Input and Interaction

CS 537 Interactive Computer Graphics
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Objectives

• Introduce the basic input devices
  - Physical Devices
  - Logical Devices
  - Input Modes
• Event-driven input
• Introduce double buffering for smooth animations
• Programming event input with GLUT
Project Sketchpad

- Ivan Sutherland (MIT 1963) established the basic interactive paradigm that characterizes interactive computer graphics:
  - User sees an object on the display
  - User points to (picks) the object with an input device (light pen, mouse, trackball)
  - Object changes (moves, rotates, morphs)
  - Repeat
Graphical Input

• Devices can be described either by
  - Physical properties
    • Mouse
    • Keyboard
    • Trackball
  - Logical Properties
    • What is returned to program via API
      – A position
      – An object identifier
      – A scalar value

• Modes
  - How and when input is obtained
    • Request or event
Physical Devices

mouse

trackball

light pen

data tablet

joy stick

space ball
Incremental (Relative) Devices

• Devices such as the data tablet return a position directly to the operating system.
• Devices such as the mouse, trackball, and joystick return incremental inputs (or velocities) to the operating system.
  - Must integrate these inputs to obtain an absolute position.
    • Rotation of cylinders in mouse.
    • Roll of trackball.
    • Difficult to obtain absolute position.
    • Can get variable sensitivity.
Logical Devices

• Consider the C and C++ code
  - C++: `cin >> x;`
  - C: `scanf ("%d", &x);`

• What is the input device?
  - Can’t tell from the code
  - Could be keyboard, file, output from another program

• The code provides *logical input*
  - A number (an `int`) is returned to the program regardless of the physical device
Graphical Logical Devices

• Graphical input is more varied than input to standard programs which is usually numbers, characters, or bits

• Two older APIs (GKS, PHIGS) defined six types of logical input
  - **Locator**: return a position
  - **Pick**: return ID of an object
  - **Keyboard**: return strings of characters
  - **Stroke**: return array of positions
  - **Valuator**: return floating point number
  - **Choice**: return one of n items
The X Window System introduced a client-server model for a network of workstations.

- **Client**: OpenGL program
- **Graphics Server**: bitmap display with a pointing device and a keyboard
Input Modes

- Input devices contain a *trigger* which can be used to send a signal to the operating system
  - Button on mouse
  - Pressing or releasing a key
- When triggered, input devices return information (their *measure*) to the system
  - Mouse returns position information
  - Keyboard returns ASCII code
Request Mode

- Input provided to program only when user triggers the device
- Typical of keyboard input
  - Can erase (backspace), edit, correct until enter (return) key (the trigger) is depressed
Event Mode

• Most systems have more than one input device, each of which can be triggered at an arbitrary time by a user.

• Each trigger generates an event whose measure is put in an event queue which can be examined by the user program.
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
Callbacks

• Programming interface for event-driven input
• Define a callback function for each type of event the graphics system recognizes
• This user-supplied function is executed when the event occurs
• GLUT example:

```c
glutMouseFunc(mymouse)
```

GLUT callbacks

GLUT recognizes a subset of the events recognized by most/all window systems (Windows, X, Macintosh)

- `glutDisplayFunc`
- `glutMouseFunc`
- `glutReshapeFunc`
- `glutKeyboardFunc`
- `glutIdleFunc`
- `glutMotionFunc`, `glutPassiveMotionFunc`
GLUT Event Loop

• Recall that the last line in `main.c` for a program using GLUT must be
  ```c
  glutMainLoop();
  ```
  which puts the program in an infinite event loop

• In each pass through the event loop, GLUT
  - looks at the events in the queue
  - for each event in the queue, GLUT executes the appropriate callback function if one is defined
  - if no callback is defined for the event, the event is ignored
The display callback

• The display callback is executed whenever GLUT determines that the window should be refreshed, for example
  - When the window is first opened
  - When the window is reshaped
  - When a window is exposed
  - When the user program decides it wants to change the display

• In `main.c`
  - `glutDisplayFunc(mydisplay)` identifies the function to be executed
  - Every GLUT program must have a display callback
Posting redisplays

- Many events may invoke the display callback function
  - Can lead to multiple executions of the display callback on a single pass through the event loop
- We can avoid this problem by instead using `glutPostRedisplay();`
  - which sets a flag.
- GLUT checks to see if the flag is set at the end of the event loop
- If set then the display callback function is executed
- Call `glutPostRedisplay` at the end of all callback functions that should change the display
Animating a Display

• When we redraw the display through the display callback, we usually start by clearing the window
  - `glClear()`
  then draw the altered display
• Problem: the drawing of information in the frame buffer is decoupled from the display of its contents
  - Graphics systems use dual ported memory
• Hence we can see partially drawn displays
  - See the program `single_double.c` for an example with a rotating cube
Double Buffering

• Instead of one color buffer, we use two
  - **Front Buffer**: one that is displayed but not written to
  - **Back Buffer**: one that is written to but not displayed

• Program then requests a double buffer in main.c
  - `glutInitDisplayMode(GLUT_RGB | GLUT_DOUBLE)`
  - At the end of the display callback buffers are swapped

```c
void mydisplay()
{
    glClear();
    /* draw graphics here */
    glutSwapBuffers();
}
```
Using the idle callback

• The idle callback is executed whenever there are no events in the event queue
  - `glutIdleFunc(myidle)`
  - Useful for animations

```c
void myIdle() {
    /* change something */
    t += dt
    glutPostRedisplay();
}

void myDisplay() {
    glutClear();
    /* draw something that depends on t */
    glutSwapBuffers();
}
```

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Using globals

• The form/interface of all GLUT callbacks is fixed
  - void mydisplay()
  - void mymoues(GLint button, GLint state, GLint x, GLint y)
• Must use globals to pass information to callbacks

```c
float t; /*global */

void mydisplay()
{
/* draw something that depends on t */
}```
Working with Callbacks
Objectives

• Learn to build interactive programs using GLUT callbacks
  - Mouse
  - Keyboard
  - Reshape

• Introduce menus in GLUT
The mouse callback

```c
glutMouseFunc(mymouse)
void mymouse(GLint button, GLint state, GLint x, GLint y)
```

• Is called with the following information
  - which button (`GLUT_LEFT_BUTTON`, `GLUT_MIDDLE_BUTTON`, `GLUT_RIGHT_BUTTON`) caused event
  - state of that button (`GLUT_UP`, `GLUT_DOWN`)
  - Position in window
Positioning

- The position in the screen window is usually measured in pixels with the origin at the top-left corner
  - Consequence of refresh done from top to bottom
- OpenGL uses a world coordinate system with origin at the bottom left
  - Must invert y coordinate returned by callback by height of window
  - \( y = h - y; \)
Obtaining the window size

- To invert the y position we need the window height
  - Height can change during program execution
  - Track with a global variable
  - New height returned to reshape callback that we will look at in detail soon
- Can also use query functions
  - `glGetIntv`
  - `glGetFloatv`

to obtain any value that is part of the state
Terminating a program

- In our original programs, there was no way to terminate them through OpenGL
- We can use the simple mouse callback

```c
void mouse(int btn, int state, int x, int y)
{
    if(btn==GLUT_RIGHT_BUTTON && state==GLUT_DOWN)
        exit(0);
}
```
Using the mouse position

• In the next example, we draw a small square at the location of the mouse each time the left mouse button is clicked.

• This example does not use the display callback but one is required by GLUT; We can use the empty display callback function

  mydisplay(){}

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void mymoused(int btn, int state, int x, int y) {
    if(btn==GLUT_RIGHT_BUTTON && state==GLUT_DOWN)
        exit(0);
    if(btn==GLUT_LEFT_BUTTON && state==GLUT_DOWN)
        drawSquare(x, y);
}

void drawSquare(int x, int y) {
    y=h-y; /* invert y position */
    points[i] = point2(x+size, y+size);
    points[i+1] = point2(x-size, y+size);
    points[i+2] = point2(x-size, y-size);
    points[i+3] = point2(x+size, y-size);
    i+=4;
    glutPostRedisplay();
}
Using the motion callback

• We can draw squares (or anything else) continuously as long as a mouse button is depressed by using the motion callback

  \[-\text{glutMotionFunc}(\text{drawSquare})\]

• Calls \texttt{drawSquare} if mouse is moving in window and any button is depressed

• Function is called with mouse’s \((x, y)\) location at the time of the event
Using the motion callback

- We can draw squares without depressing a button using the passive motion callback
  - `glutPassiveMotionFunc(drawSquare)`
- The magnitude of motion that triggers this event is system dependent
The entry callback

• The cursor generates an entry event whenever it enters or leaves the OpenGL window

• The callback for this event is registered with `glutEntryFunc()`

```c
void glutEntryFunc(void (*f) (int state))
```

• Event specifies state of entry
  - `(GLUT_ENTERED, GLUT_LEFT)`
Using the keyboard

```c
# glutKeyboardFunc (mykey)
void mykey(unsigned char key, int x, int y)
{
    if(key == 'Q' || key == 'q')
        exit(0);
}
```

- Is called with ASCII code of key depressed and mouse location
Special Keys

• GLUT defines the special keys in glut.h
  - Function key 1: GLUT_KEY_F1
  - Up arrow key: GLUT_KEY_UP
    • if(key == ‘GLUT_KEY_F1’ ......

• glutSpecialFunc(myspecial) specifies the callback function that is called when a special key (i.e. a function or arrow key) is depressed
Modifier Keys

• Can also check if one of the modifiers
  - GLUT_ACTIVE_SHIFT
  - GLUT_ACTIVE_CTRL
  - GLUT_ACTIVE_ALT
  is depressed with glutGetModifiers()

  ```
  if((glutGetModifiers() == GLUT_ACTIVE_CTRL) &&
    (key == 'c') || (key == 'C'))
    exit(0);
  ```

• Allows emulation of three-button mouse with one- or two-button mice
Reshaping the window

• We can reshape and resize the OpenGL display window by pulling the corner of the window.

• What happens to the display?
  - Must redraw from application
  - Two possibilities
    • Display part of world
    • Display whole world but force to fit in new window
      – Can alter aspect ratio
Reshape possibilities

original

reshaped
The Reshape callback

`glutReshapeFunc(myreshape)`

`void myreshape( int w, int h)`

- Returns width and height of new window (in pixels)
- A redisplay is posted automatically at end of execution of the callback
- GLUT has a default reshape callback but you probably want to define your own

• The reshape callback is good place to put viewing functions because it is invoked when the window is first opened
Example Reshape

• We will revisit this once we have learned about viewing

```c
void myReshape(int w, int h)
{
    glViewport(0, 0, w, h); /* Make viewport and window the same size */

    // More to come
}
```
Timers

• Callback function that is triggered after a specified number of milliseconds

```c
// change color each second
glutTimerFunc(1000,timerColor,0);
// change the shape after five seconds
glutTimerFunc(5000,timerShape,0);

void timerColor(int value){
    // get new color or a value in [0,1]
    r = (1.0*(random()%256))/256.0;
    g = (1.0*(random()%256))/256.0;
    b = (1.0*(random()%256))/256.0;

    // draw it + reinitialise timer
    glutPostRedisplay();
    glutTimerFunc(1000,timerColor,0);
}
```
Redefining Callbacks

• Callback functions can be redefined
• Change binding during program execution
• Callbacks can be undefined
  – glutReshapeFunc(NULL);
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
Defining a simple menu

In main.c

```c
menu_id = glutCreateMenu(mymenu);
glutAddmenuEntry("clear Screen", 1);
glutAddMenuEntry("exit", 2);
glutAttachMenu(GLUT_RIGHT_BUTTON);
```

entries that appear when right button depressed

identifiers

clear screen
exit
Menu actions

- Menu callback

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

- Note each menu has an id that is returned when it is created
- Add submenus by

```c
glutAddSubMenuItem(char *submenu_name, submenu id)
```

entry in parent menu
void createGLUTMenus() {

    int menu, submenu;

    submenu = glutCreateMenu(processMenuEvents);
    glutAddMenuEntry("Red", RED);
    glutAddMenuEntry("Blue", BLUE);
    glutAddMenuEntry("Green", GREEN);

    menu = glutCreateMenu(processMenuEvents);
    glutAddMenuEntry("White", WHITE);
    glutAddSubMenu("RGB Menu", submenu);
    glutAttachMenu(GLUT_RIGHT_BUTTON);

}
void processMenuEvents(int option)
{
    switch (option)
    {
        case RED : red = 1.0; green = 0.0; blue = 0.0; break;
        case GREEN : red = 0.0; green = 1.0; blue = 0.0; break;
        case BLUE : red = 0.0; green = 0.0; blue = 1.0; break;
        case WHITE : red = 1.0; green = 1.0; blue = 1.0; break;
    }

    glutPostRedisplay();
}
Dynamic, Multiple Windows and Subwindows

```c
int glutCreateWindow(char *name)

void glutDestroyWindow(int id)

int glutGetWindow()  // returns id of current window
void glutSetWindow(int id)

void glutCreateSubWindow(int parent, int x, int y, int width, int height)

void glutPostWindowRedisplay(int winid)

– Posts a redisplay for a particular window

– Menus are defined for specific windows
```
int mainWindow, subWindow1;
int main(int argc, char **argv)
{
    glutInit(&argc, argv);
    glutInitDisplayMode(GLUT_DEPTH | GLUT_DOUBLE | GLUT_RGBA);
    glutInitWindowSize(w, h);
    mainWindow = glutCreateWindow("SnowMen from 3D-Tech");
    // keyboard stuff
    glutKeyboardFunc(processNormalKeys);
    // reshape function
    glutReshapeFunc(changeSize);
    // display and idle function
    glutDisplayFunc(renderScene);
    glutIdleFunc(renderSceneAll);
    subWindow1 = glutCreateSubWindow(mainWindow,
                                       border, border, w-2*border, h/2 - border*3/2);
    // Must register a display func for each window
    glutDisplayFunc(renderScene1);
Displaying in Multiple Windows

- Each window has its own graphics context
- For each window set up a separate VAO, buffers and compiled shader programs
- Creating a window / setting its ID makes it current
- Subsequent OpenGL structures will be associated with current window
- Be sure that the correct window is current before executing its display function
Suggestions for HW3

• Structure of `main()`

```c
    glutInit( argc, argv );
    glutInitDisplayMode( GLUT_RGBA | GLUT_DOUBLE);
    glutInitWindowSize( WIDTH, HEIGHT );
    glutInitWindowPosition(0, 0);

    mainWindow = glutCreateWindow( "HW3 - Window 1" );
    // Specify callback functions for Window 1
    initMain();  // initialize buffers and data needed for Window 1
    // Specify menus for Window 1
    subWindow = glutCreateSubWindow(mainWindow, 0, 0, SUB_WIDTH, SUB_HEIGHT );
    glutDisplayFunc( subDisplay );
    initSub();  // initialize buffers and data needed for subwindow
    // Specify menus for subwindows
    window2 = glutCreateWindow( "Window 2" );
    glutDisplayFunc( window2Display );
    // Specify callback functions for Window 2
    initWindow2(); // initialize buffers and data needed for Window 1

    glutMainLoop();
```

Suggestions for HW3

• Structure of each init()

  // Compute geometric data needed for this window

  // Create a vertex array object
  glGenVertexArrays( 1, vao );
  glBindVertexArray( vao[0] );

  // Create and initialize a buffer object
  glGenBuffers( 1, &buffer );
  glBindBuffer( GL_ARRAY_BUFFER, buffer );
  glBufferData( ... )

  // Load shaders and use the resulting shader program

  // Initialize the vertex position attribute from the vertex shader

  // Initialize the vertex color attribute from the vertex shader

  glClearColor( 0, 0, 0, 1.0 ); // black background
Suggestions for HW3

• Structure of display callback function

```c
// clear the window
glClear( GL_COLOR_BUFFER_BIT);

// update triangle vertices for animation

// update circle vertices for animation

// send vertex data to GPU
glBufferSubData( ... , window2Vertices);
glBufferSubData( ... , window2Colors);
glDrawArrays( ... );    // draw the triangle

// draw the circle

// flush pending commands to GPU

// swap the front and back buffers
```

Suggestion for HW3

• Structure of idle function

// Do calculations needed to animate objects
// e.g. increment angle or time

glutPostWindowRedisplay(mainWindow);
glutPostWindowRedisplay(subWindow);
glutPostWindowRedisplay(window2);