

Announcements

- Program #4

- Due on Tuesday
- Reminder: We grade your *final* submission
- See notes on web page regarding linking
 - `-L. -ldl -rdynamic`
 - `"./libavl.so.1"`
 - `setenv LD_LIBRARY_PATH .`

- Reading

- Notes (Today)
- Notes (Tuesday)

Events

- Many programs need to respond to external activity
 - keyboard
 - mouse
 - network
 - sensors
- Many programs can expect input from multiple sources
 - often don't know where the next input will come
 - will the user press a key or move the mouse next?
- Events are a way to represent these activities
 - can also includes other things (such as timer alarms)

Event Driven Programming

- Program consists of a main loop waiting for events
- Define set of functions to handle each event
 - process event, and then return
- Often uses function pointers to define events and their handlers

Structure of an Event Driven Program

```
while (1) {  
    event = getNextEvent();  
    switch (event.type) {  
        case MOUSE_EVENT:  
            processMouse(event);  
            break;  
        case KEYBOARD_EVENT:  
            processKeyboard(event);  
            break;  
        .....  
    }  
}
```

Handling Multiple Events - Select

- Often events are coming from file descriptors
 - keyboard input
 - file I/O
 - network communication
- Select system call
 - blocks waiting for I/O to be ready on a set of file descriptor
 - returns when one or more file descriptors have I/O ready
 - does **NOT** perform the I/O
 - can include a timeout
 - prevent blocking forever
 - allows time based events

Select System Call

- `int select(int n, fd_set *readfds, fd_set *writefds, fd_set *exceptfds, struct timeval *timeout);`
 - `n` – largest number of a file descriptor in any one of the sets +1
 - `readfds`, `writefds`, `exceptfds` - sets of file descriptors
 - `timeout` - how long to wait for events
 - return
 - value is number of descriptors in sets
 - sets modified to indicate which file descriptors are active
- set routines
 - `FD_ISSET(int fd, fd_set *set);`
 - is `fd` in the set
 - `FD_SET(int fd, fd_set *set);`
 - added `fd` to set
 - `FD_ZERO(fd_set *set);`
 - clear out the set

Why select for writing?

- Why select for writing?
 - Output buffers have finite size.
 - All communication fd's have buffered output.
 - To keep devices busy while application does something else.
 - `write()` ordinarily blocks if buffer is full; waits for drain.
 - Easy for `select()` to tell if there is space.
 - So it makes sense to `select()` for writing.
- Why select for errors?
 - learn about I/O problems
 - learn when a network connection closes down

Select Example

```
int main() {
    int ret, myServerFD, maxFd = 0;  FD_SET set;
    myServerFD = connectToServer();
    while (1) {
        FD_ZERO(&set);
        FD_SET(0, &set);
        FD_SET(myServerFD, &set);
        if (myServerFD > maxFd) maxFd = myServerFD;
        ret = select(maxFd+1, &set, NULL, NULL, NULL);
        if (ret) {
            if (FD_ISSET(0, &set)) { /* read from standard input */ }
            if (FD_ISSET(myServerFD, &set)) { /* read from net */ }
        }
    }
}
```


Handling I/O Events

- Reading from Standard input

```
void readStandardIO() {  
    ret = read(0, line, sizeof(line));  
  
    /* process line */  
  
}
```

Coordinating Events

- Sometimes Events come from sources other than file descriptors
 - other threads
- Solution:
 - use a queue of events
 - threads wishing to communicate en-queue events
- main loop for event queue paradigm:

```
while (1) {  
    event = myEventQueue->dequeue();  
    /* process event */  
    anotherEventQueue->enqueue(response);  
}
```

How do event-driven programs maintain state?

- Ordinary programs, and threads, use variables on the stack.
 - Thread's stack persists across thread context switches
- Event-Driven programs can't keep state on the stack.
 - Since each callback must return immediately.
 - We want to associate data/state with each callback.
- Solution:
 - Keep data in heap allocated structure
 - associate structure instance with file descriptor
 - can include `functionPointer+arg`
 - function pointer defines what to call
 - arg defines state for that function

How to Keep Programs Modular

- Problem:

- Multiple parts of the system want to process events
- Everyone wants to write to a main loop

- Solution:

- Define an interface to allow event handlers to register
- Single common event loop
- Callback functions to specific event handlers

Example Using Callbacks

```
typedef int (*handlerFunc)(int fd, void *arg);
```

```
typedef struct {  
    handlerfunc handler;  
    int fd;  
    void *arg;  
} eventHandler;
```