# Today's Agenda

**Input and Interaction**

**Geometry**

# OpenGL Sources

OpenGL website

https://www.opengl.org/

# Event Types

**Window: resize, expose, iconify**

**Mouse: click one or more buttons**

**Motion: move mouse**

**Keyboard: press or release a key**

**Idle: nonevent**

- Define what should be done if no other event is in queue

# GLUT Callbacks

**GLUT recognizes a subset of the events recognized by any particular window system (Windows, X, Macintosh)**

- **`glutDisplayFunc`**
- **`glutMouseFunc`**
- **`glutReshapeFunc`**
- **`glutKeyboardFunc`**
- **`glutIdleFunc`**
- **`glutMotionFunc,`**
- **`glutPassiveMotionFunc`**

**These call back functions except the reshape require posting redisplays**

```
glutPostRedisplay();
```

# Using the Keyboard

```
glutKeyboardFunc(mykey)

glutKeyboardUpFunc(mykey)

void mykey(unsigned char key,int x, int y)
```

- Returns ASCII code of key depressed and mouse location

```
void mykey()
{
    if(key == ‘Q’ | key == ‘q’)
        exit(0);
}
```

# Handling Multiple Key Inputs

- **For ASCII character**

  Each key press of will trigger the key callback function
  - Use switch & case
  - Or use a buffer to store the key strokes

  buffer[key] = true

- **For Non ASCII character**
  - **Function keys** (e.g., F1) or directional keys (e.g. →)

  void glutSpecialFunc(void (*func)(int key, int x, int y));

  - **State modifier keys** (e.g., “Shift” and “Ctrl”)

    glutGetModifiers()

# Manage Multiple Windows

- Create a second window

```
uint id = glutCreateWindow("second window");
```

- Set the window as the current window for rendering

```
glutSetWindow(id);
```

- Each window can have its own call back functions

# Toolkits and Widgets

**Most window systems provide a toolkit or library of functions for building user interfaces that use special types of windows called *widgets***

**Widget sets include tools such as**

- Menus
- Slidebars
- Dials
- Input boxes

**But toolkits tend to be platform dependent**

**GLUT provides a few widgets including menus**

# Menus

**GLUT supports pop-up menus**

- A menu can have submenus

**Three steps**

- Define entries for the menu
- Define action for each menu item
  - Action carried out if entry selected
- Attach menu to a mouse button
- Register a callback function for each menu

# Defining a simple menu

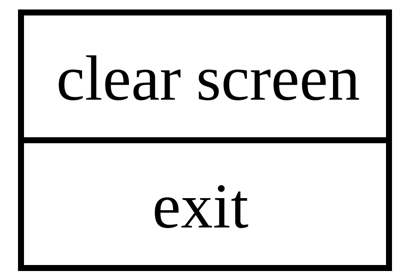
**In main.c**

used for parent menu

```
menu_id = glutCreateMenu(mymenu);
glutAddmenuEntry(“clear Screen”, 1);

gluAddMenuEntry(“exit”, 2);

glutAttachMenu(GLUT_RIGHT_BUTTON);
```




entries that appear when right button depressed

identifiers

# Menu Actions

- Menu callback

```
void mymenu(int id)
{
        if(id == 1) glClear();
        if(id == 2) exit(0);
}
```

- Add submenus by

```
glutAddSubMenu(char *submenu_name, submenu id)
```

entry in parent menu

**Note Menu is a deprecated feature and will not work for a core profile**

# Reading Assignments

**Chapter 2. of Angels et al**

**Chapter 2&3 Shreiner et al**

# Geometric Objects and Transformations

# Basic Elements

**Geometry is the study of the relationships among objects in an n-dimensional space**

- In computer graphics, we are interested in objects that exist in three dimensions

**Want a minimum set of primitives from which we can build more sophisticated objects**

**We will need three basic elements**

- Points ← represented by uppercase letters, e.g., P, Q
- Scalars ← represented by Greek letters, e.g., $\alpha,\beta$
- Vectors ← represented by lowercase letters, e.g., v,w

# Points

- Fundamental geometric object
- Associated with location
- No size & shape

# Scalars

Scalars can be defined as members of sets which can be combined by two operations (addition and multiplication) obeying some fundamental axioms (associativity, commutivity, inverses)

- Examples: the real and complex number systems

Scalars alone have no geometric properties

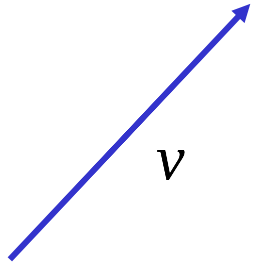
# Vectors

**Physical definition: a vector is a quantity with two attributes**

- Direction
- Magnitude

**Examples include**

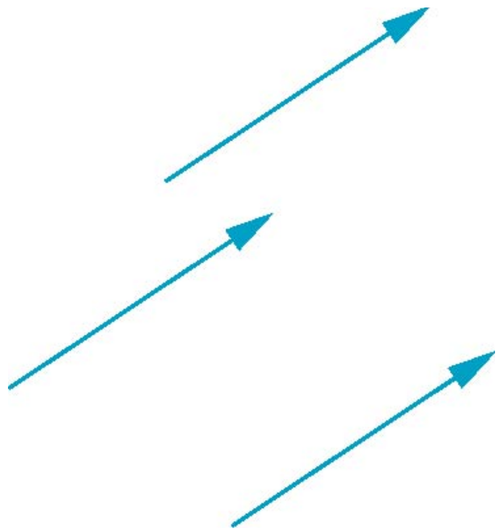
- Force
- Velocity
- Directed line segments
  - Most important example for graphics
  - Can map to other types



# Vectors Lack Position

**These vectors are identical**

- Same length and magnitude



**Vectors spaces insufficient for geometry**

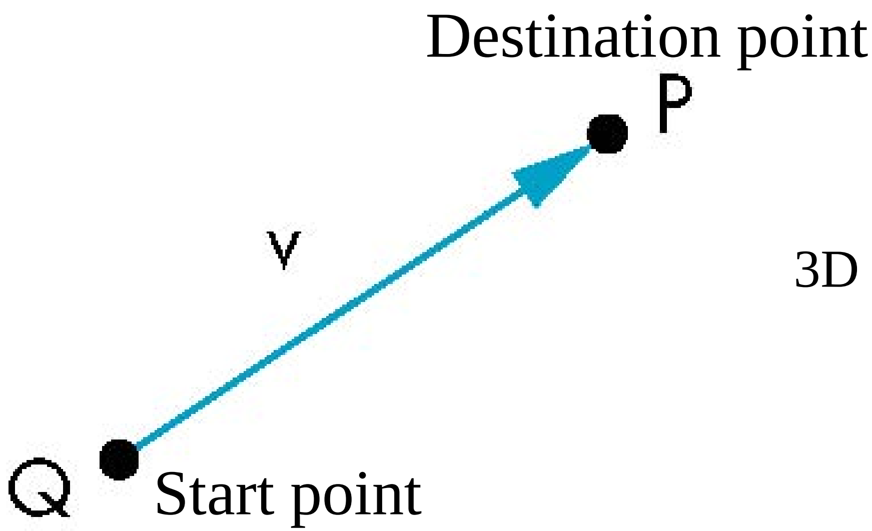
- Need points

# Point-Vector Addition/Subtraction

**Points define locations in space**

**Operations allowed between points and vectors**

- Point-point subtraction yields a vector
- Point-vector addition yields a new point




3D vector representing displacement

$$v = P - Q$$

3D vectors representing points

$$P = v + Q$$

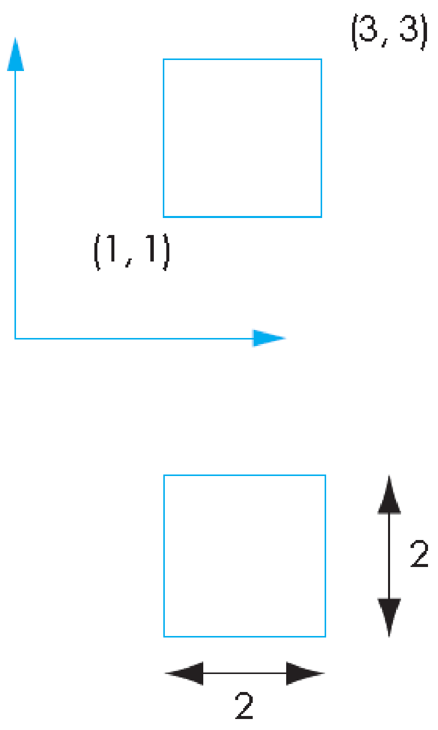
# Coordinate-Free Geometry

**When we learned simple geometry, most of us started with a Cartesian approach**

- Points were at locations in space **p**=(x,y,z)

**This approach was nonphysical**

- Physically, points exist regardless of the location of an arbitrary coordinate system
- Most geometric results are independent of the coordinate system
  - Example: two triangles are identical if two corresponding sides and the angle between them are identical



# Spaces

**(Linear) vector space: scalars and vectors**

**Affine space: vector space + points**

**Euclidean space: vector space + distance**

# Vector Operations

**Every vector has an inverse**

- Same magnitude but points in opposite direction

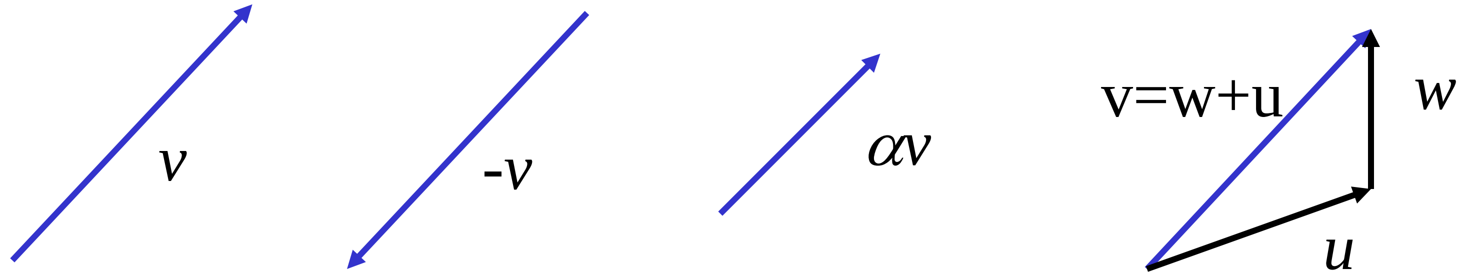
**Every vector can be multiplied by a scalar**

**There is a zero vector**

- Zero magnitude, undefined orientation

**The sum of any two vectors is a vector**

- Use head-to-tail axiom



# Linear Vector Spaces

**Mathematical system for manipulating vectors**

**Operations**

- Scalar-vector multiplication $u=\alpha v$
- Vector-vector addition: $w=u+v$

**Expressions such as**

$v=u+2w-3r$

**Make sense in a vector space**

# Linear Independence

A set of vectors $v_1, v_2, \ldots, v_n$ is *linearly independent* if

$$\alpha_1 v_1 + \alpha_2 v_2 + .. \alpha_n v_n = 0 \text{ iff } \alpha_1 = \alpha_2 = \ldots = 0$$

If a set of vectors is linearly independent, we cannot represent one in terms of the others

If a set of vectors is linearly dependent, at least one can be written in terms of the others

# Dimension, Basis, and Representation

**Dimension of the space:** the maximum number of linearly independent vectors

- Fixed for a space

In an *n*-dimensional space, any set of n linearly independent vectors form a *basis* for the space

The basis for the space is not unique!

Given a basis $v_1, v_2, \ldots, v_n$, any vector $v$ can be written as

$$v = \alpha_1 v_1 + \alpha_2 v_2 + \ldots + \alpha_n v_n$$

where the $\{\alpha_i\}$ are unique

# Changing Representation

**The same vector *v* can be represented differently given different bases**

For a basis $v_1, v_2, \ldots, v_n$, a vector $v$ can be written as

$$v = \alpha_1 v_1 + \alpha_2 v_2 + \ldots + \alpha_n v_n$$

For a different basis $v_1', v_2', \ldots, v_n'$, $v$ can be written as

$$v = \alpha_1' v_1' + \alpha_2' v_2' + \ldots + \alpha_n' v_n'$$

**Where**

$$\begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \vdots \\ \alpha_n \end{bmatrix} = \mathbf{M} \begin{bmatrix} \alpha_1' \\ \alpha_2' \\ \vdots \\ \alpha_n' \end{bmatrix}$$

# Affine Spaces

**Point + a vector space**

**Operations**

- Vector-vector addition
- Scalar-vector multiplication
- Scalar-scalar operations
- Point-vector addition
- Point-point addition
- Scalar-Point multiplication

} Affine sum

## For any point define

- $1 \cdot P = P$
- $0 \cdot P = \mathbf{0}$ (zero vector)

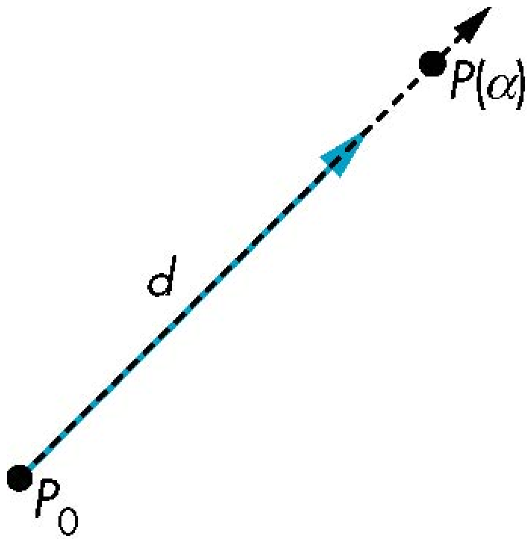
# Lines and Rays

**Consider all points of the form**

- $P(\alpha)=P_0 + \alpha\, \mathbf{d}$
- Set of all points that pass through $P_0$ in the direction of the vector $\mathbf{d}$
- If $\alpha >= 0$, then $P(\alpha)$ is the *ray* leaving $P_0$ in the direction $\mathbf{d}$

**This form is known as the parametric form of**

- More robust and general than other forms
- Extends to curves and surfaces



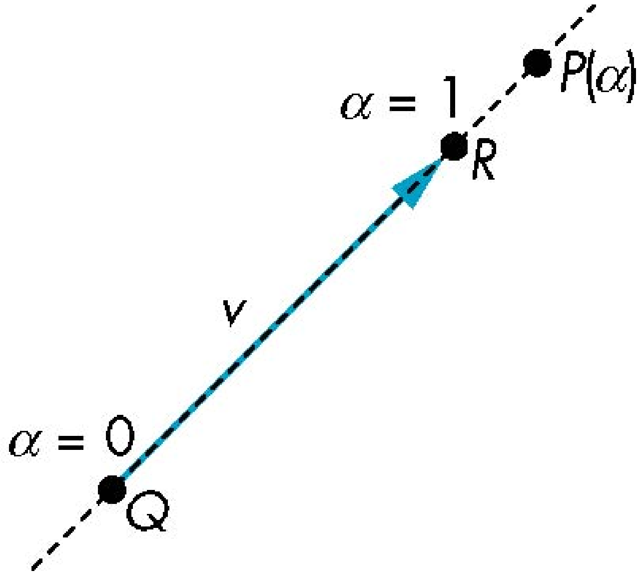
# Line Segments

**If we use two points to define v, then**

$$P(\boldsymbol{\alpha}) = Q + \boldsymbol{\alpha} v = Q + \boldsymbol{\alpha}(R - Q) = \boldsymbol{\alpha} R + (1 - \boldsymbol{\alpha})Q$$

**For $0 \leq \boldsymbol{\alpha} \leq 1$ we get all the points on the *line segment***

**joining R and Q**



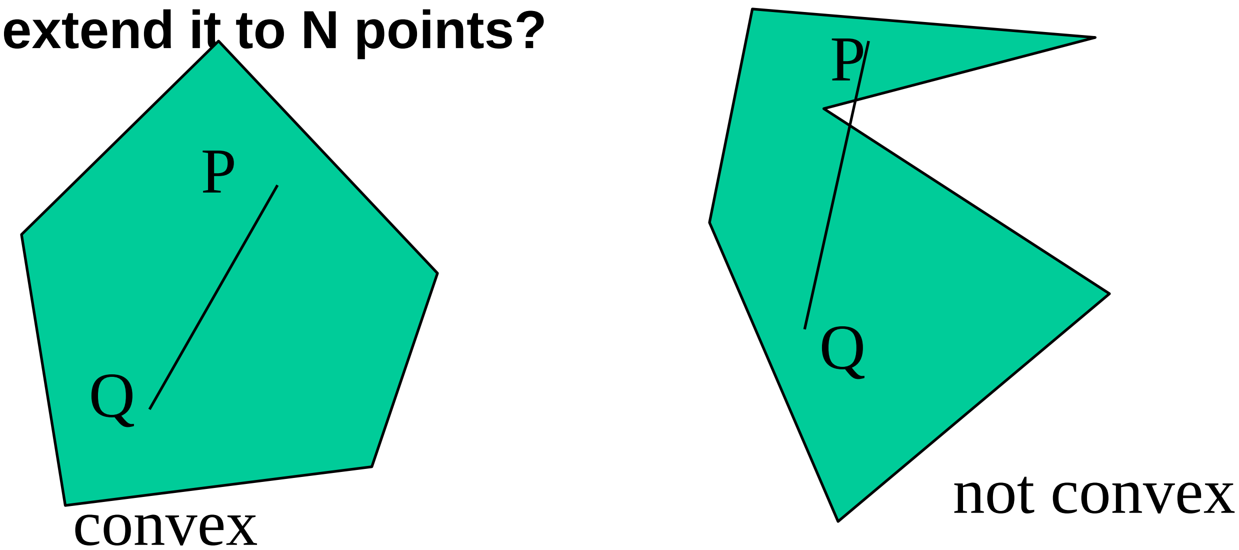
# Convexity

**An object is *convex* iff for any two points in the object all points on the line segment between these points are also in the object**

**A line segment is a convex object**

$$P(\boldsymbol{\alpha}) = \boldsymbol{\alpha}R + (1-\boldsymbol{\alpha})Q = \boldsymbol{\alpha}_R R + \boldsymbol{\alpha}_Q Q$$

**Can we extend it to N points?**



# Affine Sums and Convex Hull

**Consider the "sum"**

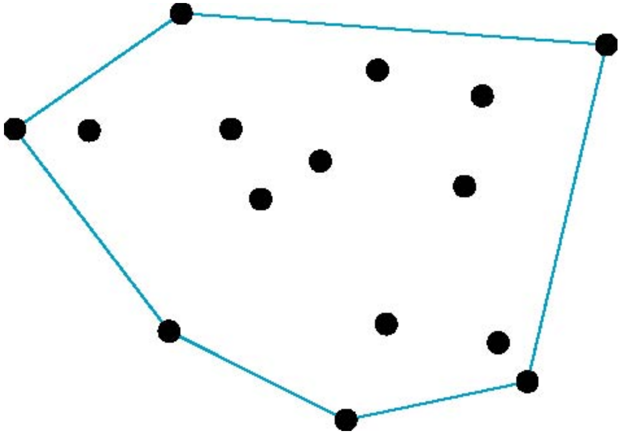
$$P = \boldsymbol{\alpha}_1 P_1 + \boldsymbol{\alpha}_2 P_2 + \cdots + \boldsymbol{\alpha}_n P_n$$

**Can show by induction that this sum makes sense iff**

$$\boldsymbol{\alpha}_1 + \boldsymbol{\alpha}_2 + \cdots + \boldsymbol{\alpha}_n = 1$$

**in which case we have the *affine sum* of the points $P_1,P_2,\ldots..P_n$**

**If, in addition, $\alpha_i >= 0$, we have the *convex hull* of $P_1,P_2,\ldots..P_n$**



**Smallest convex object containing $P_1,P_2,\ldots..P_n$**

**Formed by "shrink wrapping" points**