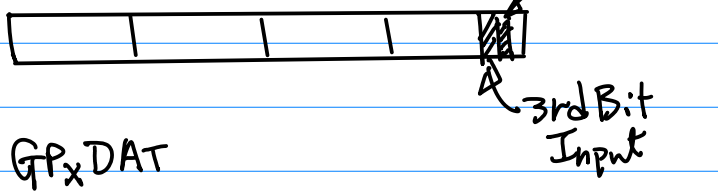
Design Requirements (Spec.)

1. 2nd Bit As An Output
2. 3rd Bit As An Input

To perform Init & Config.

GPACON[7:4] = 0001 = 0x1

GPACON[11:8] = 0000 = 0x0



GPx_{DAT}

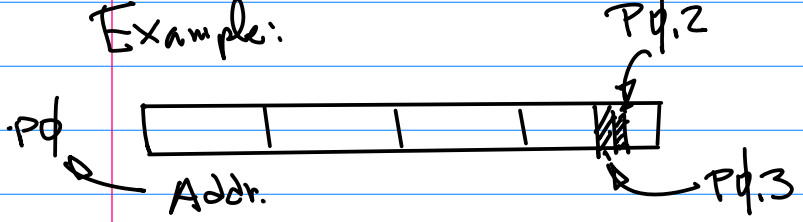
GPACON[3:0] = 0x10

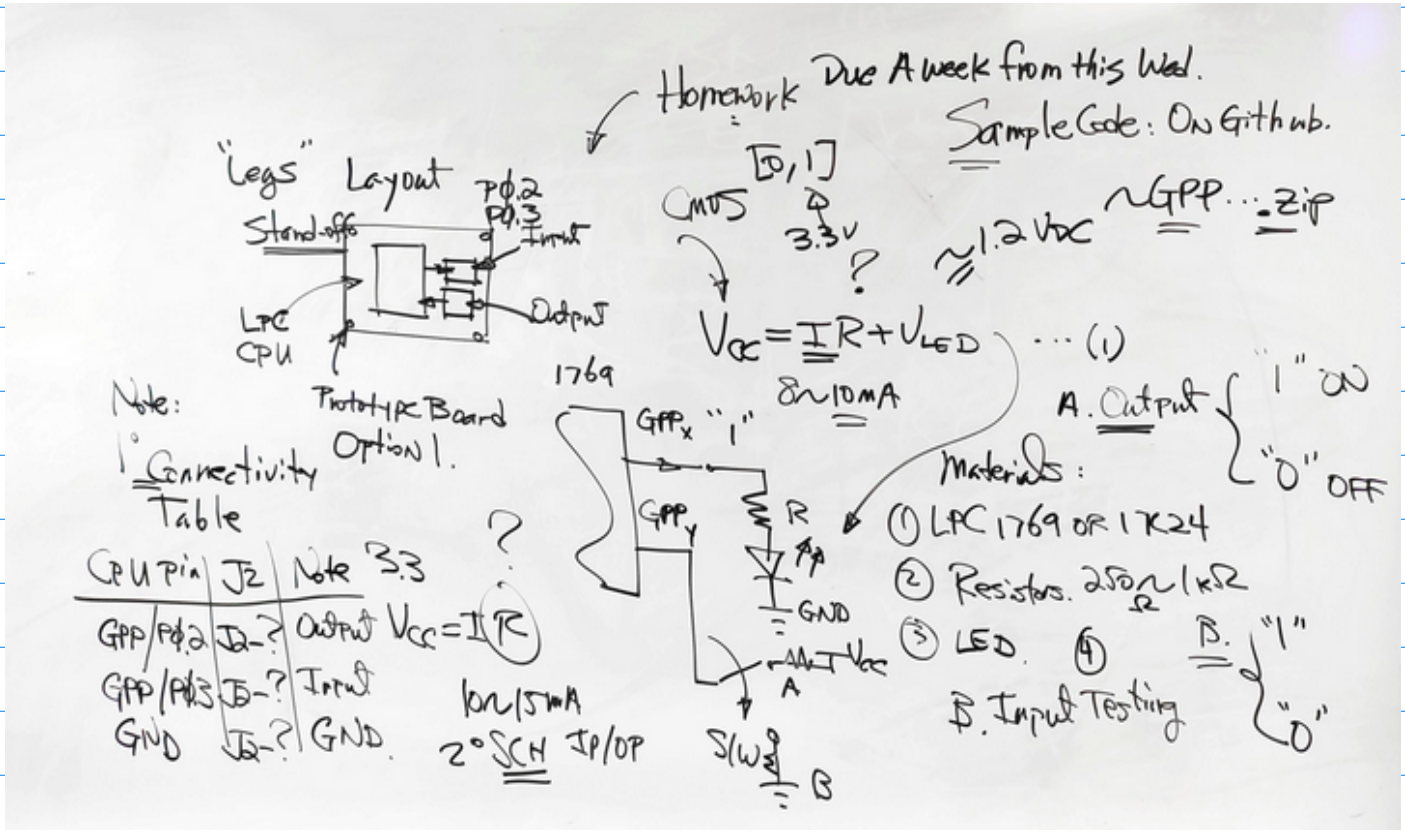
Sept. 12 (monday)

1. Homework (2pts)
2. Special Purpose Register

Note: Target platform.
LPC1768, LPC1124

Example:





Sept. 14 (Wed).

Note: 1° Check Homework Assignment on CANVAS.

Two Options { Prototype Board
{ e-Bay, Board B.

Topics today: IDE

1° GPP Software/Program

2° 2D Graphics Processing Engine Design.

Example: Set up the Expresso. 2

key points:

1° Make sure Select Target Board LPC1769. (Ref. on github, 35 slides)

2° C/C++ Project settings. →
"Semihost"

3° Import LPC1769 patch.

1769 patch.zip

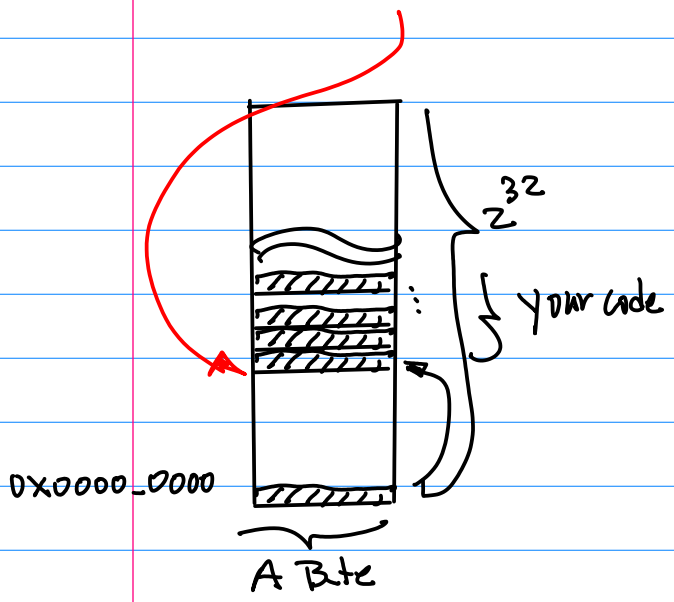
Note: 1° LPC1769 patch is already Config by NXP.

2° prob issue → fix:

Reconnect OR Reboot.

Import GPIO project to your MCU Xpresso.

Run "Debug", Once prob is detected then Your Program (Binary)



Consider G.E. Design.

Math. Formulation, for Vector Graphics.

Example.

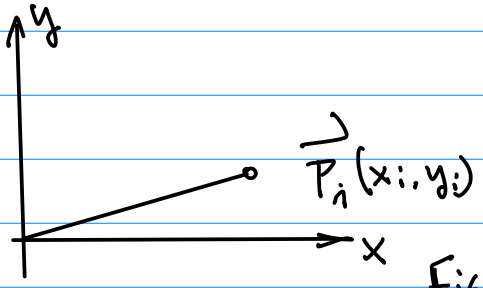


Fig. 1.

$\vec{P}$ A Point $\rightarrow \vec{P}(x,y) \rightarrow \vec{P}_i(x_i, y_i)$ for $i = 0, 1, 2, \ldots$

Also, a line $\rightarrow (x_i, y_i)$

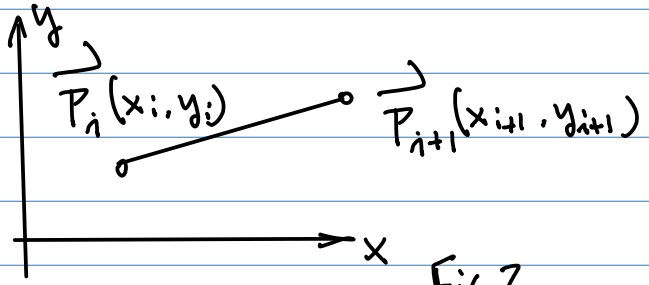


Fig. 2.

Note: To Uniquely Define A Line, we can add a directional vector, Denoted as

Definition 1:

$$\vec{d}(x,y) \triangleq \vec{P}_{i+1}(x_{i+1}, y_{i+1}) - \vec{P}_i(x_i, y_i) \quad \ldots (1)$$

$\vec{P}_{i+1}$: Ending pt. $\vec{P}_i$: Starting pt.

Definition 2: (Line Eqn. in Vector Form)

$$\vec{P}(x,y) = \vec{P}_i(x_i, y_i) + \lambda \vec{d}(x,y) \quad \ldots (2)$$

$$-\infty < \lambda < +\infty$$

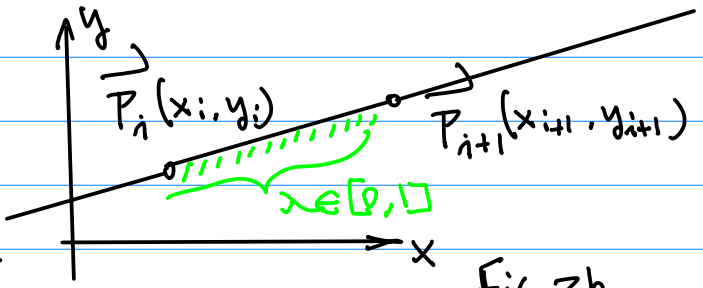


Fig. 2b.

Observation 1:

When $\lambda = 0$, Eqn (2) gives the Starting pt: $\vec{P}_i(x_i, y_i)$

$\lambda = 1$, ... Ending point $\vec{P}_{i+1}(x_{i+1}, y_{i+1})$

$0 < \lambda < 1$, $\vec{P}(x,y)$ Any Arbitrary pt Between $\vec{P}_i(x_i, y_i)$ and $\vec{P}_{i+1}(x_{i+1}, y_{i+1})$

Sept. 21. Today's Topics:

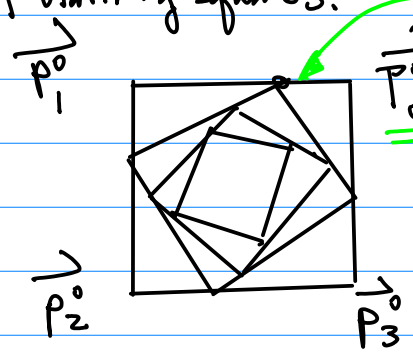
1° Check CANVAS for the Submission of the In-Class Exercise;

2° Graphics Lib has been ported to LPC11C24, Ref. Code & PPT will be provided.

Example: Given the equation Below,

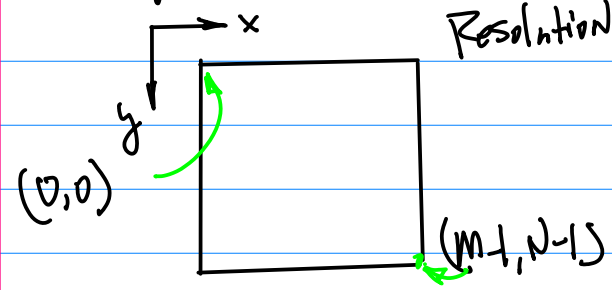
$$\vec{P}^{j+k}_{i}(x, y) = \vec{P}^{j}_{i}(x^{j}_{i}, y^{j}_{i}) + \lambda\left(\vec{P}^{j}_{i+1}(x^{j}_{i+1}, y^{j}_{i+1}) - \vec{P}^{j}_{i}(x^{j}_{i}, y^{j}_{i})\right) \quad \ldots (1)$$

Let's Design A Graphic Algorithm to Create A set of Counter Clockwise (CCW) Rotating Squares.



Step 1. Define the initial set of Data Points $\{\vec{P}_i(x_i, y_i) \mid i = 0, 1, \ldots, 3\}$ for Resolution of A Display Device defined as $M \times N$

$\max(M, N) \leq 200$, Select the Size of the Cube $\simeq 50$



M x N
↑ ↑ No. of Rows
No. of Pixels per Row (Col).

2021S-105-CMPE240-2021-03-22-Note.pdf

$\vec{P}^0_0(x^0_0, y^0_0), \vec{P}^0_1(x^0_1, y^0_1), \ldots, \vec{P}^0_3(x^0_3, y^0_3)$ are defined as the same data pts on pp15.

Step 2. Get Line Equation, Based on Eqn (1). First pt on Level 1

$$\vec{P}^1_0(x^1_0, y^1_0) = \vec{P}^0_0(x^0_0, y^0_0) + \lambda\left(\vec{P}^0_1(x^0_1, y^0_1) - \vec{P}^0_0(x^0_0, y^0_0)\right)$$

$$= (60, 60) + \lambda\left((10, 60) - (60, 60)\right)$$

$$= (60, 60) + \lambda(-50, 0)$$

From the Given Condition, CCW Rotation

Let $\lambda = 0.2$

Note: Based on the Above Calculation Can be Conducted for the Rest of the Pts, And Rest of the Levels.

Step 3. Suppose we want to generate 10 Levels of the Rotating Squares. Let Write C/C++ for this Purpose.

From Eqn(1), we have

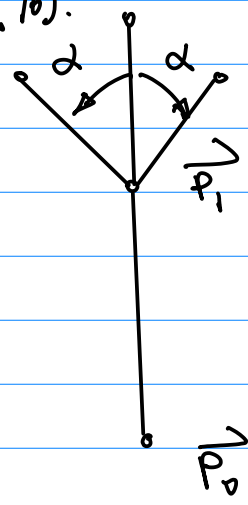
$$\begin{cases} x_i^{j+1} = x_i^j + \lambda(x_{i+1}^j - x_i^j) & \cdots (2a) \\ y_i^{j+1} = y_i^j + \lambda(y_{i+1}^j - y_i^j) & \cdots (2b) \end{cases}$$

```
x[i][j+1] = x[i][j] + lambda*(x[i+1][j] - x[i][j]);
y[i][j+1] = y[i][j] + lambda*(y[i+1][j] - y[i][j]);
```

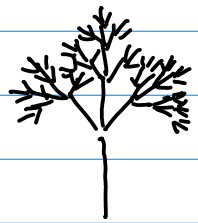
Consider Creating A Screen Saver
By Generating A tree.

Note: Level 0 : Tree Trunk;
Level 1 : { Branch (Main) : Mag. Reduction By 20% $\lambda = 0.8$ (Same Direction, Directional Vect. Same.)
Side Branch { L (CCW), Rotation by α ($\pi/6$). $\alpha > 0$
R (CW), $\alpha < 0$

α : Positive

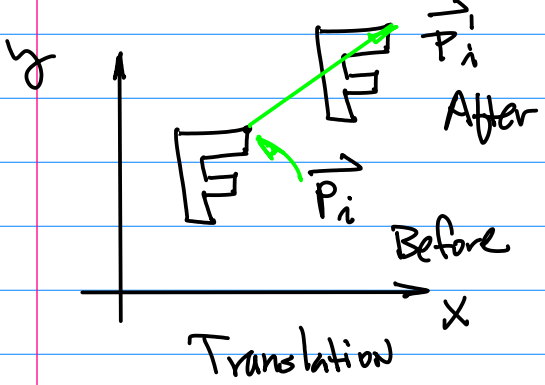


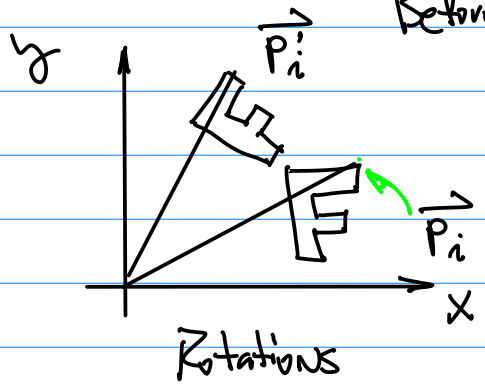
level 2, 3, ..., k.
Repeat Level 1 with Reference Vector (P_i) Updated Accordingly.



Background (2D Transformations)

Note: Mapping Between $\vec{P}_i$ & $\vec{P}_i'$ e.g. Before & After.





Sept. 26.

Rotation: 1° Positive Angle is defined as a Counter Clockwise Rotation;

2° Reference pt is defined as the Origin.

3° physical Display (Coordinate System) v.s. Virtual Display (virtual Coordinate System).

pt (After) $\vec{P_i'}$ pt (Before) $\vec{P_i}$

$$\begin{pmatrix} x_i' \\ y_i' \\ 1 \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & \cdots & a_{23} \\ a_{31} & \cdots & a_{33} \end{pmatrix}_{3\times 3} \begin{pmatrix} x_i \\ y_i \\ 1 \end{pmatrix} \quad \cdots (1b)$$

3D vector with One "Dummy" Dimension.

Rotation Matrix for Eqn (1b)

$$\begin{pmatrix} x_i' \\ y_i' \\ 1 \end{pmatrix} = \begin{pmatrix} \cos\alpha & -\sin\alpha & 0 \\ \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x_i \\ y_i \\ 1 \end{pmatrix} \quad \cdots (2)$$

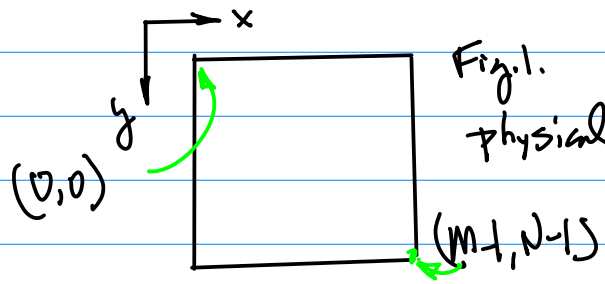
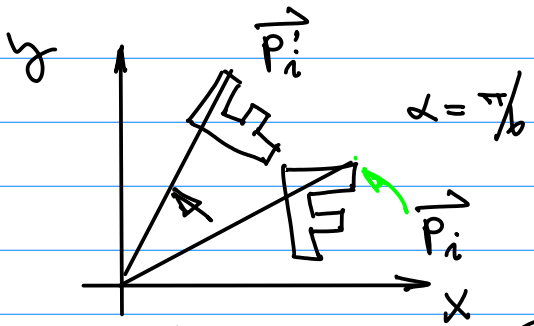


Fig.1. physical Display

$$\begin{cases} x_i' = x_i \cos\alpha - y_i \sin\alpha & \cdots (2\text{-}b) \\ y_i' = x_i \sin\alpha + y_i \cos\alpha & \cdots (2\text{-}c) \end{cases}$$

```
X_Prim[i] = X[i]*cos(alpha)
          - y[i]*sin(alpha)
```

for the Reference of Doing C/C++ Coding.



Rotations

Fig.2 Virtual Display.

Note: Reference pt. for the Definition of Rotation. This Rotation Cannot be Simply defined by Eq(2)

Example: for the Rotation illustrated in Fig.2.

pt (After) $\vec{P_i'}$ pt (Before) $\vec{P_i}$

$$\begin{pmatrix} x_i' \\ y_i' \\ 1 \end{pmatrix} \stackrel{?}{=} \Phi \begin{pmatrix} x_i \\ y_i \\ 1 \end{pmatrix} \quad \cdots (1)$$

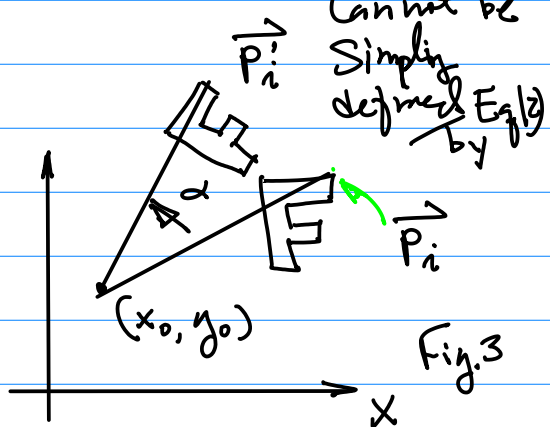


Fig.3

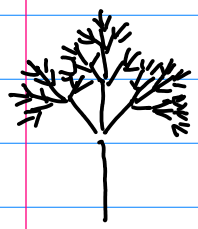


Fig. 4a

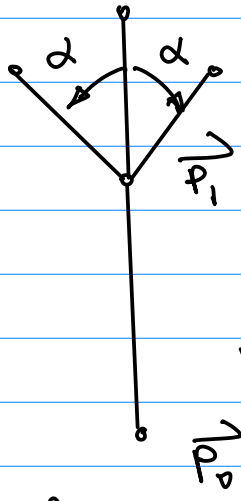


Fig. 4b.

These are different Rotations than that in Eqn (2).

Consider the Composition of 2D Transforms.

Example: Build/Design to Realize a 2D Tree Pattern in Fig. 4.

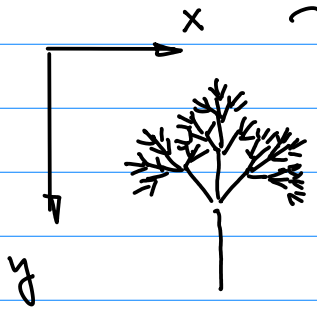


Fig. 5a. Physical Display

Mapping. ϕ_1

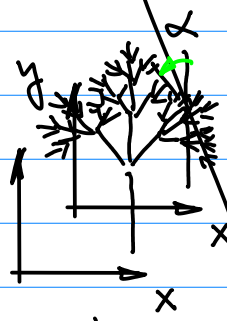


Fig. 5b. Virtual Display

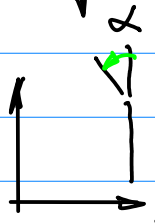


Fig. 5c. Rotation by α. CCW.

Mapping: Preprocessing — Translation. ϕ_2 "M" matrix. $T_{3\times3}$

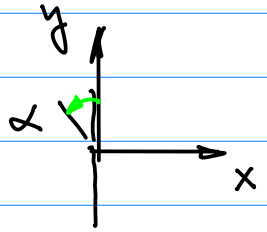
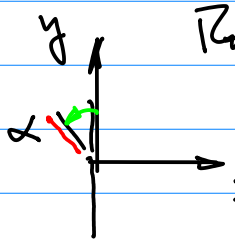


Fig. 5d. Preprocessing By Translation.

Rotation Eqn. (2).



Rotation: ϕ_3 $R_{3\times3}$

Fig. 5e. Rotation: Done

Post Processing. To "move Back" to its original Position.

ϕ_4 undo preprocessing $\phi_4 = \phi_2^{-1}$ or.

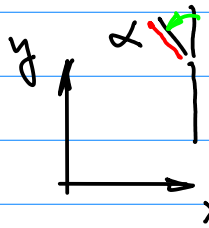


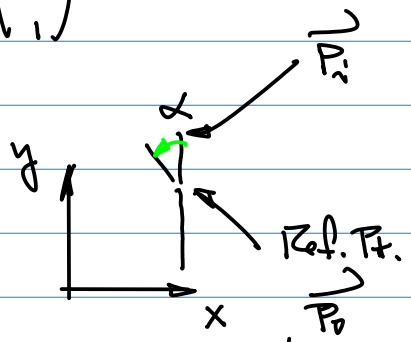
Fig. 5f.

$$\phi_4 = \phi_2\Big|_{\phi_2 = T_{3\times3}} = T_{3\times3}^{-1} \quad \ldots (3)$$

Based on Step by step Analysis.
(Analyze "Before" and "After" Relationship).

Start at given pt. to Be Rotated

$$\vec{P}_i = \begin{pmatrix} x_i \\ y_i \\ 1 \end{pmatrix} \quad \ldots (4)$$



Next. Preprocessing ϕ_2, $T_{3\times3}$

To make $\vec{P}_0(x_0, y_0)$ to overlap with the origin $(0,0)$.

$$T_{3\times3} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ 0 & 0 & 1 \end{pmatrix} \quad \ldots (5)$$

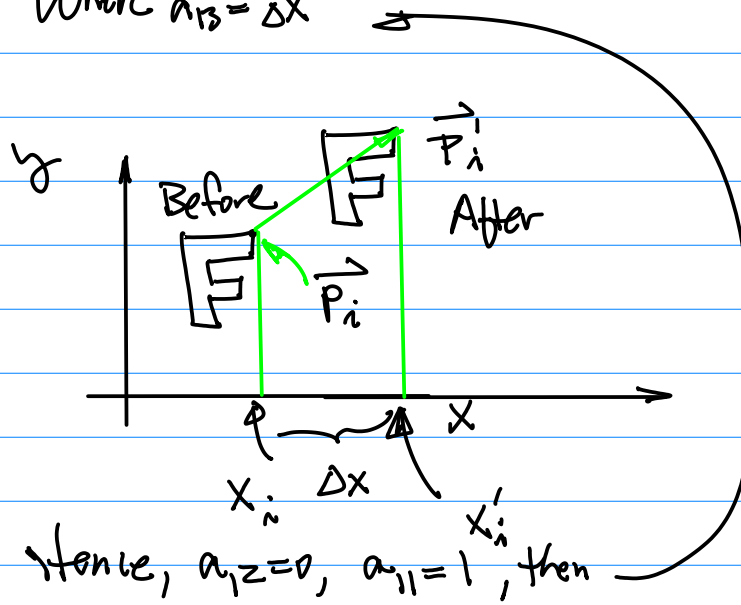
$$\begin{pmatrix} x_i' \\ y_i' \\ 1 \end{pmatrix} = T_{3\times3} \begin{pmatrix} x_i \\ y_i \\ 1 \end{pmatrix} \quad \ldots (6)$$

P_i' After — Before

$$= \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ 0 & 0 & 1 \end{pmatrix}$$

$$x_i' = a_{11}x_i + a_{12}y_i + a_{13}\cdot 1 \quad \ldots (6b)$$

Where $a_{13} = \Delta X$



Hence, $a_{12}=0$, $a_{11}=1$, then

So

$$x_i' = x_i + 0 + \Delta X = x_i + \Delta X \quad \ldots (6c)$$

$$y_i' = y_i + \Delta Y \quad \ldots (6d)$$

Therefore

$$T_{3\times3} = \begin{pmatrix} 1 & 0 & \Delta X \\ 0 & 1 & \Delta Y \\ 0 & 0 & 1 \end{pmatrix} \quad \ldots (7).$$

Note: $\Delta X = -(x_i - x_0)$,

$\Delta Y = -(y_i - y_0)$.

in Our Fig 5. Series.

Now, Rotation, $R_{3\times3}$.

Then, Post Processing. ϕ_4

$$M_{\phi_3} = T_{3\times3}^{-1} = \begin{pmatrix} 1 & 0 & -\Delta X \\ 0 & 1 & -\Delta Y \\ 0 & 0 & 1 \end{pmatrix} \quad \ldots (8)$$

CmpE240
Sept.26, 22

Put All these together, we have

$$\begin{pmatrix} x_i'' \\ y_i'' \\ 1 \end{pmatrix} = T_{3\times3}^{-1} R_{3\times3} T_{3\times3} \begin{pmatrix} x_i \\ y_i \\ 1 \end{pmatrix} \quad \dots (9)$$

Rotated Post-Processed point.

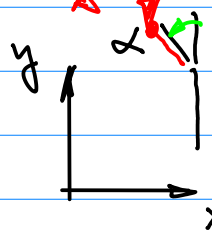


Fig.7

Step by step Derivation is also provided at the Lecture Notes.

$XL[i] = \cos\alpha * X[i] - \sin\alpha * y[i] + \Delta x \cos\alpha - \Delta y \sin\alpha - \Delta x$

Similarly for y_L,

delta_x

$YL[i] = \sin\alpha * X[i] + \cos\alpha * y[i] + \Delta x \sin\alpha + \Delta y \cos\alpha - \Delta y$

Note: Work on Virtual to physical mapping

delta_y

Sept.28 Wed.

Note: Conclusion on 2D Transforms is given in the Above Eqn.(9), Coding/Implementation in C/C++.

Composition of

$$\begin{pmatrix} x_i'' \\ y_i'' \\ 1 \end{pmatrix} = \overbrace{T_{3\times3}^{-1} R_{3\times3} T_{3\times3}}^{T_\Sigma} \begin{pmatrix} x_i \\ y_i \\ 1 \end{pmatrix}$$

T_Σ is 3x3 matrix

Last Row of $T_{\Sigma(3\times3)}$ is (0,0,1) No Need for Coding.

Only the top 2 Rows from the matrix matter.

Notation is introduced to Keep track if the new point is generated By CCW or CW

$\vec{P_i}$ ← Load

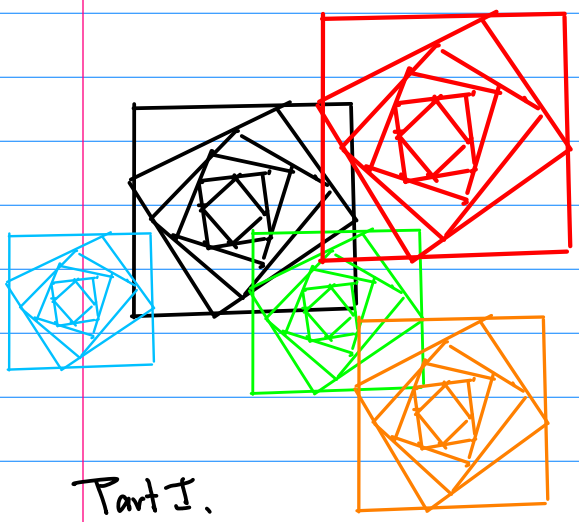
i ← Enumeration of the Points.

$\vec{P_{i,l}}$ or $\vec{P_{i,r}}$

(l - left - CCW, r - Right - CW)

1st project, 2D Graphics Engine

2D Graphics Screen Saver a collection of Rotating Squares.



Part I.

Fig. 1

(Level 10 or higher)

Interface Between the LPC1769 and LCD is By S.P.I (Serial Peripheral Interface)

LPC1769 CPU — LCD

Part II. Trees. Optional for Artistic Presentation.

Fig. 2

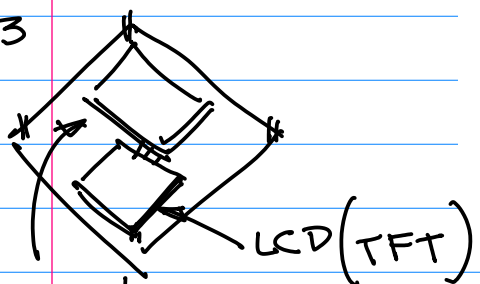
"3+1" pins for S.P.I.

1. MOSI Output
2. MISO Input
3. SCK (Clock) Output
4. SSEL (CS) Output

Now, consider LPC1769, CPU Datasheet pp451. CRΦ 2021F-107b-sch-#LPC...

Consider the Graphics Engine Design from System View.

Fig. 3



LPC1769 or LPC11C24

Thin Film Transistor Technology

NXP Semiconductors — UM10360

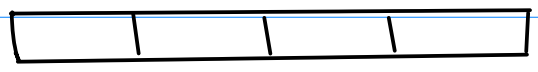
a. SSP → Chapter 18: LPC176x/5x SSP0/1

b. CRΦ, CR1 → Table 371: SSPn Control Register 0 (SSP0CR0 - address 0x4008 8000 SSP1CR0 - 0x4003 0000) bit description

Bit	Symbol	Value	Description	Reset Value
3:0	DSS		Data Size Select. This field controls the number of bits transferred in each frame. Values 0000-0010 are not supported and should not be used.	0000
		0011	4-bit transfer	

(SSP0CR0)

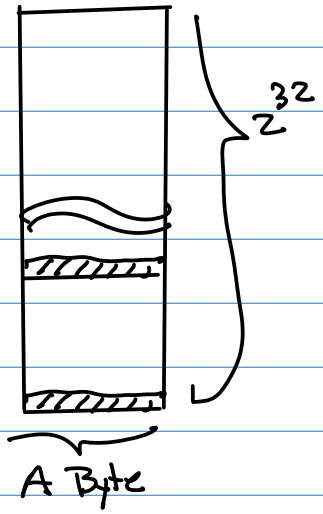
CRΦ



Addr. 0x4008_0000

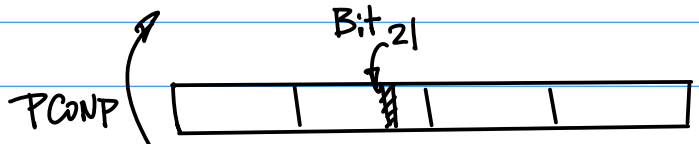
CMPE240

21



Find its memory Location at Which memory Bank?

20	-	Reserved.
21	PCSSP0	The SSP0 interface power/clock control bit.
22	PCTIM2	Timer 2 power/clock control bit.



Oct.5 (Wed)

Example: SPR (for SSP/SPI) CR0.

Note: 2nd STR: PCLKSEL

a. PCONP, Naming Convention "LPC_SC->PCONP"
Source Code from DrawLine~ (github)

```
147 ** parameters:          None
148 ** Returned value:     None
149 **
150 *****************************************************
151 void SSP0Init( void )
152 {
153   uint8_t i, Dummy=Dummy;
154
155   /* Enable AHB clock to the SSP0. */
156   LPC_SC->PCONP |= (0x1<<21);
157
158   /* Further divider is needed on SSP0 clock.
159   LPC_SC->PCLKSEL1 &= ~(0x3<<10);
160
```

Note: Bitwise op to just (only) set Bit 21

TP.58, Table 41

b. CPU Datasheet, for PCONP.
C. Code (15b)

RTC interrupt is generated.

4.8.9 Power Control for Peripherals register (PCONP - 0x400F C0C4)

The PCONP register allows turning off selected peripheral functions for the purpose of saving power. This is accomplished by gating off the clock source to the specified peripheral blocks. A few peripheral functions cannot be turned off (i.e. the Watchdog timer, the Pin Connect block, and the System Control block).

CMPE240
Oct. 5th, 12

Table 41. Peripheral Clock Selection register 1 (PCLKSEL1 - address description

Bit	Symbol	Description
1:0	PCLK_QEI	Peripheral clock selection for the Quadrature E Interface.
3:2	PCLK_GPIOINT	Peripheral clock selection for GPIO interrupts.
5:4	PCLK_PCB	Peripheral clock selection for the Pin Connect
7:6	PCLK_I2C1	Peripheral clock selection for I2C1.
9:8	-	Reserved.
11:10	PCLK_SSP0	Peripheral clock selection for SSP0.
13:12	PCLK_TIMER2	Peripheral clock selection for TIMER2.

Note: PINSEL

```
161  /* P0.15~0.18 as SSP0 */
162  LPC_PINCON->PINSEL0 &= ~(0x3UL<<30);
163  LPC_PINCON->PINSEL0 |= (0x2UL<<30);
164  LPC_PINCON->PINSEL1 &= ~((0x3<<0)|(0x3<<2)|(0x3<<4));
165  LPC_PINCON->PINSEL1 |= ((0x2<<0)|(0x2<<2)|(0x2<<4));
166
```

pp117.

8.5.1 Pin Function Select register 0 (PINSEL0 - 0x4002 C000)

The PINSEL0 register controls the functions of the lower half of Port 0. The direction control bit in FIO0DIR register is effective only when the GPIO function is selected f pin. For other functions, the direction is controlled automatically.

Table 80. Pin function select register 0 (PINSEL0 - address 0x4002 C000) bit descripti

PINSEL0	Pin name	Function when 00	Function when 01	Function when 10	Function when 11	R v
1:0	P0.0	GPIO Port 0.0	RD1	TXD3	SDA1	0
3:2	P0.1	GPIO Port 0.1	TD1	RXD3	SCL1	0
5:4	P0.2	GPIO Port 0.2	TXD0	AD0.7	Reserved	0
7:6	P0.3	GPIO Port 0.3	RXD0	AD0.6	Reserved	0
9:8	P0.4[1]	GPIO Port 0.4	I2SRX_CLK	RD2	CAP2.0	0
11:10	P0.5[1]	GPIO Port 0.5	I2SRX_WS	TD2	CAP2.1	0
13:12	P0.6	GPIO Port 0.6	I2SRX_SDA	SSEL1	MAT2.0	0
15:14	P0.7	GPIO Port 0.7	I2STX_CLK	SCK1	MAT2.1	0
17:16	P0.8	GPIO Port 0.8	I2STX_WS	MISO1	MAT2.2	0
19:18	P0.9	GPIO Port 0.9	I2STX_SDA	MOSI1	MAT2.3	0
21:20	P0.10	GPIO Port 0.10	TXD2	SDA2	MAT3.0	0

(1) (2)

a pin. For other functions the direction is controlled automatically.

Table 81. Pin function select register 1 (PINSEL1 - address 0x4002 C004) bit description

PINSEL1	Pin name	Function when 00	Function when 01	Function when 10	Function when 11
1:0	P0.16	GPIO Port 0.16	RXD1	SSEL0	SSEL
3:2	P0.17	GPIO Port 0.17	CTS1	MISO0	MISO
5:4	P0.18	GPIO Port 0.18	DCD1	MOSI0	MOSI
7:6	P0.19[1]	GPIO Port 0.19	DSR1	Reserved	SDA1
9:8	P0.20[1]	GPIO Port 0.20	DTR1	Reserved	SCL1

Note: FIODIR (Direction, e.g. Input/Output is defined)

```
167 #if !USE_CS
168   LPC_PINCON->PINSEL1 &= ~(0x3<<0);
169   LPC_GPIO0->FIODIR |= (0x1<<16);       /* P0.16 defined as GPIO and Outputs */
170 #endif
```

Note: a. Code → Tech. Spec. (Interpretation)

```
172   /* Set DSS data to 8-bit, Frame format SPI, CPOL = 0, CPHA = 0, and SCR is 15 */
173   LPC_SSP0->CR0 = 0x0707;
```

0000 : 0111 : 0000 : 0111

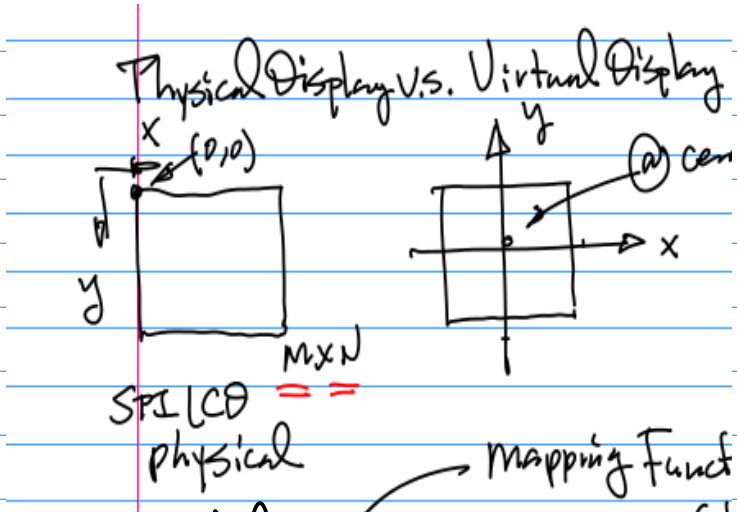
SCR | SPI | 8 bit

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

Consider Display Device Interface.

Background: Low Level Design of GUI
↓ Hardware Driver Design.
Physical Display v.s. Virtual Display.

Example: Physical Display v.s. Virtual Display.
pp 19. from Ref.
(github. Notes ~105~)



CMPE240

Oct.10, 22

$$x_p = x_v + M/2 \quad \cdots(7)$$

{ a Direction
{ b Offset

$$y_p \stackrel{?}{=} -y_v + \frac{N}{2} \quad \cdots(8)$$

(half of the No. of Rows)

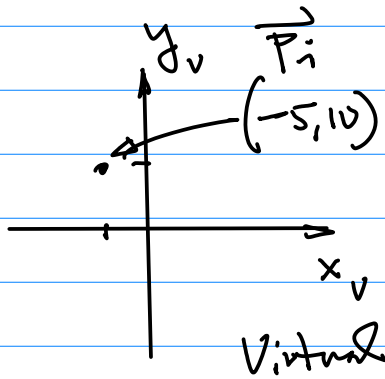


Fig 1. Virtual Display.

$$\begin{cases} x_p = x_v + M/2 & \cdots(7) \\ y_p = -y_v + N/2 & \cdots(8) \end{cases}$$

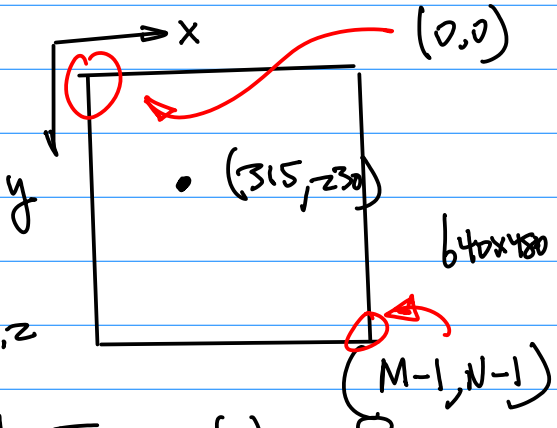


Fig.2

Oct.10 (Monday) Due Oct.17th (Monday)

Homework: In-Class Demo. 1 pt.

Requirements: 1. Prototype Board with LCD Display. 2. Execution of 2D Graphics Processing (2D Screen Savers And/OR Trees).

Example: Suppose we have a design which gives $\vec{P_i}(x_i, y_i) = (-5, 10)$ in the virtual Coordinate System.

Given: 1. Physical Display with Resolution MxN (640x480),

Find the New point $\vec{P_i}(x_i', y_i')$ After the transformation from the Virtual Display to the physical Display.

Sol: From Eqn(7) we have

$$x_p = x_v + M/2 \Big|_{M=640} = x_v + 640/2 = x_v + 320$$

Where we have $x_v = -5$, so

$$x_p = x_v + 320 = -5 + 320 = 315 ;$$

For y_p from Eqn(8).

$$y_p = -y_v + N/2 \Big|_{N=480} = -y_v + 480/2 = -y_v + 240$$

$y_v = 10$, hence,

$$y_p = -10 + 240 = 230 . //$$

Now, Consider the Design of Display Driver (Hardware)

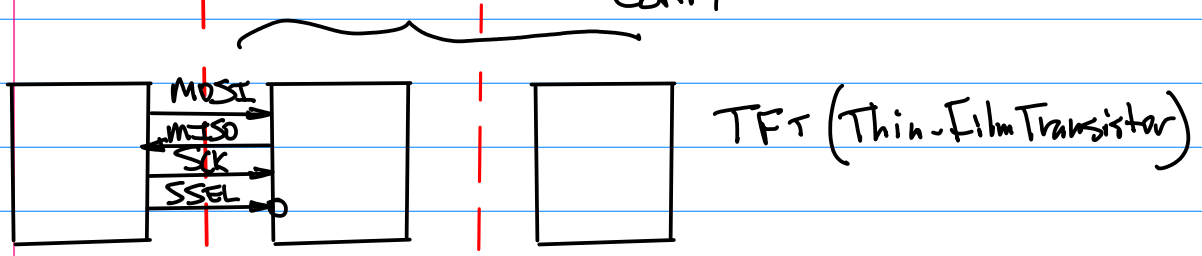
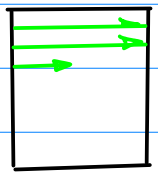


Fig.3

2nd LPC1769 For Example
(Not most Cost Effective Solution)

The Hardware Features of T.F.T. Display:

1. Sync. Signals
   - ① Frame Sync. Example: 30 F.P.S. $\text{Sync.}_F \rightarrow f_F = 30\,\text{Hz}$ ... (1)
   - ② Horizontal Sync. for M x N Resolution, it Repeats N Times Per frame.
   - ③ Data Sync. (Pixel) for M x N Resolution, Per Each Line, it Repeats M



Time to Scan Each Row is determined by Horizontal Sync.

M x N

2. Data Bus (Bi-Directional): 24 bits or Higher, 32 Bits Common
3. Control Signals. { Backlight, Enable }

Note: Design Hardware Counter, Counts by N. PCLK $\rightarrow \text{Sync.}_F$

Consider the Relationships Between Sync_F & Sync_H, Denoted as f_H

$$f_H = N \cdot f_F \quad \cdots (2a)$$

$$\text{Sync}_H = N \cdot \text{Sync.}_F \quad \cdots (2b)$$

Consider $Sync._D$ V.S. $Sync._H$.

$f_D = m \cdot f_H$ ... (3a)

$Sync_D = M \cdot Sync_H$ ... (3b) M: No. of Cols.

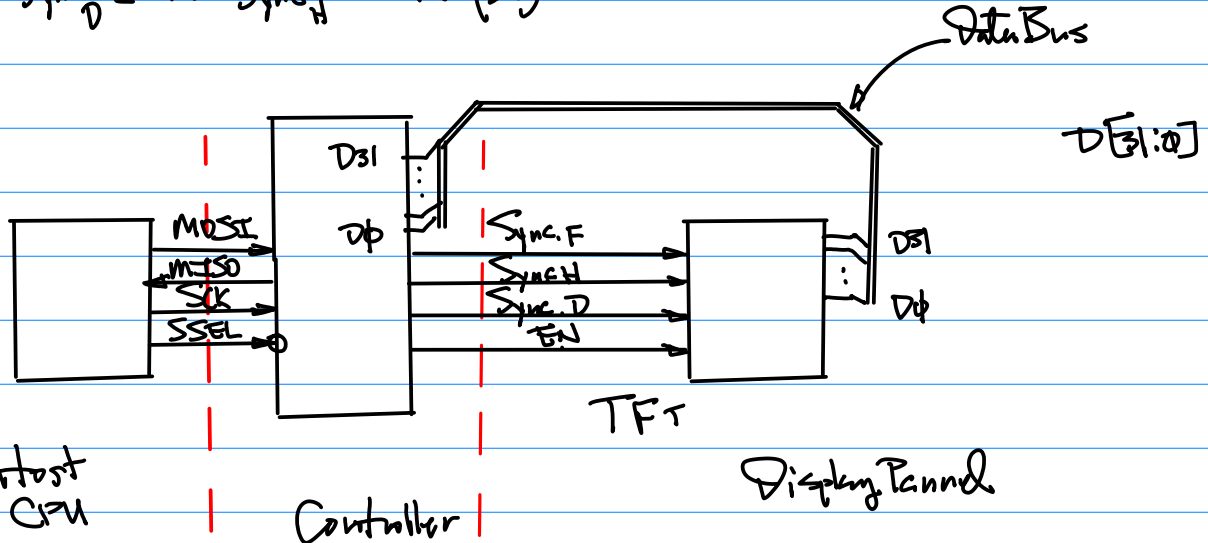
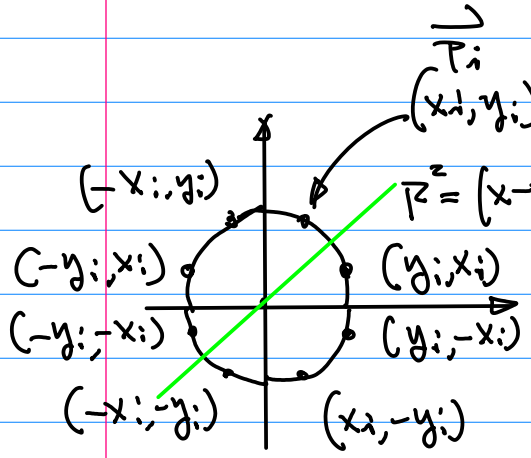


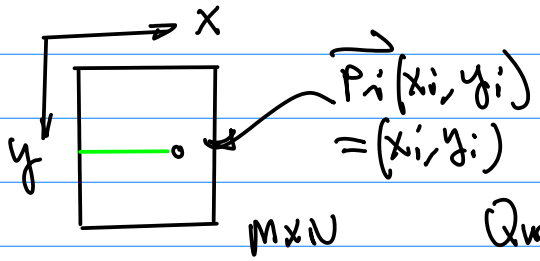
Fig.4



$r^2 = (x-x_0)^2 + (y-y_0)^2 \rightarrow r^2 = x^2 + y^2 \rightarrow$ Symmetric Property.

Oct. 12 (Wed)

Example:



Calculate the location information Based on Timing ($Sync._F$, $Sync._H$, $Sync._D$)

Assume Frame Rate 30FPS.

Question: How much time does it take for the Scanning to Reach line $y_i - 1$

$T_H = 1/Sync_H$ ... (1)

And $T = (y_i - 1) T_H \Big|_{T_H = 1/Sync_H}$

$= (y_i - 1)/Sync_H$ ... (2)

From this line at col = 0 Location, we start counting the time Needed to get ready to plot the pixel

$T_D = 1/Sync_D$ ... (3)

$Sync_D = M\, Sync_H$

So

$T' = (x_i - 1) T_D = (x_i - 1)/M Sync_H$

... (4)

Hence

$T_\Sigma = T + T'$

$= (y_i - 1)/Sync_H + (x_i - 1)/(M Sync_H)$

... (5)

3. Vector Graphics Manipulation

$\vec{P}(x,y) = \vec{P}_i(x_i, y_i) + \lambda(\vec{P}_{i+1}(x_{i+1}, y_{i+1}) - \vec{P}_i(x_i, y_i))$

4. Primitive Graphics Basic Building Blocks.

Line Segment, Arcs (circle), Ellipses etc.

No multiplication

$y = ax + b$

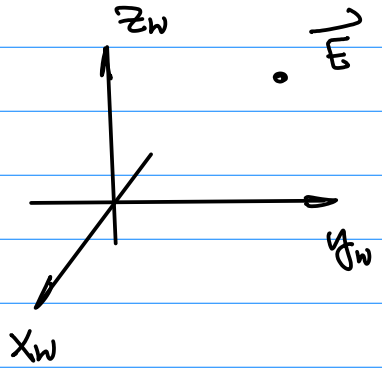
No. Sqrt Computation

$R^2 = (x - x_0)^2 + (y - y_0)^2$

Consider 3D G.E. (Graphics Engine Design).

Ref. github/hnalli/cmpe240 ...

...note.. May... Fig.1.



World Coordinate System.

RH: Right-Hand System Defined By Vector Cross Product

$\vec{X_W i} \times \vec{Y_W j}$

In Summary: 2D G.E. Design.

1. Display Driver
   - Architectural Design
   - Timing Analysis
     - $Sync_F$
     - $Sync_H$
     - $Sync_D$
2. 2D Transforms.
   - Translation
   - Rotation
   - Composition of the Above

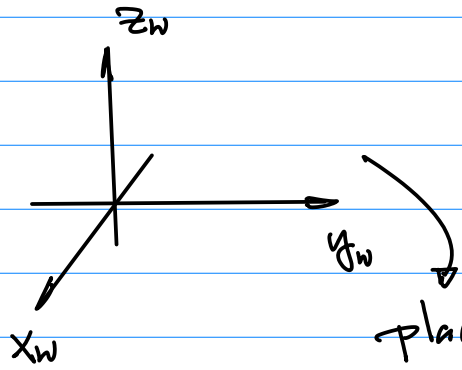


Fig.2

place A virtual Camera @ $\vec{E}(x_e, y_e, z_e)$

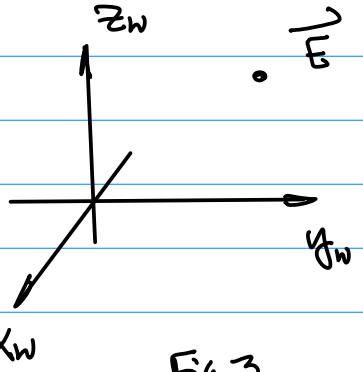


Fig.3

"pin-Hole" Camera for its simplicity. its properties include:

1° An Enclosure, and a pin-Hole, and projection plane.

2° Only light reaches the projection plane is the light passing Through the pin-Hole.

3° The Camera is always Looking Towards the origin of the X_w-Y_w-Z_w System.

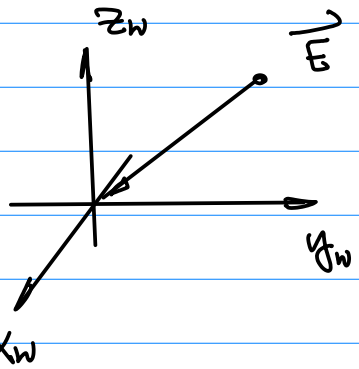


Fig.4

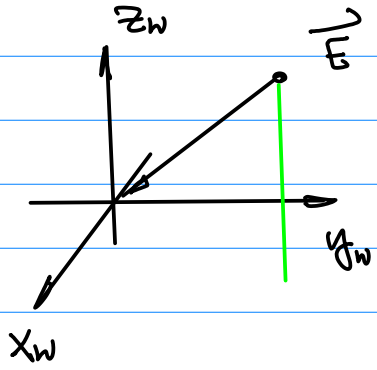


Fig.5

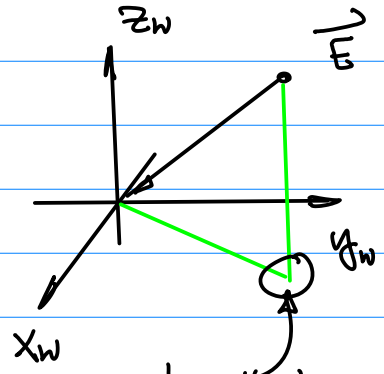


Fig.6

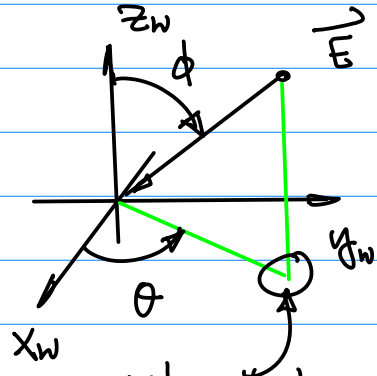


Fig.7

Angle θ: ON X_w-Y_w plane C.C.W as a Positive Angle

Angle ϕ: Formed By $\vec{E}$ and z_w Axis.

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

$\rho = \sqrt{x_e^2 + y_e^2 + z_e}$

Oct. 17 (Monday).

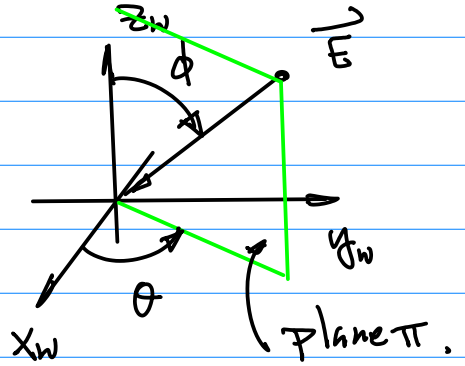


Fig. 8

Example: Perspective Projection.

Projection of 3D objects onto 2D plane.

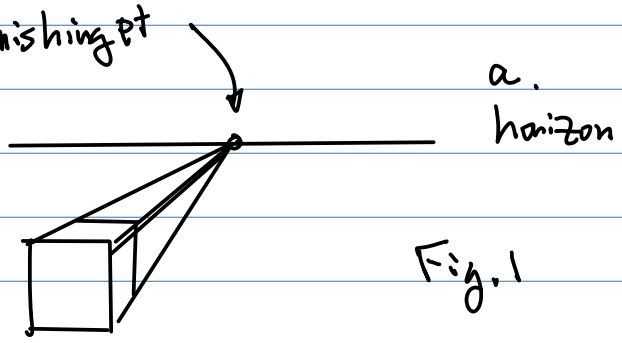


Fig. 1

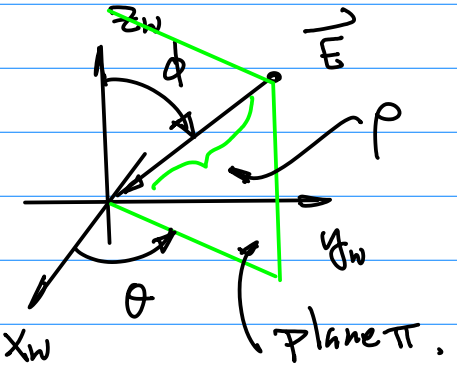


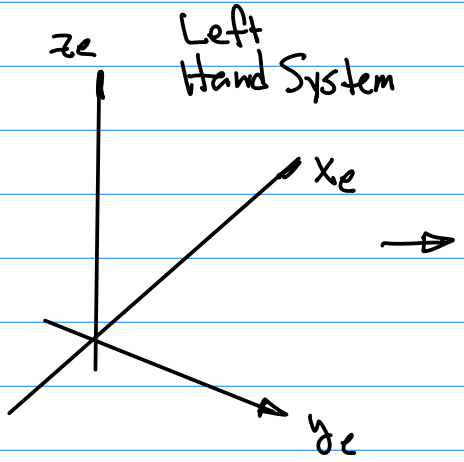
Fig. 9

c. Object $\{\vec{P_i} \mid i = 0, 1, 2, \ldots, N-1\}$, Connect Each pt $\vec{P_i}$ to the Vanishing pt.

d. Use Parallel plane to Cut the Vector lines, to form a 3D object.

Let's consider the Viewer Coordinate

X_v-y_v-z_v



Re-Arrange it

Add Projection plane

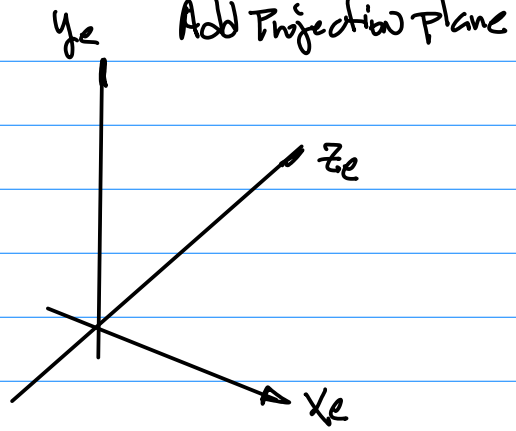
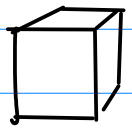


Fig. 10

CmpE240

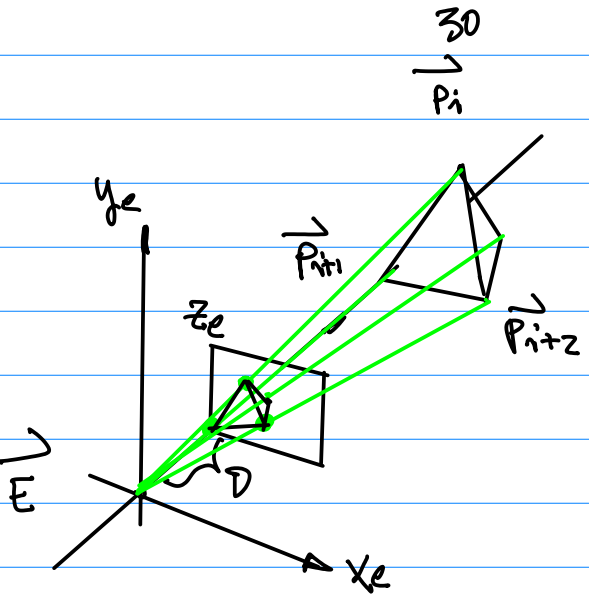
Oct.17,22



Perspective projection.

Fig.2.

Note: The X_v-Y_v-Z_v System, Virtual Camera.



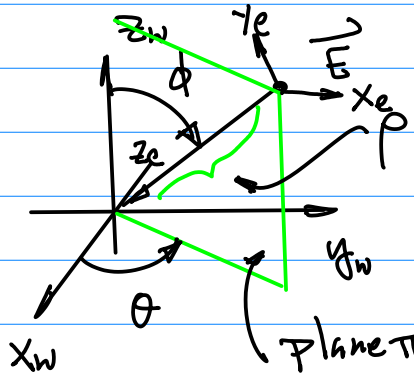


Fig.3

Transformation pipeline: X_w-Y_w-Z_w to X_v-Y_v-Z_v World 2 Viewer

Perspective Projection

X_w-Y_w-Z_w → X_v-Y_v-Z_v → P.P.

$\vec{P_i}(x_i, y_i, z_i)$ → $\vec{P_i'}(x_i', y_i', z_i')$ → $\vec{P_i''}(x_i'', y_i'', D)$ In Viewer

Drop D in Z so 3D with "Depth".

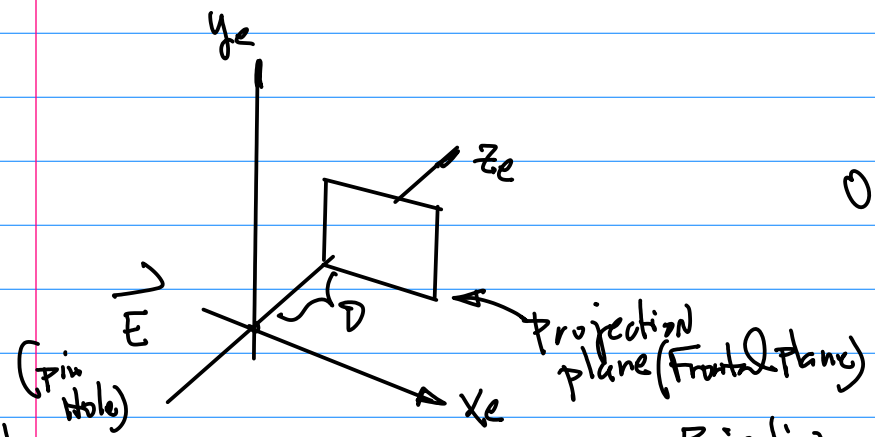
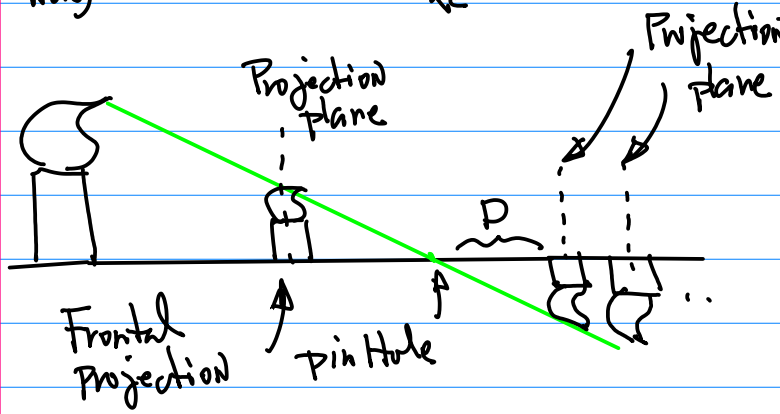


Fig.4



Oct.19(W)

Note:

1° Midterm Scheduled on Nov.7 (Monday).

Homework: Due One Week from Today. and a half Oct.30. 11:59 PM.

1° Build (Implement C-Code on the Transformation Pipeline in the target platform.

2°. Build (Plot) X_w-Y_w-Z_w

Step 1.

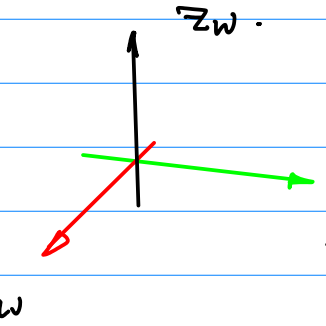


Fig. 1.

① Make $\theta \in [20, 50]$;

② Length of Each axis = 50 ~ 100

③ $\vec{E}(x_e, y_e, z_e) = (200, 200, 200)$

Vectors for X_w, Y_w, Z_w.

for example Starting pt (0,0,0)
Ending pt (100,0,0)
for X_w-axis

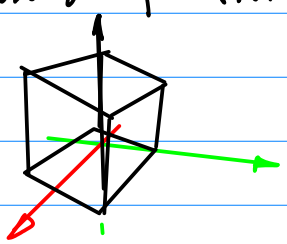
Note: Make sure the implementation of Virtual to physical Display is ready. (Eqn (7) & (8) in the previous Lecture Note).

Step 2. Design A Data set for a Cube.

$$\{\vec{P_i}(x_i, y_i, z_i) \mid i = 0, 1, 2, \cdots, N-1\} \quad \cdots (1)$$

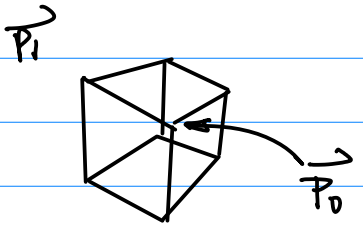
a. With Size as 100 x 100 x 100 as illustrated Below

b. And elevated By 10 from X_w-Y_w plane



Pick An Arbitrary point $\vec{P_0}$

$\vec{P_0}(x_0, y_0, z_0) = (100, 100, 110)$

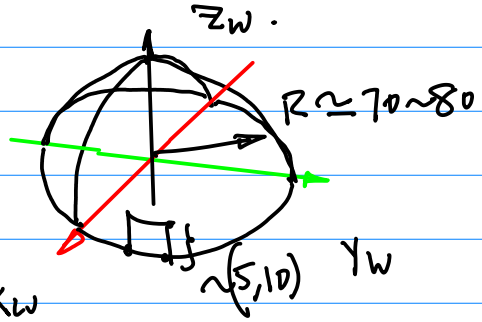


$\vec{P_1}(x_1, y_1, z_1) = (0, 0, 110)$, etc.

Displaying the Cube.

Step 3.

a. $R \simeq 80$



b. Size of the upper part = 80. (from R).

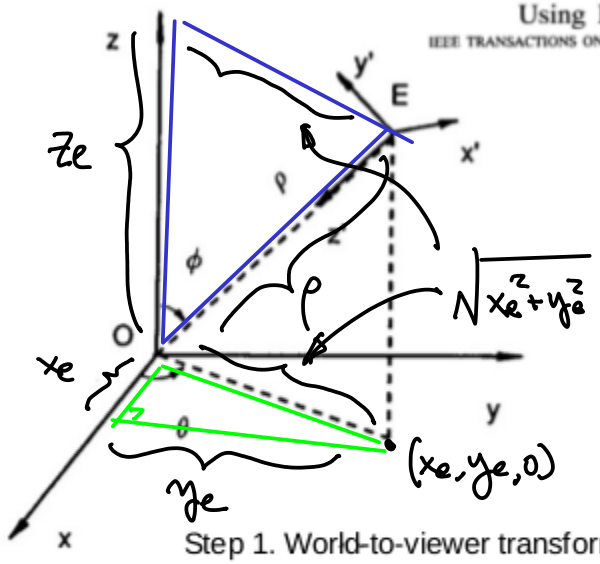
Note: Do Each "Ring", with Different R, then add Z value.

$$R^2 = \sqrt{(x - x_0)^2 + (y - y_0)^2} \quad \Big| \; x_0 = y_0 = 0$$

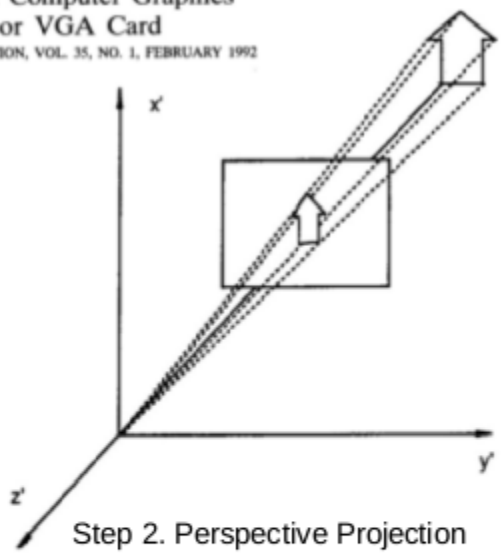
R_i for $i = 1, 2, \cdots, 8$.

2018F-114-lec-3D-vectors-v3-2018-10-26.pdf

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

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

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

Harry Li, Ph.D.

Points in X_W-Y_W-Z_W : $\vec{P_i}(x_i, y_i, z_i)$
" in X_V-Y_V-Z_V : $\vec{P_i'}(x_i', y_i', z_i')$
Points After Perspective Projection
$\vec{P_i''}(x_i'', y_i'')$

$$\rho = \sqrt{x_e^2 + y_e^2 + z_e^2}$$

Oct. 24 (Mon).
Continued from The Transformation Pipeline.
Example:

After

$$\begin{pmatrix} x_i' \\ y_i' \\ z_i' \\ 1 \end{pmatrix} = \begin{bmatrix} -\sin\theta & \cos\theta & 0 & 0 \\ -\cos\phi\cos\theta & -\cos\phi\sin\theta & \sin\phi & 0 \\ -\sin\phi\cos\theta & -\sin\phi\cos\theta & -\cos\phi & \rho \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{pmatrix} x_i \\ y_i \\ z_i \\ 1 \end{pmatrix}$$

Before

$x_i' = -\sin\theta \cdot x_i + \cos\theta \cdot y_i$ (X_prim[i] = -sin(theta) * X[i] + cos(Theta) * y[i];) ... (1)

$y_i' = -\sin\phi\cos\theta\, x_i - \cos\phi\sin\theta\, y_i + \sin\phi\, z_i$ ... (2)

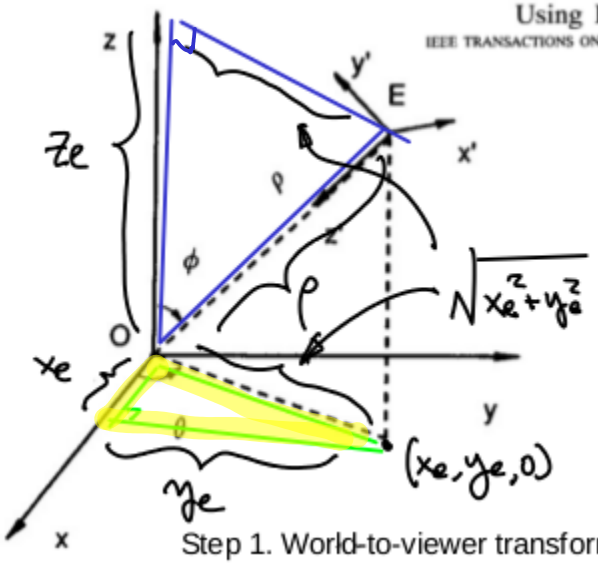
$$z_i' = -\sin\phi\cos\theta\, x_i - \sin\phi\cos\theta\, y_i - \cos\phi\, z_i + \rho \quad \dots (3)$$

C-code can be derived accordingly. Similar to Eqn (1)

Assume $E(x_e, y_e, z_e) = (200, 200, 200)$

Find $\cos\theta = \dfrac{x_e}{\sqrt{x_e^2 + y_e^2}} = \dfrac{200}{\sqrt{200^2 + 200^2}} = \dfrac{1}{\sqrt{2}} = \dfrac{\sqrt{2}}{2}$

Reference: H. Li Three-Dimensio
Using EG
IEEE TRANSACTIONS ON ED



Step 1. World-to-viewer transform

Find $\sin\theta = \dfrac{y_e}{\sqrt{x_e^2 + y_e^2}} = \dfrac{200}{\sqrt{200^2 + 200^2}} = \dfrac{1}{\sqrt{2}} = \dfrac{\sqrt{2}}{2}$

Now, for $\cos\phi$ (Blue Triangle)

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

$$= \frac{200}{\sqrt{200^2 + 200^2 + 200^2}} = \frac{1}{\sqrt{3}} = \frac{\sqrt{3}}{3}$$

$$\sin\phi = \frac{\sqrt{x_e^2 + y_e^2}}{\sqrt{x_e^2 + y_e^2 + z_e^2}} =$$

$$= \frac{200\sqrt{2}}{200\sqrt{3}} = \frac{\sqrt{2}\cdot\sqrt{3}}{3}$$

CmpE240

Oct. 24, 22

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

a. $\begin{bmatrix} - & & \\ - & - & \\ - & - & - \end{bmatrix}$ b. for θ $\begin{bmatrix} S & C & \\ C & S & \\ C & C & \end{bmatrix}$

c. for ϕ $\begin{bmatrix} C & C & S & \\ S & S & C & \rho \end{bmatrix}$

Example: Perspective Projection

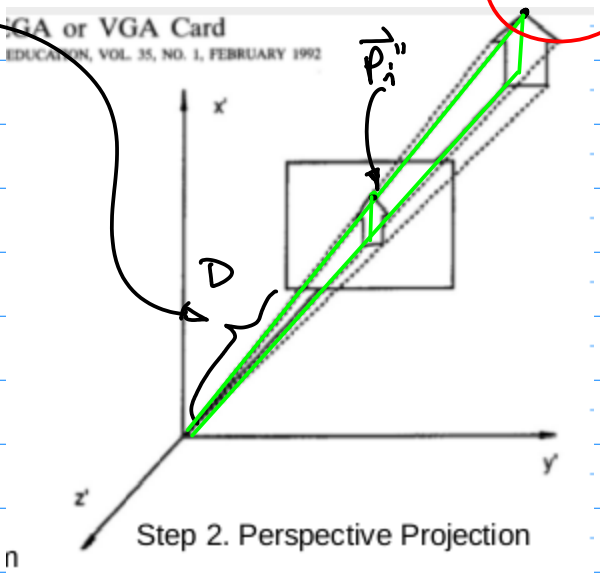
$$x_p = x_e\left(\frac{D}{z_e}\right)$$
$$y_p = y_e\left(\frac{D}{z_e}\right)$$

Mapping Before (In X_v-Y_v-Z_v) Virtual Camera Coordinate, and After (In 2D Display Space);

Note: $\frac{x_i'}{x_i''} = \frac{y_i'}{y_i''} = \frac{z_i'}{z_i''}$, z_i'' = D

Due to the Similar Triangle (see Fig.1) In Green.

$\frac{D}{z_e}$:



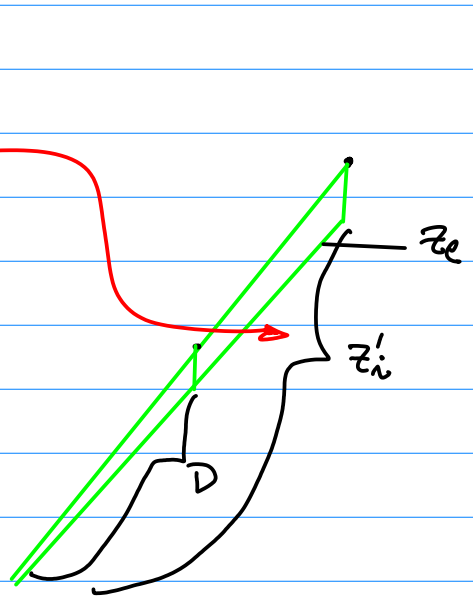
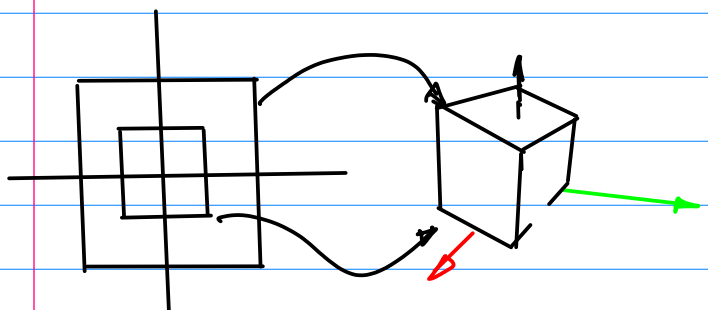


Fig.1.

CmPE240

Oct.24,22



2018F-118-13diffuseInterpolation20181127...

Ref: Sample code.

$\vec{E}(xe, ye, ze)$

```
34  float Xe = 200.0f, Ye = 200.0f, Ze = 250.0f;  //virtual camera location
35  float Rho = sqrt(pow(Xe,2) + pow(Ye,2) + pow(Ze,2));
36  float D_focal = 100.0f;
```

ρ

D

Define Xw-Yw-Zw

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

```
127     //sin and cosine computation for world-to-viewer
128     float sPheta = Ye / sqrt(pow(Xe,2) + pow(Ye,2));
129     float cPheta = Xe / sqrt(pow(Xe,2) + pow(Ye,2));
130     float sPhi = sqrt(pow(Xe,2) + pow(Ye,2)) / Rho;
131     float cPhi = Ze / Rho;
```