In the following problems, we will explore two different data structures and associated algorithms. Both data structures have similar interfaces but very different implementations. These data structures could be used in an operating system to manage programs running on a server. Every program is given a unique process ID, and every program is also associated with the username of the user running the program. For example, the following commands will display your username and the process IDs of all programs you are currently running on ecelinux:

```bash
$ whoami
cb535
$ ps
 PID TTY TIME CMD
16734 pts/0 00:00:00 bash
17018 pts/0 00:00:00 ps
```

We will explore data structures to store the username and process ID for each program currently running on a system. The data structures should support queries by the operating system. The operating system should be able to query which user is running the program with a given process ID, and the operating system should also be able to list all process IDs associated with a given username. For this problem, you can assume process IDs range from zero to 31.

**Problem 1. List-Based Program Info Data Structure**

Our first data structure will be similar in spirit to the list data structure discussed in lecture. The data structure is named `list_pinfo`, since it is a list meant to store information about programs. We are using a list-based instead of a vector-based implementation, because we anticipate needing to frequently insert and remove entries as programs are started and then finish. The interface for `list_pinfo` is as follows.

```c
typedef struct _list_pinfo_entry_t {
    int pid;
    char* uname;
    struct _list_pinfo_entry_t* next_p;
} list_pinfo_entry_t;

typedef struct {
    list_pinfo_entry_t* head_p;
    list_pinfo_entry_t* tail_p;
} list_pinfo_t;

void list_pinfo_construct ( list_pinfo_t* this );
void list_pinfo_destruct ( list_pinfo_t* this );
void list_pinfo_add ( list_pinfo_t* this, int pid, char* uname );
void list_pinfo_remove ( list_pinfo_t* this, int pid );
char* list_pinfo_get_uname ( list_pinfo_t* this, int pid );
void list_pinfo_print_pids ( list_pinfo_t* this, char* uname );
```
Part 1.A Implementing list_pinfo_add

The implementation for the list_pinfo_construct and list_pinfo_add functions are shown below. Notice that we always add the new entry to the end of the linked list. Draw the state diagram that corresponds to the execution of this C program.

```c
/*
 * void list_pinfo_construct( list_pinfo_t* this )
 * { }
 * this->head_p = NULL;
 * this->tail_p = NULL;
 */

void list_pinfo_add( list_pinfo_t* this, int pid, char* uname )
{
    list_pinfo_entry_t* new_entry_p
    = malloc( sizeof(list_pinfo_entry_t) );

    new_entry_p->pid = pid;
    new_entry_p->uname = uname;
    new_entry_p->next_p = NULL;

    // Handle case where list is empty
    if ( this->tail_p == NULL ) {
        this->head_p = new_entry_p;
        this->tail_p = new_entry_p;
    }

    // Handle case where list is not empty
    else {
        this->tail_p->next_p = new_entry_p;
        this->tail_p = new_entry_p;
    }
}

int main( void )
{
    list_pinfo_t pinfo;
    list_pinfo_construct( &pinfo );

    char u0[] = "cfb";
    list_pinfo_add( &pinfo, 1, u0 );

    char u1[] = "clt";
    list_pinfo_add( &pinfo, 31, u1 );
    return 0;
}
```
Part 1.B Implementing `list_pinfo_get_uname`

Develop an implementation for `list_pinfo_get_uname` function. The function should return the username corresponding to the given process ID (pid). If the pid is not present in the data structure, then the function should return a NULL pointer to indicate an error.

```c
Curr* list_pinfo_get_uname( list_pinfo_t* this, uint pid )
{
    list_pinfo_entry_t* curr_p = this->head_p;

    while ( curr_p != NULL )
    {
        if ( curr_p->pid == pid )
        {
            return curr_p->uname;
        }
        curr_p = curr_p->next_p;
    }

    return NULL;
}
```
Problem 2. Lookup-Table Program Info Data Structure

Our second data structure uses a new technique called a lookup table. A lookup table is an array where we can transform what we are searching for into an array index; then we can directly use the array index to access the corresponding entry. The data structure is named lut_pinfo; lut stands for lookup-table. The interface for lut_pinfo is as follows.

```c
typedef struct
{
    // This is an array of 32 char pointers
    char* pid2uname[32];
} lut_pinfo_t;

void lut_pinfo_construct ( lut_pinfo_t* this );
void lut_pinfo_destruct ( lut_pinfo_t* this );
void lut_pinfo_add ( lut_pinfo_t* this, int pid, char* uname );
void lut_pinfo_remove ( lut_pinfo_t* this, int pid );
char* lut_pinfo_get_uname ( lut_pinfo_t* this, int pid );
void lut_pinfo_print_pids ( lut_pinfo_t* this, char* uname );
```
Part 2.A Implementing lut_pinfo_add

The implementation for the lut_pinfo_construct and lut_pinfo_add functions are shown below. Notice that we explicitly initialize all entries in the pid2uname array to be NULL. We will use a NULL pointer to indicate whether or not the corresponding entry is valid. Draw the state diagram that corresponds to the execution of this C program.

```c
void lut_pinfo_construct( lut_pinfo_t* this )
{
    for ( size_t i = 0; i < 32; i++ )
        this->pid2uname[i] = NULL;
}

void lut_pinfo_add( lut_pinfo_t* this,
    int pid, char* uname )
{
    this->pid2uname[pid] = uname;
}

int main( void )
{
    lut_pinfo_t pinfo;
    lut_pinfo_construct( &pinfo );  
    char u0[] = "cfb";
    lut_pinfo_add( &pinfo, 1, u0 );  
    char u1[] = "clt";
    lut_pinfo_add( &pinfo, 31, u1 );
    return 0;
}
```
Part 2. B Implementing lut_pinfo_get_uname

Develop an implementation for lut_pinfo_get_uname function. The function should return the username corresponding to the given process ID (pid). If the pid is not present in the data structure, then the function should return a NULL pointer to indicate an error.

```c
CHAR * lut_pinfo_get_uname ( lut_pinfo_t * this, int pid )
{
    return this -> pid2uname[pid];
}
```

Part 2. C Implementing lut_pinfo_print_pids

Develop an implementation for lut_pinfo_print_pids function. The function should use printf to print every process ID corresponding to the given username (uname). You can use the strcmp function from the C standard library to compare to strings. Note that this function returns zero if the strings are equal.

```c
VOID lut_pinfo_print_pids ( lut_pinfo_t * this, char * uname )
{
    for ( size_t i = 0; i < size; i++ )
    {
        if ( strcmp ( this -> pid2uname[i], uname ) == 0 )
            printf ( "%d: %s\n", i );
    }
}
```
Problem 3. Comparative Analysis

In this problem, you should perform a comparative analysis of the two implementations explored in Problems 1 and 2, with the ultimate goal of making a compelling argument for which implementation will perform better across a large number of workloads. While you are free to use whatever approach you like, we recommend you structure your response in several paragraphs. The first paragraph might discuss the performance of both implementations using time complexity analysis. Remember that time complexity analysis is not the entire story; it is just the starting point for performance analysis. The second paragraph might discuss the space requirements of both implementations using space complexity analysis. Remember that space complexity analysis is not the entire story; it is just the starting point for storage requirement analysis. The third paragraph might discuss other qualitative metrics such as generality, maintainability, and design complexity. The final paragraph can conclude by making a compelling argument for which implementation will perform better in the general case, or if you cannot strongly argue for either implementation explain why.