Operating System Practicals

Problem

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1. To implement first fit, best fit and worst fit storage allocation algorithms for memory management.

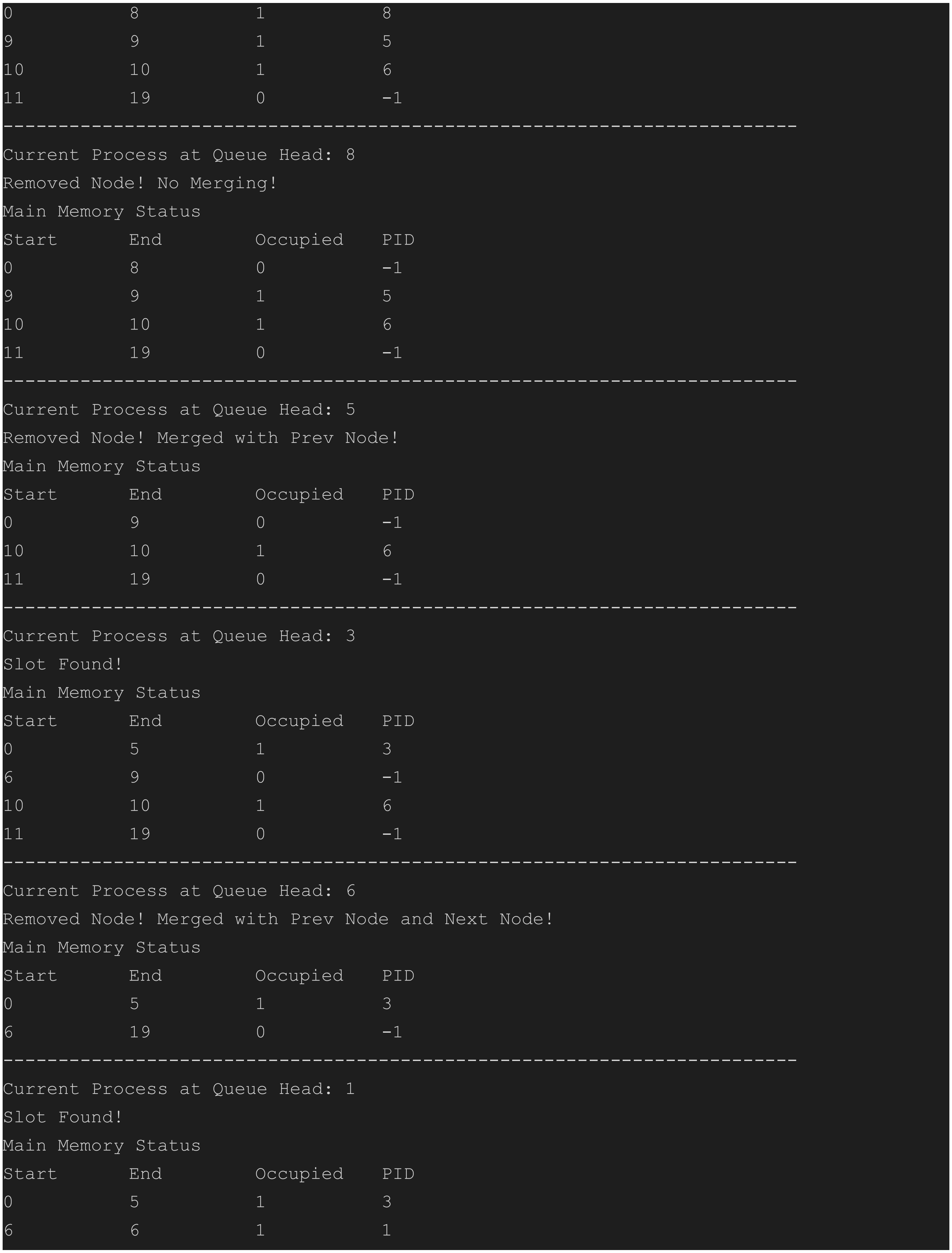
```cpp
#include <bits/stdc++.h>
#define N 10
#define pii pair<int, pair<int,pair<int, int>>>
#define F first
#define S second
using namespace std;

struct Node
{
   int start;
   int end;
   bool occupied = false;
   int pid;
   Node *next;
   Node *prev;
   Node(int s, int e, bool o = false, int pid = -1, Node *n = NULL, Node *p = NULL)
   {
       this->start = s;
       this->end = e;
       this->next = n;
       this->occupied = o;
       this->prev = p;
       this->pid = pid;
   }
};

struct Process
{
   int pid, arrival_time, burst_time, memory_requirement;
   Process(int p, int a, int b, int m)
   {
       this->pid = p;
       this->arrival_time = a;
       this->burst_time = b;
       this->memory_requirement = m;
   }
};
```

```
void print_linked_list(Node* main_memory){
   Node* head=main_memory;
   cout<<"Start\t\tEnd\t\tOccupied\tPID"<<endl;
   while(head){

cout<<head->start<<"\t\t"<<head->end<<"\t\t"<<head->occupied<<"\t\t"<<head->pid<<"\t\
t"<<endl;
       head = head->next;
   }
   return;
}

Node* find_first_fit_node(Node* main_memory,int mem_req){
   Node* head = main_memory;
   while(head){
       if(head->end - head->start+1>=mem_req && head->occupied==false) return head;
       head = head->next;
   }
   return NULL;
}

Node* find_best_fit_node(Node* main_memory,int mem_req){
   Node* head = main_memory;
   Node* req = NULL;
   while(head){
       if(head->end - head->start+1>=mem_req && head->occupied==false){
           if(!req) req = head;
           else if(req->end-req->start>head->end-head->start) req = head;
       }
       head = head->next;
   }
   return req;
}

Node* find_worst_fit_node(Node* main_memory,int mem_req){
   Node* head = main_memory;
   Node* req = NULL;
   while(head){
       if(head->end - head->start+1>=mem_req && head->occupied==false){
           if(!req) req = head;
           else if(req->end-req->start<head->end-head->start) req = head;
       }
       head = head->next;
```

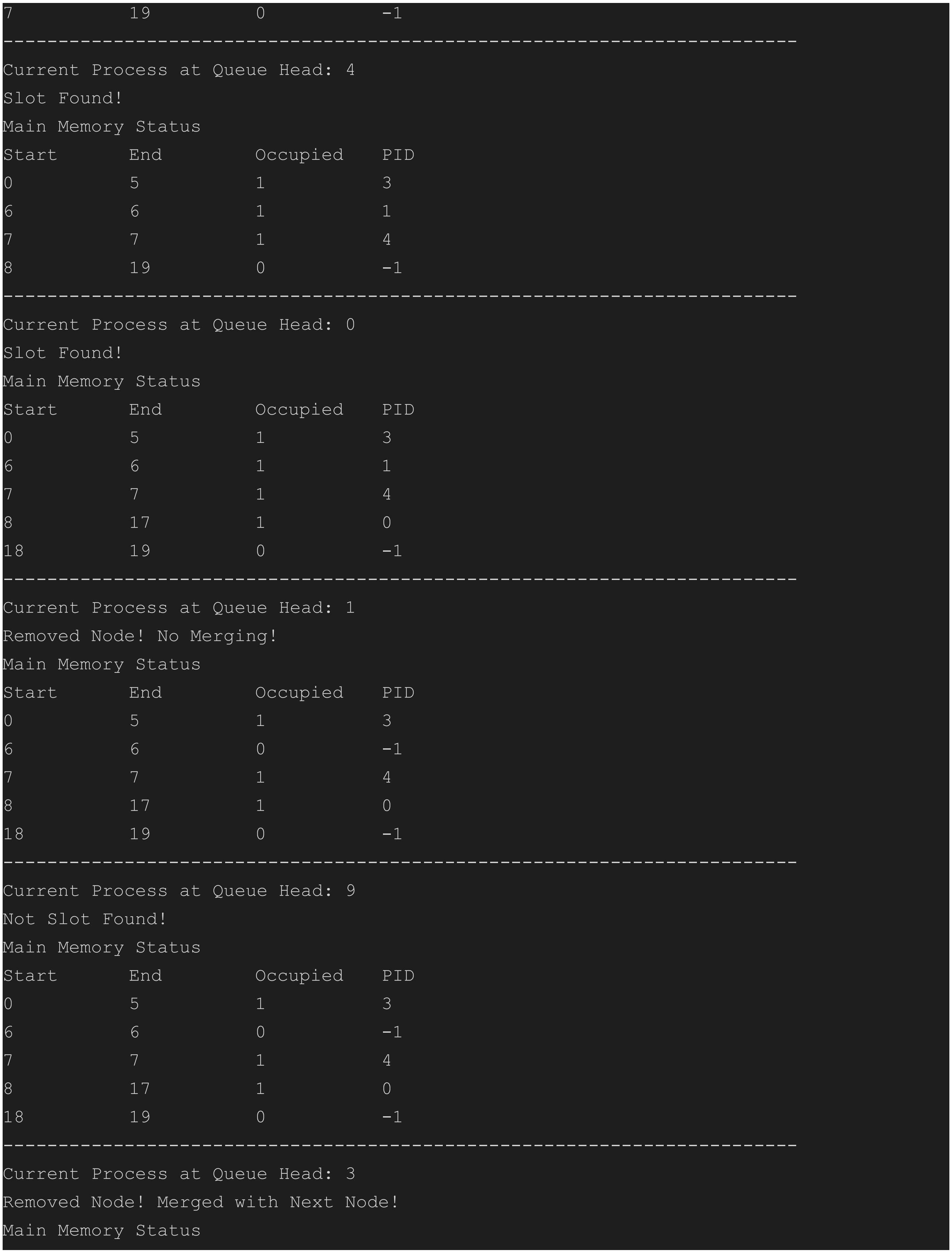
```
    }
    return req;
}

Node* find_occupied_node(Node* main_memory,int pid){
    Node* head =  main_memory;
    while(head){
        if(head->pid==pid) return head;
        head = head->next;
    }
    return NULL;
}

void fit_algorithm(vector<Process *> &processes,int arg = 0)
{
    Node *main_memory = new Node(0, 19);
    if(arg==0)
        cout<<"First Fit Memory Allocation Algorithm"<<endl;
    else if(arg==1)
        cout<<"Best Fit Memory Allocation Algorithm"<<endl;
    else if(arg==2)
        cout<<"Worst Bit Memory Allocation Algorithm"<<endl;

    priority_queue<pii, vector<pii>, greater<pii>> pq;
    for(auto i: processes)
pq.push({i->arrival_time,{1,{i->memory_requirement,i->pid}}});
    set<int> free_times;
    while(!pq.empty()){
        pii top = pq.top();
        pq.pop();
        int a_time = top.F;
        int is_entry = top.S.F;
        int mem_req = top.S.S.F;
        int pid = top.S.S.S;
        Process* p = processes[pid];


cout<<"------------------------------------------------------------------------"<<end
l;
        cout<<"Current Process at Queue Head: "<<p->pid<<endl;
        if(is_entry){
            Node* result;
            if(arg==0) result = find_first_fit_node(main_memory,mem_req);
            else if(arg==1) result = find_best_fit_node(main_memory,mem_req);
            else if(arg==2) result = find_worst_fit_node(main_memory,mem_req);
            if(!result){
                pii t1 = pq.top();
                pq.push({*free_times.begin(),{1,{mem_req,pid}}});
                cout<<"Not Slot Found!"<<endl;
            }else{
                int end = result->end;
                Node* next = result->next;
                result->occupied = true;
                result->pid = p->pid;
                result->end = result->start + mem_req - 1;
                int start = result->end + 1;
                Node* new_node = new Node(start,end);
                result->next = new_node;
                new_node->prev = result;
                if(next && next->occupied==false){
                    new_node->end = next->end;
                    new_node->next = next->next;
                    if(next->next)
                        next->next->prev = new_node;
                }else{
                    new_node->next = next;
                    if(next)
                        next->prev = new_node;
                }
                pq.push({a_time+p->burst_time,{0,{mem_req,pid}}});
                free_times.insert(a_time+p->burst_time);
                cout<<"Slot Found!"<<endl;
            }
        }else{
            free_times.erase(a_time);
            Node* occupied_node = find_occupied_node(main_memory,p->pid);
            Node* prev_node = occupied_node->prev;
            Node* next_node = occupied_node->next;
            if(!prev_node || prev_node->occupied==true){
                if(next_node->occupied==false){
                    occupied_node->end = next_node->end;
                    occupied_node->next = next_node->next;
                    if(next_node->next) next_node->next->prev = occupied_node;
                    occupied_node->occupied = false;
                    occupied_node->pid = -1;
                    free(next_node);
                    cout<<"Removed Node! Merged with Next Node!"<<endl;
                }else{
                    occupied_node->occupied = false;
                    occupied_node->pid = -1;
                    cout<<"Removed Node! No Merging!"<<endl;
                }

            }
            else if(!next_node || next_node->occupied==true){
                if(prev_node->occupied==false){
                    prev_node->end = occupied_node->end;
                    prev_node->next = occupied_node->next;
                    if(occupied_node->next) occupied_node->next->prev = prev_node;
                    free(occupied_node);
                    cout<<"Removed Node! Merged with Prev Node!"<<endl;
                }else{
                    occupied_node->occupied = false;
                    occupied_node->pid = -1;
                    cout<<"Removed Node! No Merging!"<<endl;
                }
            }else{
                prev_node->end = next_node->end;
                prev_node->next = next_node->next;
                if(next_node->next) next_node->next->prev = prev_node;
                free(next_node);
                free(occupied_node);
                cout<<"Removed Node! Merged with Prev Node and Next Node!"<<endl;
            }

        }
        cout<<"Main Memory Status"<<endl;
        print_linked_list(main_memory);
    }

 }

 int main()
 {
    srand(time(NULL));
    vector<Process *> processes;
    for (int i = 0; i < N; i++)
    {
        processes.push_back(new Process(i, rand() % 10, rand() % 10+1, rand() %
 10+1));
    }
    cout<<"Processes:"<<endl;
    cout<<"PID\t\tA.Time\tB.Time\tMemory Requirement"<<endl;
    for(auto i: processes)
 cout<<i->pid<<"\t\t"<<i->arrival_time<<"\t\t"<<i->burst_time<<"\t\t"<<i->memory_requi
 rement<<"\t\t"<<endl;

    fit_algorithm(processes,2);
 }
```

First Fit:

```
Processes:
PID         A.Time      B.Time      Memory Requirement
0           6           3           10
1           5           3           1
2           9           6           10
3           3           6           6
4           6           5           1
5           1           2           1
6           1           3           1
7           9           9           10
8           0           2           9
9           8           6           9
First Fit Memory Allocation Algorithm
------------------------------------------------------------------------
Current Process at Queue Head: 8
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           8           1           8
9           19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 5
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           8           1           8
9           9           1           5
10          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 6
Slot Found!
Main Memory Status
Start       End         Occupied    PID
```

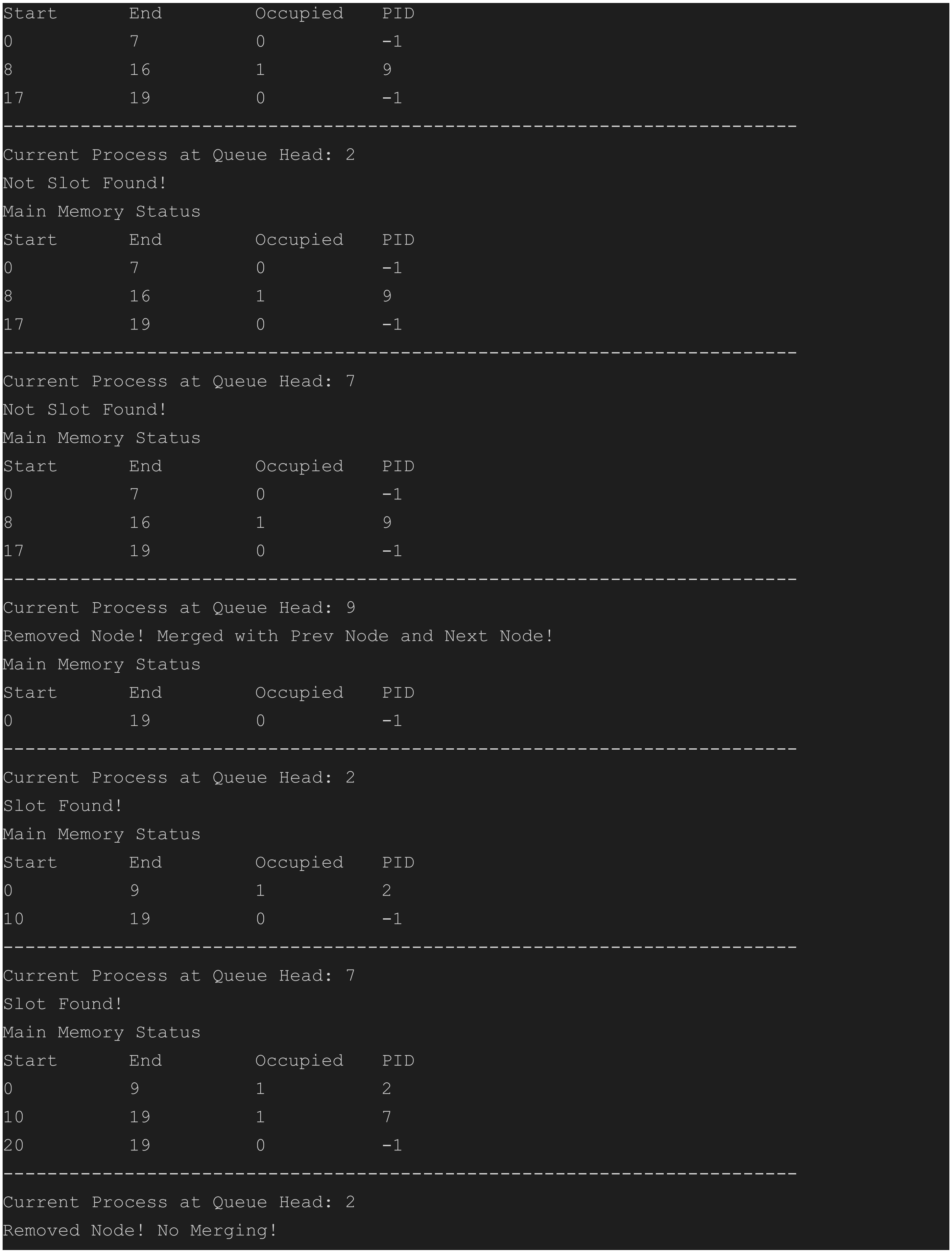


```
0           8           1           8
9           9           1           5
10          10          1           6
11          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 8
Removed Node! No Merging!
Main Memory Status
Start       End         Occupied    PID
0           8           0           -1
9           9           1           5
10          10          1           6
11          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 5
Removed Node! Merged with Prev Node!
Main Memory Status
Start       End         Occupied    PID
0           9           0           -1
10          10          1           6
11          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 3
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           5           1           3
6           9           0           -1
10          10          1           6
11          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 6
Removed Node! Merged with Prev Node and Next Node!
Main Memory Status
Start       End         Occupied    PID
0           5           1           3
6           19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 1
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           5           1           3
6           6           1           1
```



```
7           19          0           -1
--------------------------------------------------------------------------
Current Process at Queue Head: 4
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           5           1           3
6           6           1           1
7           7           1           4
8           19          0           -1
--------------------------------------------------------------------------
Current Process at Queue Head: 0
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           5           1           3
6           6           1           1
7           7           1           4
8           17          1           0
18          19          0           -1
--------------------------------------------------------------------------
Current Process at Queue Head: 1
Removed Node! No Merging!
Main Memory Status
Start       End         Occupied    PID
0           5           1           3
6           6           0           -1
7           7           1           4
8           17          1           0
18          19          0           -1
--------------------------------------------------------------------------
Current Process at Queue Head: 9
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           5           1           3
6           6           0           -1
7           7           1           4
8           17          1           0
18          19          0           -1
--------------------------------------------------------------------------
Current Process at Queue Head: 3
Removed Node! Merged with Next Node!
Main Memory Status
```

```
Start       End         Occupied    PID
0           6           0           -1
7           7           1           4
8           17          1           0
18          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 0
Removed Node! Merged with Next Node!
Main Memory Status
Start       End         Occupied    PID
0           6           0           -1
7           7           1           4
8           19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 9
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           6           0           -1
7           7           1           4
8           16          1           9
17          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 2
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           6           0           -1
7           7           1           4
8           16          1           9
17          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 7
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           6           0           -1
7           7           1           4
8           16          1           9
17          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 4
Removed Node! Merged with Prev Node!
Main Memory Status
```

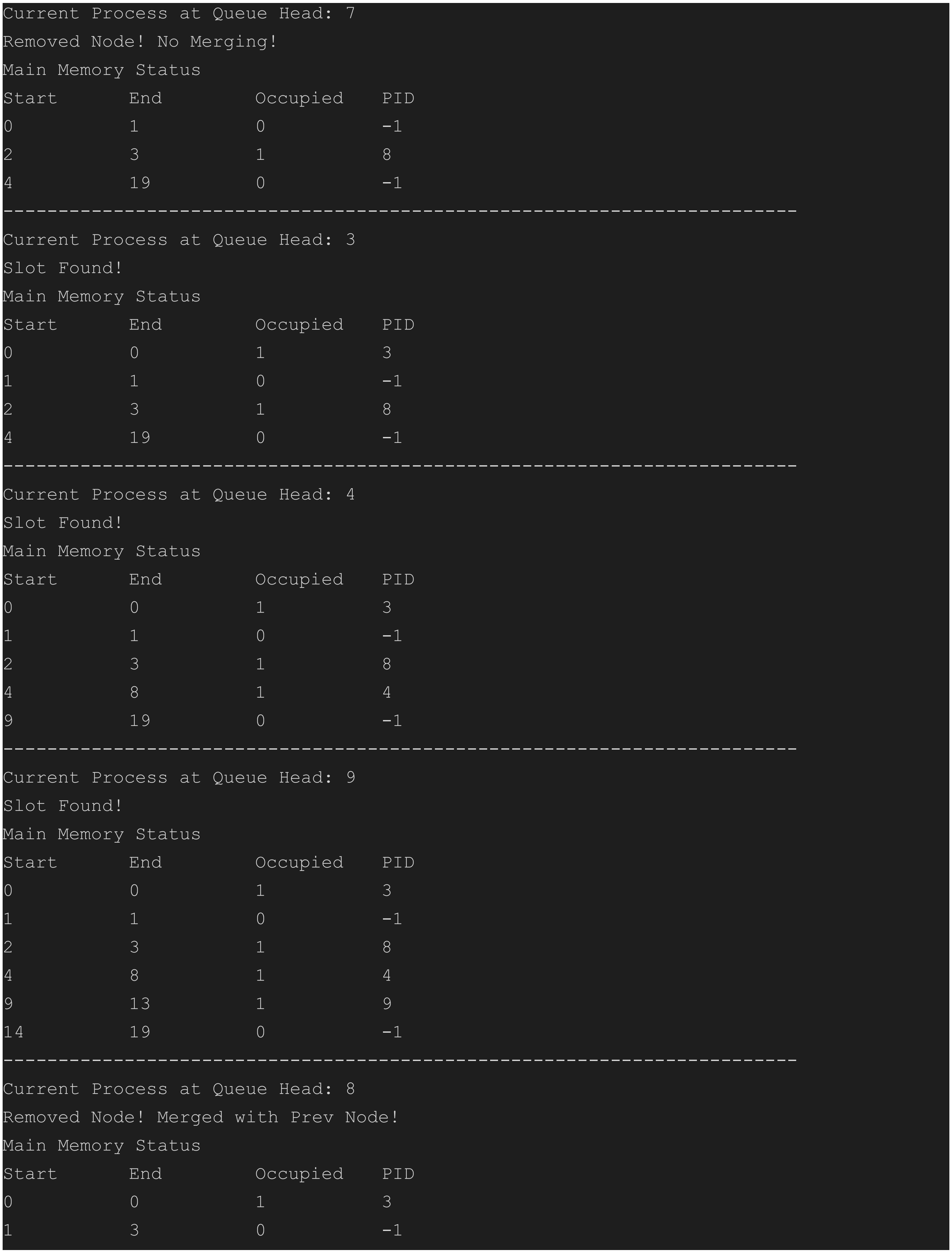


```
Start       End         Occupied    PID
0           7           0           -1
8           16          1           9
17          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 2
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           7           0           -1
8           16          1           9
17          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 7
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           7           0           -1
8           16          1           9
17          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 9
Removed Node! Merged with Prev Node and Next Node!
Main Memory Status
Start       End         Occupied    PID
0           19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 2
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           9           1           2
10          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 7
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           9           1           2
10          19          1           7
20          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 2
Removed Node! No Merging!
```

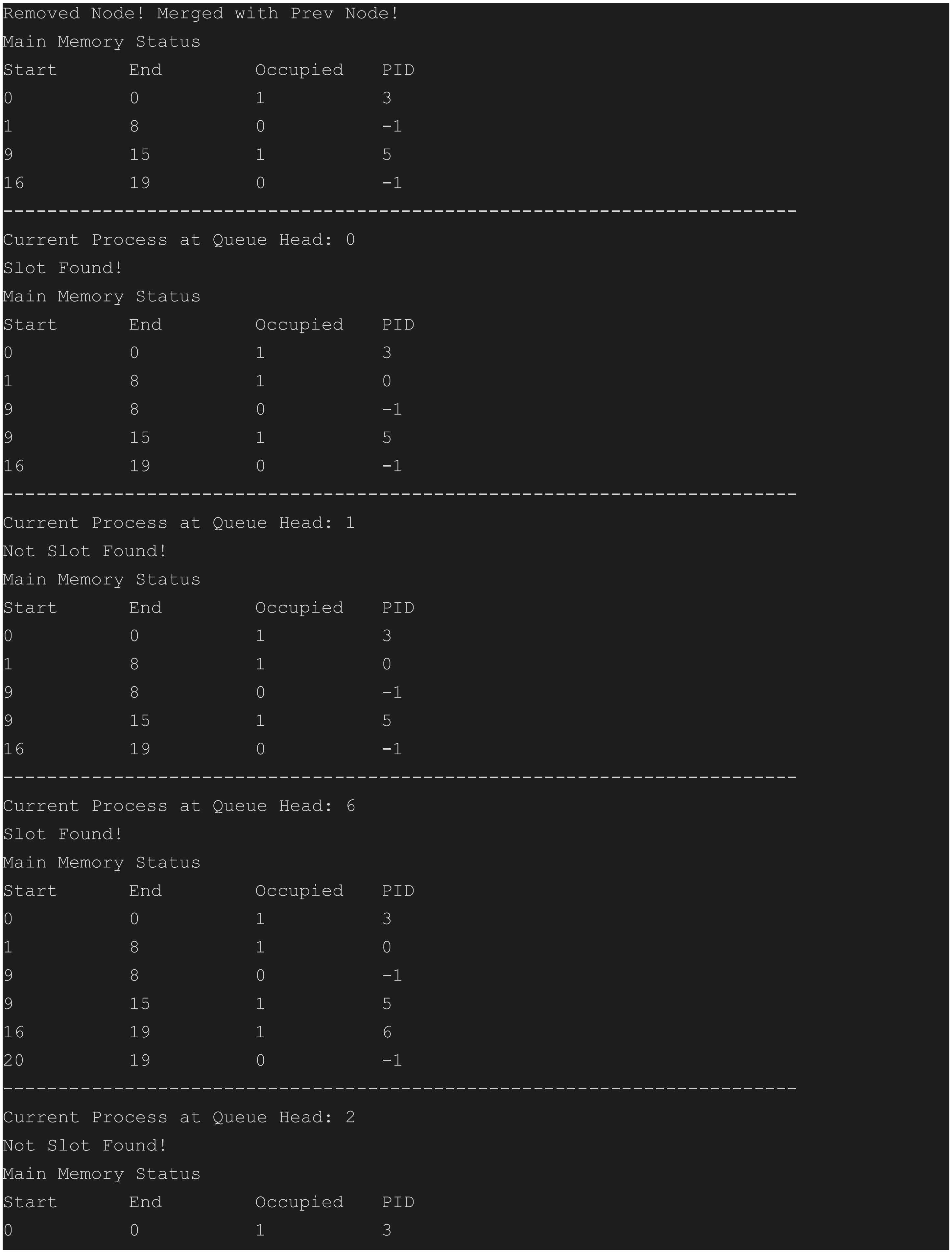
```
Main Memory Status
Start       End         Occupied    PID
0           9           0           -1
10          19          1           7
20          19          0           -1
----------------------------------------------------------------------------
Current Process at Queue Head: 7
Removed Node! Merged with Prev Node and Next Node!
Main Memory Status
Start       End         Occupied    PID
0           19          0           -1
```

Best Fit:

```
Processes:
PID         A.Time      B.Time      Memory Requirement
0           5           5           8
1           4           7           8
2           9           3           5
3           1           10          1
4           1           7           5
5           4           8           7
6           9           4           4
7           0           1           2
8           0           3           2
9           1           2           5
Best Fit Memory Allocation Algorithm
----------------------------------------------------------------------------
Current Process at Queue Head: 7
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           1           1           7
2           19          0           -1
----------------------------------------------------------------------------
Current Process at Queue Head: 8
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           1           1           7
2           3           1           8
4           19          0           -1
----------------------------------------------------------------------------
```

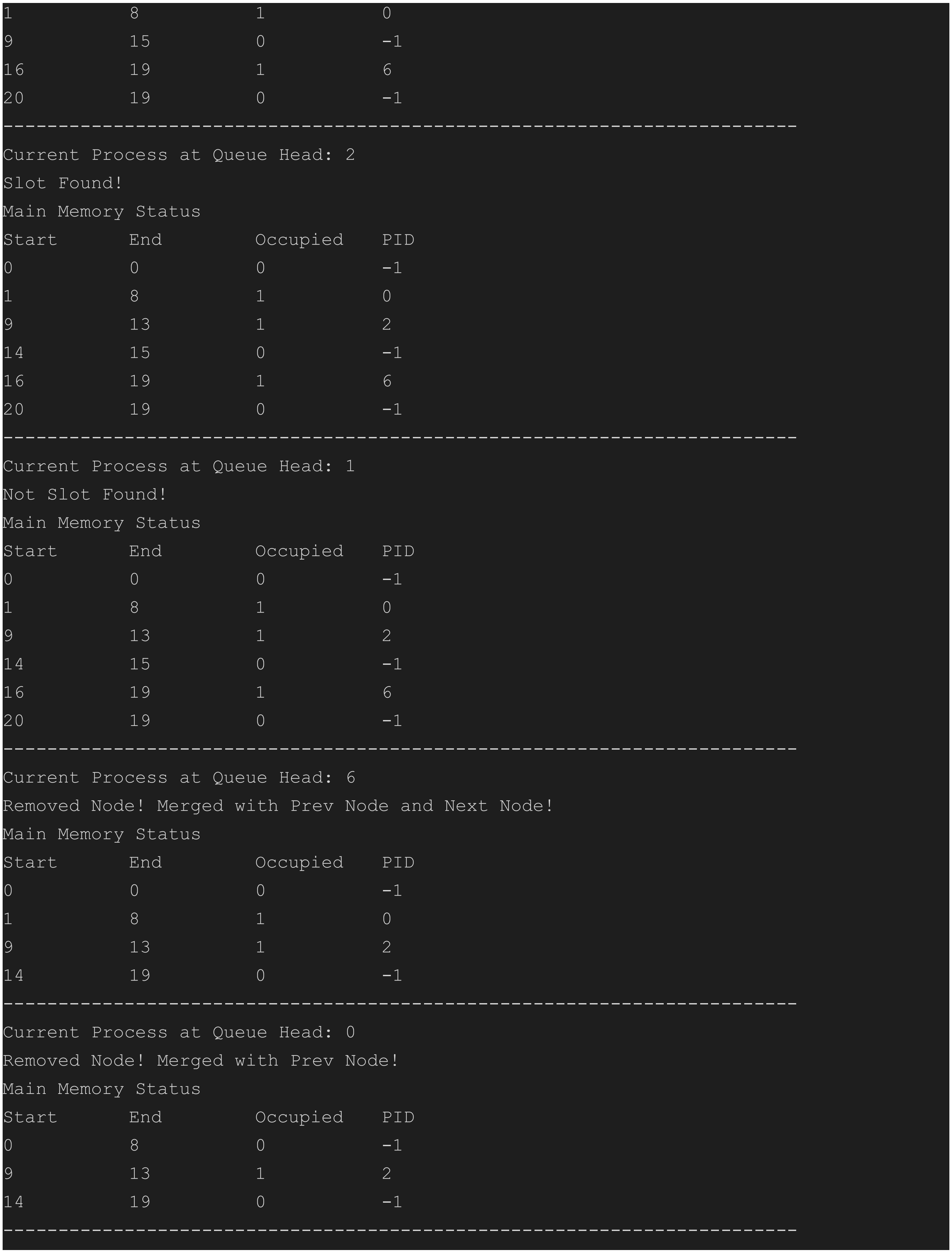

```
Current Process at Queue Head: 7
Removed Node! No Merging!
Main Memory Status
Start       End         Occupied    PID
0           1           0           -1
2           3           1           8
4           19          0           -1
---------------------------------------------------------------------------
Current Process at Queue Head: 3
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           0           1           3
1           1           0           -1
2           3           1           8
4           19          0           -1
---------------------------------------------------------------------------
Current Process at Queue Head: 4
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           0           1           3
1           1           0           -1
2           3           1           8
4           8           1           4
9           19          0           -1
---------------------------------------------------------------------------
Current Process at Queue Head: 9
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           0           1           3
1           1           0           -1
2           3           1           8
4           8           1           4
9           13          1           9
14          19          0           -1
---------------------------------------------------------------------------
Current Process at Queue Head: 8
Removed Node! Merged with Prev Node!
Main Memory Status
Start       End         Occupied    PID
0           0           1           3
1           3           0           -1
```

```
4           8           1           4
9           13          1           9
14          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 9
Removed Node! Merged with Next Node!
Main Memory Status
Start       End         Occupied    PID
0           0           1           3
1           3           0           -1
4           8           1           4
9           19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 5
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           0           1           3
1           3           0           -1
4           8           1           4
9           15          1           5
16          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 1
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           0           1           3
1           3           0           -1
4           8           1           4
9           15          1           5
16          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 0
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           0           1           3
1           3           0           -1
4           8           1           4
9           15          1           5
16          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 4
```



```
Removed Node! Merged with Prev Node!
Main Memory Status
Start       End         Occupied    PID
0           0           1           3
1           8           0           -1
9           15          1           5
16          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 0
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           0           1           3
1           8           1           0
9           8           0           -1
9           15          1           5
16          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 1
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           0           1           3
1           8           1           0
9           8           0           -1
9           15          1           5
16          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 6
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           0           1           3
1           8           1           0
9           8           0           -1
9           15          1           5
16          19          1           6
20          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 2
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           0           1           3
```

```
1           8           1           0
9           8           0           -1
9           15          1           5
16          19          1           6
20          19          0           -1
---------------------------------------------------------------------------
Current Process at Queue Head: 3
Removed Node! No Merging!
Main Memory Status
Start       End         Occupied    PID
0           0           0           -1
1           8           1           0
9           8           0           -1
9           15          1           5
16          19          1           6
20          19          0           -1
---------------------------------------------------------------------------
Current Process at Queue Head: 2
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           0           0           -1
1           8           1           0
9           8           0           -1
9           15          1           5
16          19          1           6
20          19          0           -1
---------------------------------------------------------------------------
Current Process at Queue Head: 1
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           0           0           -1
1           8           1           0
9           8           0           -1
9           15          1           5
16          19          1           6
20          19          0           -1
---------------------------------------------------------------------------
Current Process at Queue Head: 5
Removed Node! Merged with Prev Node!
Main Memory Status
Start       End         Occupied    PID
0           0           0           -1
```

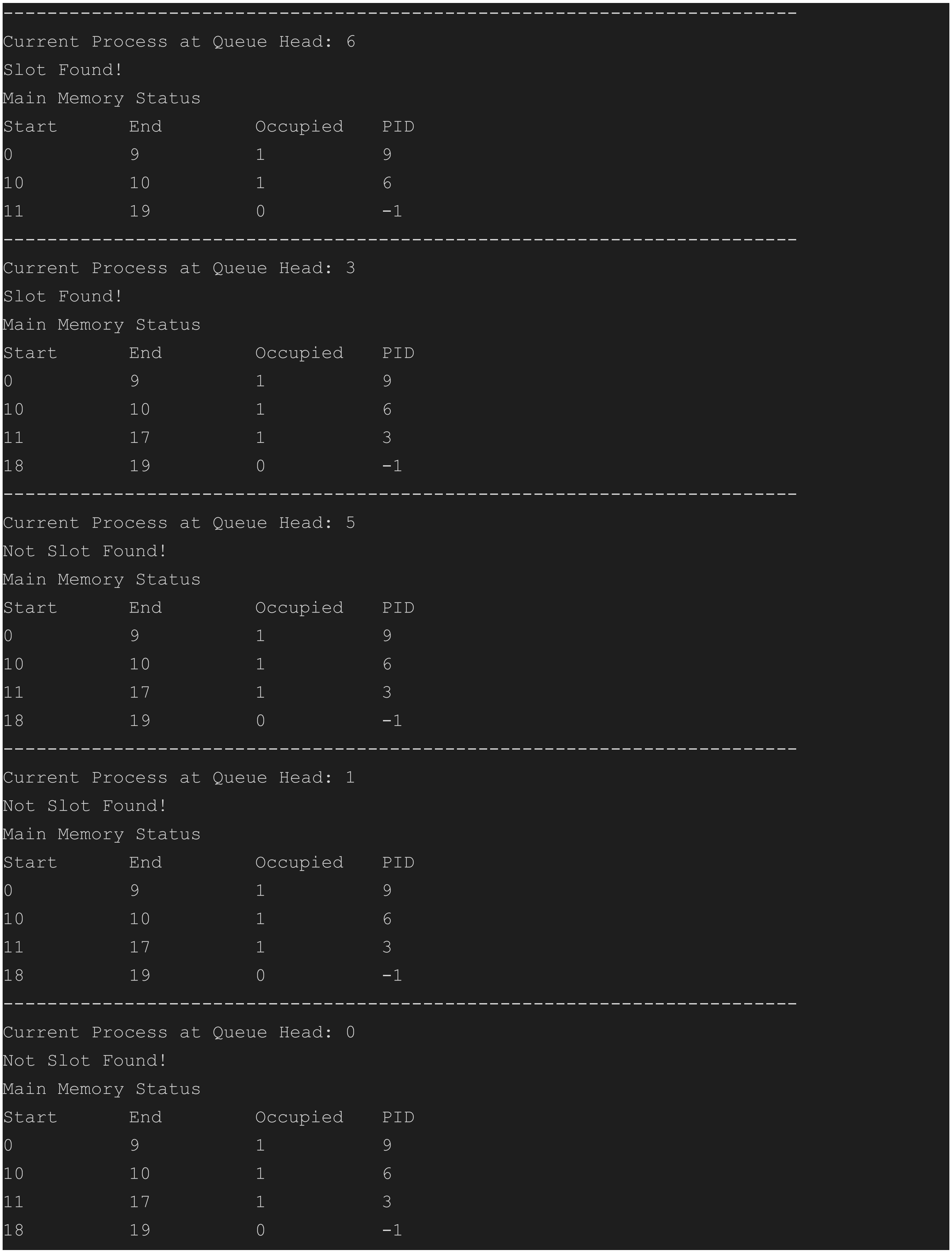


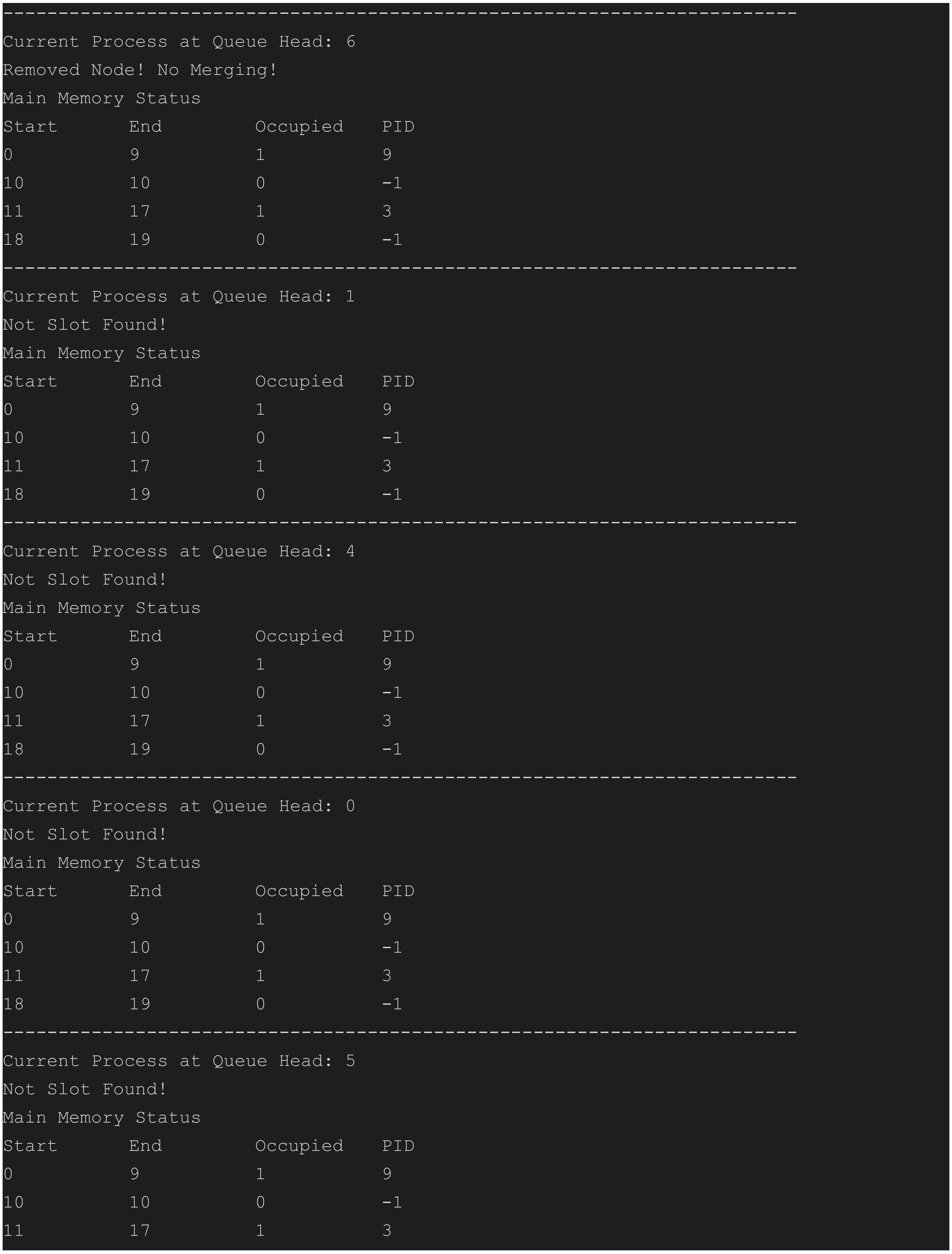
```
1           8           1           0
9           15          0           -1
16          19          1           6
20          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 2
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           0           0           -1
1           8           1           0
9           13          1           2
14          15          0           -1
16          19          1           6
20          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 1
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           0           0           -1
1           8           1           0
9           13          1           2
14          15          0           -1
16          19          1           6
20          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 6
Removed Node! Merged with Prev Node and Next Node!
Main Memory Status
Start       End         Occupied    PID
0           0           0           -1
1           8           1           0
9           13          1           2
14          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 0
Removed Node! Merged with Prev Node!
Main Memory Status
Start       End         Occupied    PID
0           8           0           -1
9           13          1           2
14          19          0           -1
------------------------------------------------------------------------
```

```
Current Process at Queue Head: 1
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           7           1           1
8           8           0           -1
9           13          1           2
14          19          0           -1
--------------------------------------------------------------------------
Current Process at Queue Head: 2
Removed Node! Merged with Prev Node and Next Node!
Main Memory Status
Start       End         Occupied    PID
0           7           1           1
8           19          0           -1
--------------------------------------------------------------------------
Current Process at Queue Head: 1
Removed Node! Merged with Next Node!
Main Memory Status
Start       End         Occupied    PID
0           19          0           -1
```

Worst Fit:

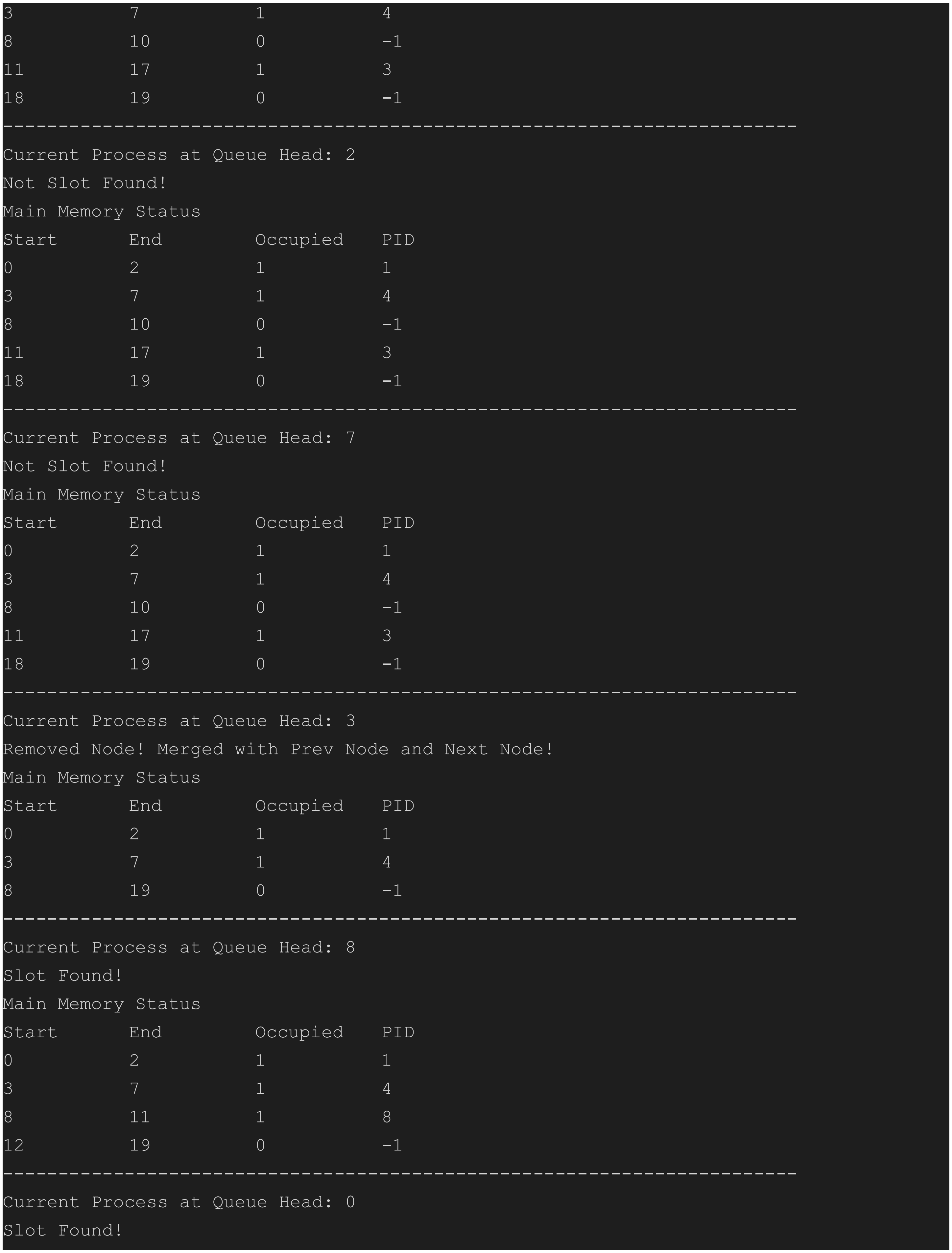
```
Processes:
PID         A.Time      B.Time      Memory Requirement
0           6           8           6
1           5           3           3
2           8           7           9
3           3           6           7
4           7           2           5
5           3           4           8
6           3           4           1
7           8           4           10
8           9           3           4
9           0           8           10
Best Fit Memory Allocation Algorithm
--------------------------------------------------------------------------
Current Process at Queue Head: 9
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           9           1           9
10          19          0           -1
```


```
--------------------------------------------------------------------------------
Current Process at Queue Head: 6
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           9           1           9
10          10          1           6
11          19          0           -1
--------------------------------------------------------------------------------
Current Process at Queue Head: 3
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           9           1           9
10          10          1           6
11          17          1           3
18          19          0           -1
--------------------------------------------------------------------------------
Current Process at Queue Head: 5
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           9           1           9
10          10          1           6
11          17          1           3
18          19          0           -1
--------------------------------------------------------------------------------
Current Process at Queue Head: 1
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           9           1           9
10          10          1           6
11          17          1           3
18          19          0           -1
--------------------------------------------------------------------------------
Current Process at Queue Head: 0
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           9           1           9
10          10          1           6
11          17          1           3
18          19          0           -1
```

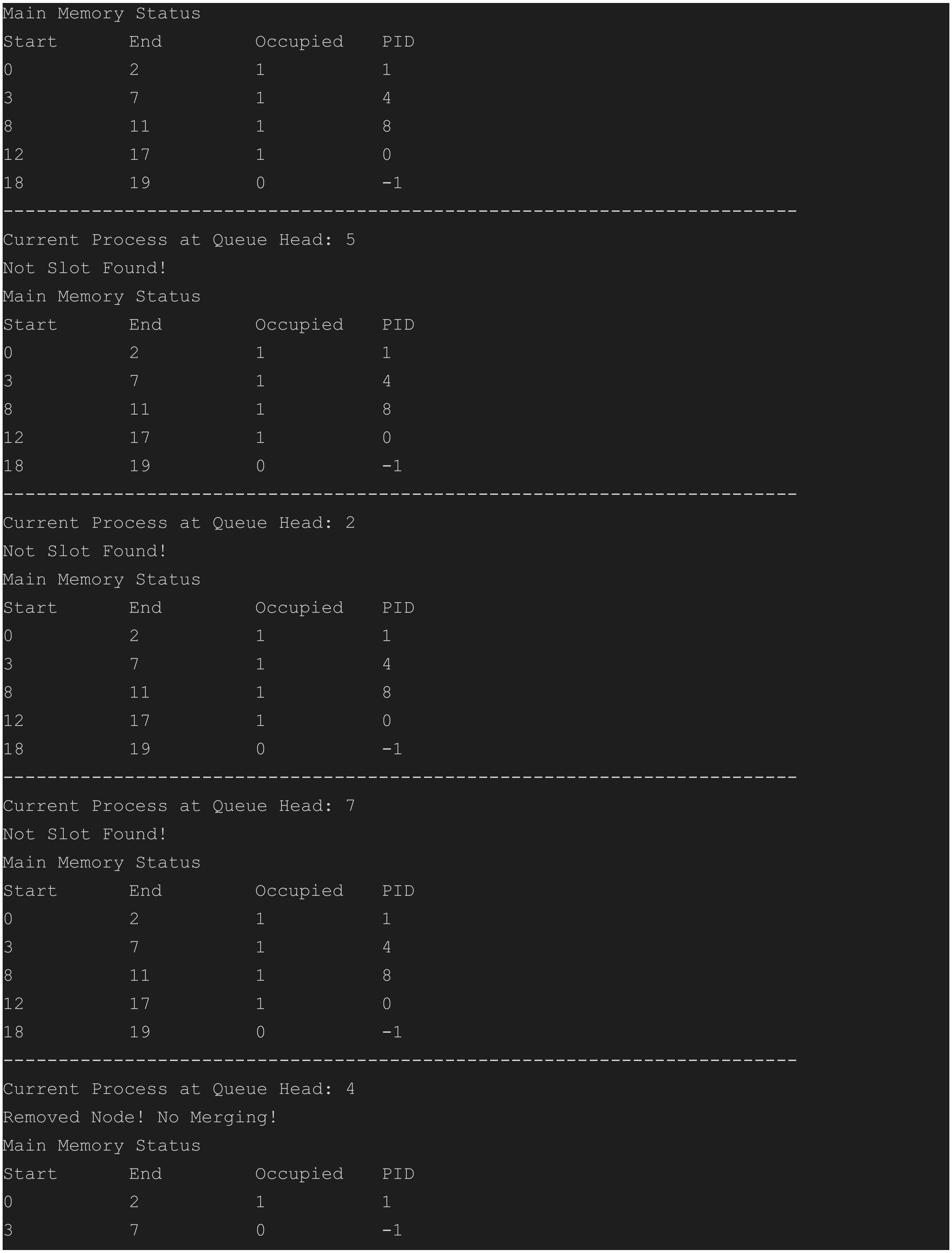


```
------------------------------------------------------------------------
Current Process at Queue Head: 6
Removed Node! No Merging!
Main Memory Status
Start      End         Occupied   PID
0          9           1          9
10         10          0          -1
11         17          1          3
18         19          0          -1
------------------------------------------------------------------------
Current Process at Queue Head: 1
Not Slot Found!
Main Memory Status
Start      End         Occupied   PID
0          9           1          9
10         10          0          -1
11         17          1          3
18         19          0          -1
------------------------------------------------------------------------
Current Process at Queue Head: 4
Not Slot Found!
Main Memory Status
Start      End         Occupied   PID
0          9           1          9
10         10          0          -1
11         17          1          3
18         19          0          -1
------------------------------------------------------------------------
Current Process at Queue Head: 0
Not Slot Found!
Main Memory Status
Start      End         Occupied   PID
0          9           1          9
10         10          0          -1
11         17          1          3
18         19          0          -1
------------------------------------------------------------------------
Current Process at Queue Head: 5
Not Slot Found!
Main Memory Status
Start      End         Occupied   PID
0          9           1          9
10         10          0          -1
11         17          1          3
```

```
18          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 9
Removed Node! Merged with Next Node!
Main Memory Status
Start       End         Occupied    PID
0           10          0           -1
11          17          1           3
18          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 1
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           2           1           1
3           10          0           -1
11          17          1           3
18          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 4
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           2           1           1
3           7           1           4
8           10          0           -1
11          17          1           3
18          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 0
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           2           1           1
3           7           1           4
8           10          0           -1
11          17          1           3
18          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 5
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           2           1           1
```



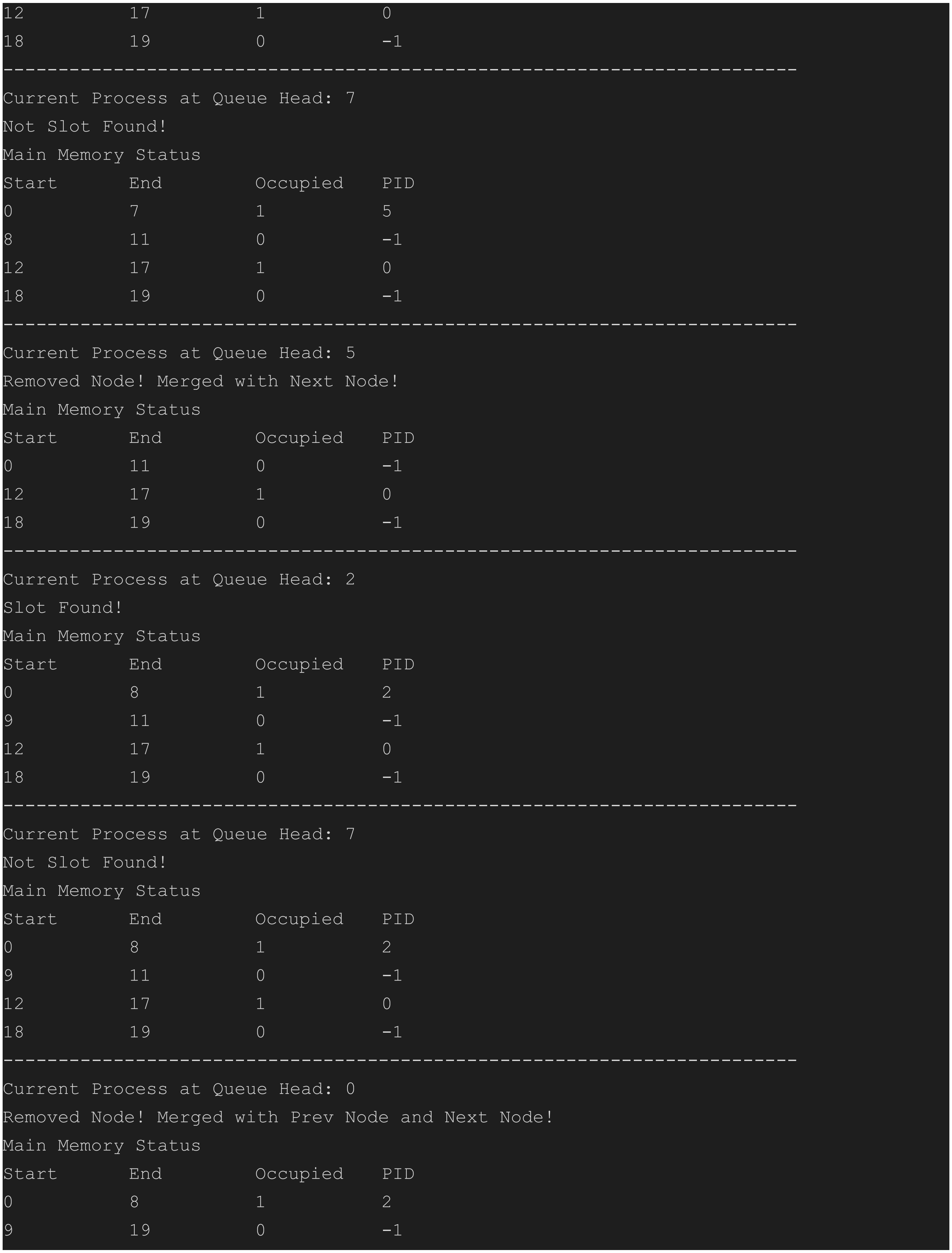
```
3           7           1           4
8           10          0           -1
11          17          1           3
18          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 2
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           2           1           1
3           7           1           4
8           10          0           -1
11          17          1           3
18          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 7
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           2           1           1
3           7           1           4
8           10          0           -1
11          17          1           3
18          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 3
Removed Node! Merged with Prev Node and Next Node!
Main Memory Status
Start       End         Occupied    PID
0           2           1           1
3           7           1           4
8           19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 8
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           2           1           1
3           7           1           4
8           11          1           8
12          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 0
Slot Found!
```



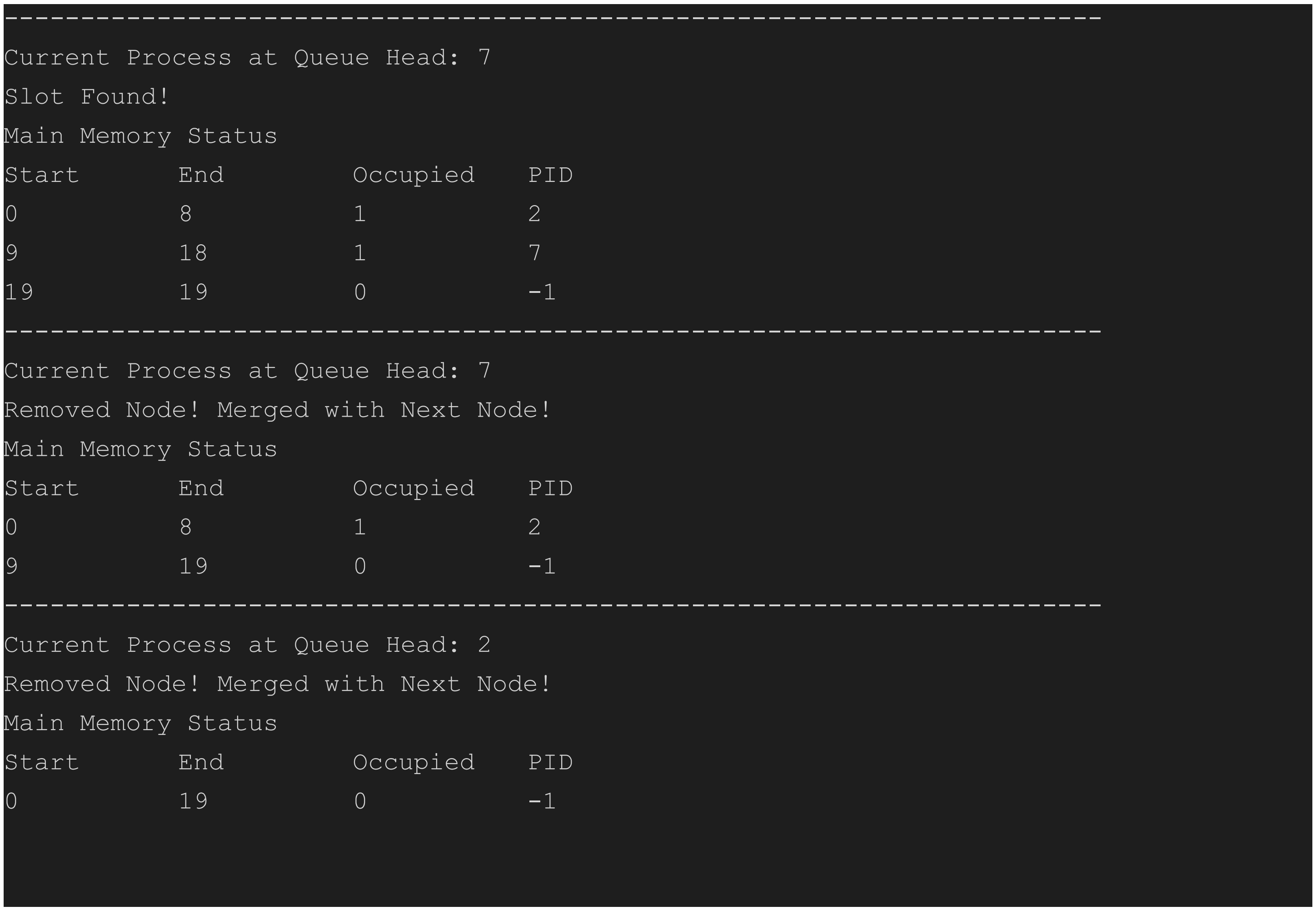
```
Main Memory Status
Start       End         Occupied    PID
0           2           1           1
3           7           1           4
8           11          1           8
12          17          1           0
18          19          0           -1
----------------------------------------------------------------------------
Current Process at Queue Head: 5
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           2           1           1
3           7           1           4
8           11          1           8
12          17          1           0
18          19          0           -1
----------------------------------------------------------------------------
Current Process at Queue Head: 2
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           2           1           1
3           7           1           4
8           11          1           8
12          17          1           0
18          19          0           -1
----------------------------------------------------------------------------
Current Process at Queue Head: 7
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           2           1           1
3           7           1           4
8           11          1           8
12          17          1           0
18          19          0           -1
----------------------------------------------------------------------------
Current Process at Queue Head: 4
Removed Node! No Merging!
Main Memory Status
Start       End         Occupied    PID
0           2           1           1
3           7           0           -1
```

```
8           11          1           8
12          17          1           0
18          19          0           -1
----------------------------------------------------------------------------
Current Process at Queue Head: 5
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           2           1           1
3           7           0           -1
8           11          1           8
12          17          1           0
18          19          0           -1
----------------------------------------------------------------------------
Current Process at Queue Head: 2
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           2           1           1
3           7           0           -1
8           11          1           8
12          17          1           0
18          19          0           -1
----------------------------------------------------------------------------
Current Process at Queue Head: 7
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           2           1           1
3           7           0           -1
8           11          1           8
12          17          1           0
18          19          0           -1
----------------------------------------------------------------------------
Current Process at Queue Head: 1
Removed Node! Merged with Next Node!
Main Memory Status
Start       End         Occupied    PID
0           7           0           -1
8           11          1           8
12          17          1           0
18          19          0           -1
----------------------------------------------------------------------------
Current Process at Queue Head: 5
```

```
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           7           1           5
8           7           0           -1
8           11          1           8
12          17          1           0
18          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 2
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           7           1           5
8           7           0           -1
8           11          1           8
12          17          1           0
18          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 7
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           7           1           5
8           7           0           -1
8           11          1           8
12          17          1           0
18          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 8
Removed Node! Merged with Prev Node!
Main Memory Status
Start       End         Occupied    PID
0           7           1           5
8           11          0           -1
12          17          1           0
18          19          0           -1
------------------------------------------------------------------------
Current Process at Queue Head: 2
Not Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           7           1           5
8           11          0           -1
```



```
12         17         1          0
18         19         0          -1
------------------------------------------------------------------------
Current Process at Queue Head: 7
Not Slot Found!
Main Memory Status
Start      End        Occupied   PID
0          7          1          5
8          11         0          -1
12         17         1          0
18         19         0          -1
------------------------------------------------------------------------
Current Process at Queue Head: 5
Removed Node! Merged with Next Node!
Main Memory Status
Start      End        Occupied   PID
0          11         0          -1
12         17         1          0
18         19         0          -1
------------------------------------------------------------------------
Current Process at Queue Head: 2
Slot Found!
Main Memory Status
Start      End        Occupied   PID
0          8          1          2
9          11         0          -1
12         17         1          0
18         19         0          -1
------------------------------------------------------------------------
Current Process at Queue Head: 7
Not Slot Found!
Main Memory Status
Start      End        Occupied   PID
0          8          1          2
9          11         0          -1
12         17         1          0
18         19         0          -1
------------------------------------------------------------------------
Current Process at Queue Head: 0
Removed Node! Merged with Prev Node and Next Node!
Main Memory Status
Start      End        Occupied   PID
0          8          1          2
9          19         0          -1
```



```
-------------------------------------------------------------------------
Current Process at Queue Head: 7
Slot Found!
Main Memory Status
Start       End         Occupied    PID
0           8           1           2
9           18          1           7
19          19          0           -1
-------------------------------------------------------------------------
Current Process at Queue Head: 7
Removed Node! Merged with Next Node!
Main Memory Status
Start       End         Occupied    PID
0           8           1           2
9           19          0           -1
-------------------------------------------------------------------------
Current Process at Queue Head: 2
Removed Node! Merged with Next Node!
Main Memory Status
Start       End         Occupied    PID
0           19          0           -1
```

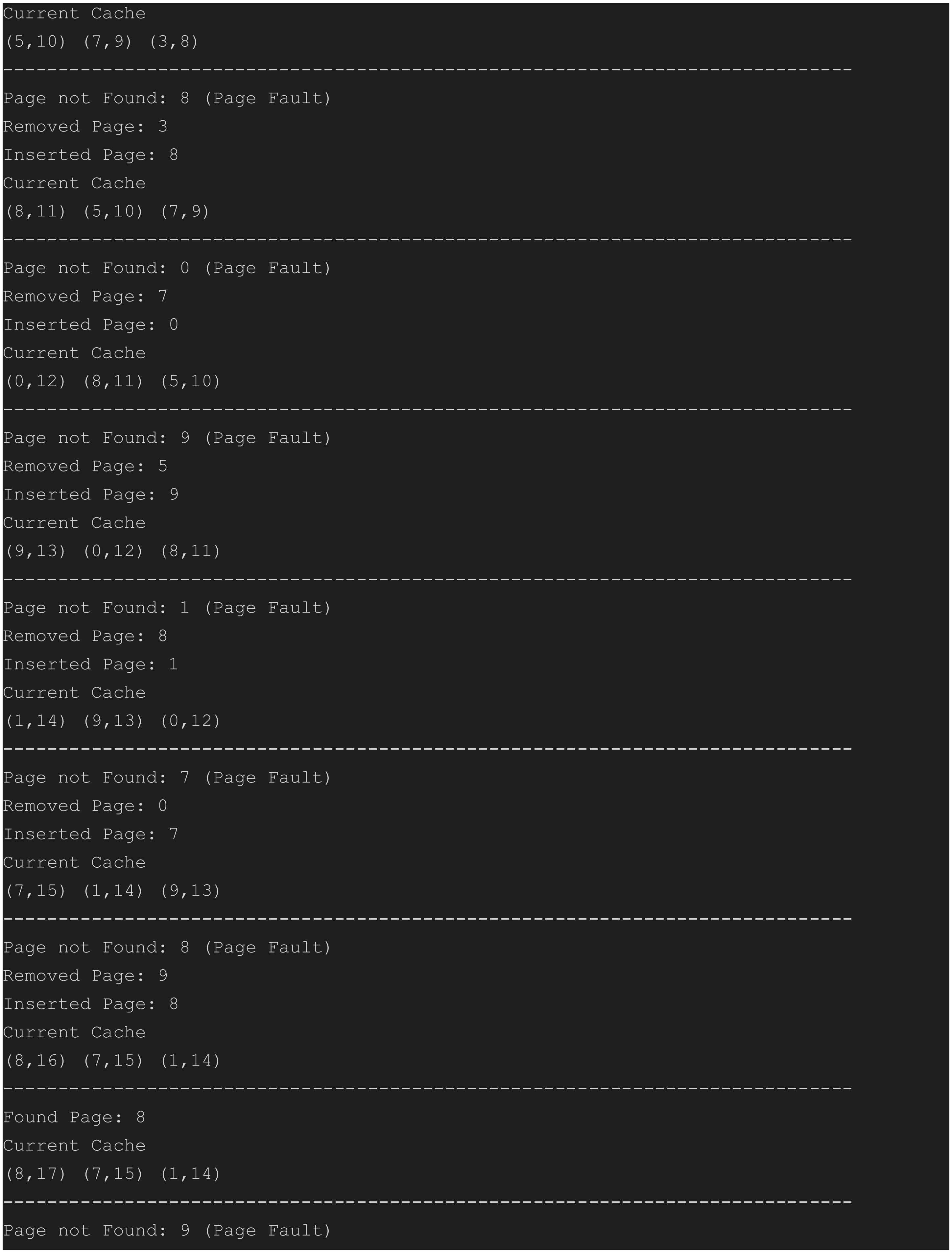
2. Write a program that implements the following Page replacement algorithm.
i) LRU (Least Recently Used)
ii) Optimal Page Replacement algorithm

```cpp
#include <bits/stdc++.h>

#define N 10
#define M 20
#define pi pair<int,int>
#define S second
#define F first

using namespace std;

void lru(vector<int>& required_pages,int frame_size){
   cout<<"Least Recently Used Cache"<<endl;
   unordered_map<int,int> umap;
   int T = 0;
   int page_faults = 0;
   for(int k = 0;k<required_pages.size();k++){
       int i = required_pages[k];
       if(umap.count(i)){
           cout<<"Found Page: "<<i<<endl;
           umap[i] = T++;
       }else{
           page_faults++;
           cout<<"Page not Found: "<<i<<" (Page Fault)"<<endl;
           if(umap.size()==frame_size){
               int least_recently_used_value = T,least_recently_used_page = -1;
               for(auto i: umap){
                   if(i.S<least_recently_used_value){
                       least_recently_used_value = i.S;
                       least_recently_used_page = i.F;
                   }
               }
               cout<<"Removed Page: "<<least_recently_used_page<<endl;
               umap.erase(least_recently_used_page);
           }
           umap[i] = T++;
           cout<<"Inserted Page: "<<i<<endl;
       }
       cout<<"Current Cache"<<endl;
       for(auto i: umap){
           cout<<"("<<i.F<<","<<i.S<<")"<<" ";
```

```
        }
        cout<<endl;

cout<<"-----------------------------------------------------------------------------"
<<endl;
    }
    cout<<"Total Page Faults: "<<page_faults<<endl;
    cout<<endl<<endl<<endl;

}

void optimum(vector<int>& required_pages,int frame_size){

    #define MAX required_pages.size();

    cout<<"Optimum Cache"<<endl;
    unordered_map<int,int> umap;
    int page_faults = 0;

    for(int k = 0;k<required_pages.size();k++){
        int i = required_pages[k];
        if(umap.count(i)){
            cout<<"Found Page: "<<i<<endl;
            umap[i] = MAX;
            for(int j =k+1;j<required_pages.size();j++){
                if(required_pages[j]==i){
                    umap[i] = j;
                    break;
                }
            }
        }else{
            page_faults++;
            cout<<"Page not Found: "<<i<<" (Page Fault)"<<endl;
            if(umap.size()==frame_size){
                int optimum_value = -1,least_optimum_page = -1;
                for(auto i: umap){
                    if(i.S>optimum_value){
                        optimum_value = i.S;
                        least_optimum_page = i.F;
                    }
                }
                cout<<"Removed Page: "<<least_optimum_page<<endl;
                umap.erase(least_optimum_page);
            }
            umap[i] = MAX;
            for(int j =k+1;j<required_pages.size();j++){
                if(required_pages[j]==i){
                    umap[i] = j;
                    break;
                }
            }
            cout<<"Inserted Page: "<<i<<endl;
        }
        cout<<"Current Cache"<<endl;
        for(auto i: umap){
            cout<<"("<<i.F<<","<<i.S<<")"<<" ";
        }
        cout<<endl;

cout<<"-----------------------------------------------------------------------------"
<<endl;
   }
   cout<<"Total Page Faults: "<<page_faults<<endl;
}

int main(){
   srand(time(NULL));
   vector<int> required_pages;
   for(int i = 0;i<M;i++){
       required_pages.push_back(rand()%N);
   }

   lru(required_pages,3);
   optimum(required_pages,3);
}
```

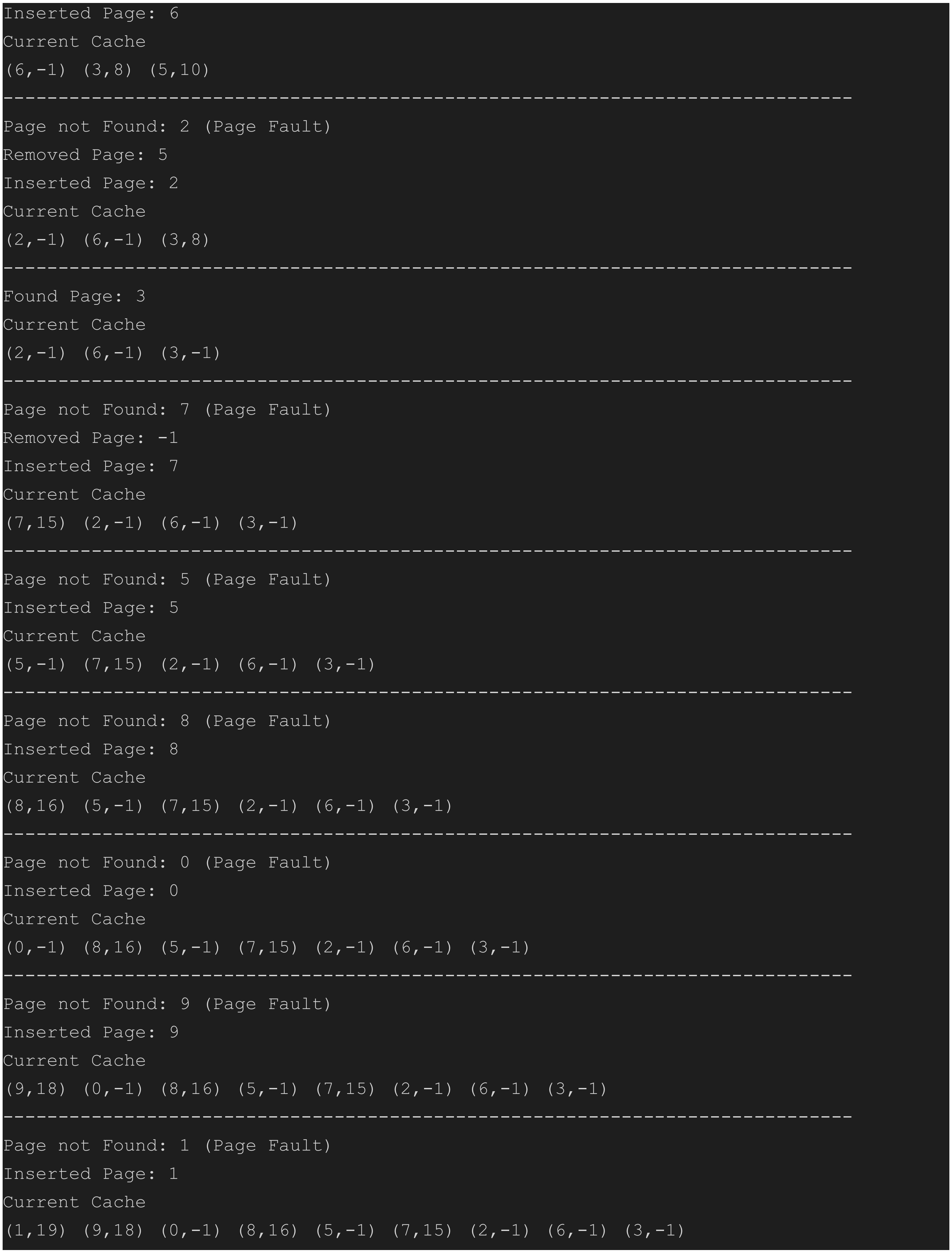
```
Least Recently Used Cache
Page not Found: 0 (Page Fault)
Inserted Page: 0
Current Cache
(0,0)
-----------------------------------------------------------------------------
Page not Found: 5 (Page Fault)
Inserted Page: 5
Current Cache
(5,1) (0,0)
-----------------------------------------------------------------------------
```

```
Page not Found: 3 (Page Fault)
Inserted Page: 3
Current Cache
(3,2) (5,1) (0,0)
------------------------------------------------------------------------------
Found Page: 0
Current Cache
(3,2) (5,1) (0,3)
------------------------------------------------------------------------------
Page not Found: 8 (Page Fault)
Removed Page: 5
Inserted Page: 8
Current Cache
(8,4) (3,2) (0,3)
------------------------------------------------------------------------------
Found Page: 3
Current Cache
(8,4) (3,5) (0,3)
------------------------------------------------------------------------------
Page not Found: 6 (Page Fault)
Removed Page: 0
Inserted Page: 6
Current Cache
(6,6) (8,4) (3,5)
------------------------------------------------------------------------------
Page not Found: 2 (Page Fault)
Removed Page: 8
Inserted Page: 2
Current Cache
(2,7) (6,6) (3,5)
------------------------------------------------------------------------------
Found Page: 3
Current Cache
(2,7) (6,6) (3,8)
------------------------------------------------------------------------------
Page not Found: 7 (Page Fault)
Removed Page: 6
Inserted Page: 7
Current Cache
(7,9) (2,7) (3,8)
------------------------------------------------------------------------------
Page not Found: 5 (Page Fault)
Removed Page: 2
Inserted Page: 5
```



```
Current Cache
(5,10) (7,9) (3,8)
-----------------------------------------------------------------------------
Page not Found: 8 (Page Fault)
Removed Page: 3
Inserted Page: 8
Current Cache
(8,11) (5,10) (7,9)
-----------------------------------------------------------------------------
Page not Found: 0 (Page Fault)
Removed Page: 7
Inserted Page: 0
Current Cache
(0,12) (8,11) (5,10)
-----------------------------------------------------------------------------
Page not Found: 9 (Page Fault)
Removed Page: 5
Inserted Page: 9
Current Cache
(9,13) (0,12) (8,11)
-----------------------------------------------------------------------------
Page not Found: 1 (Page Fault)
Removed Page: 8
Inserted Page: 1
Current Cache
(1,14) (9,13) (0,12)
-----------------------------------------------------------------------------
Page not Found: 7 (Page Fault)
Removed Page: 0
Inserted Page: 7
Current Cache
(7,15) (1,14) (9,13)
-----------------------------------------------------------------------------
Page not Found: 8 (Page Fault)
Removed Page: 9
Inserted Page: 8
Current Cache
(8,16) (7,15) (1,14)
-----------------------------------------------------------------------------
Found Page: 8
Current Cache
(8,17) (7,15) (1,14)
-----------------------------------------------------------------------------
Page not Found: 9 (Page Fault)
```

```
Removed Page: 1
Inserted Page: 9
Current Cache
(9,18) (8,17) (7,15)
------------------------------------------------------------------------------
Page not Found: 1 (Page Fault)
Removed Page: 7
Inserted Page: 1
Current Cache
(1,19) (9,18) (8,17)
------------------------------------------------------------------------------
Total Page Faults: 16
Optimum Cache
Page not Found: 0 (Page Fault)
Inserted Page: 0
Current Cache
(0,3)
------------------------------------------------------------------------------
Page not Found: 5 (Page Fault)
Inserted Page: 5
Current Cache
(5,10) (0,3)
------------------------------------------------------------------------------
Page not Found: 3 (Page Fault)
Inserted Page: 3
Current Cache
(3,5) (5,10) (0,3)
------------------------------------------------------------------------------
Found Page: 0
Current Cache
(3,5) (5,10) (0,12)
------------------------------------------------------------------------------
Page not Found: 8 (Page Fault)
Removed Page: 0
Inserted Page: 8
Current Cache
(8,11) (3,5) (5,10)
------------------------------------------------------------------------------
Found Page: 3
Current Cache
(8,11) (3,8) (5,10)
------------------------------------------------------------------------------
Page not Found: 6 (Page Fault)
Removed Page: 8
```



```
Inserted Page: 6
Current Cache
(6,-1) (3,8) (5,10)
-----------------------------------------------------------------------------
Page not Found: 2 (Page Fault)
Removed Page: 5
Inserted Page: 2
Current Cache
(2,-1) (6,-1) (3,8)
-----------------------------------------------------------------------------
Found Page: 3
Current Cache
(2,-1) (6,-1) (3,-1)
-----------------------------------------------------------------------------
Page not Found: 7 (Page Fault)
Removed Page: -1
Inserted Page: 7
Current Cache
(7,15) (2,-1) (6,-1) (3,-1)
-----------------------------------------------------------------------------
Page not Found: 5 (Page Fault)
Inserted Page: 5
Current Cache
(5,-1) (7,15) (2,-1) (6,-1) (3,-1)
-----------------------------------------------------------------------------
Page not Found: 8 (Page Fault)
Inserted Page: 8
Current Cache
(8,16) (5,-1) (7,15) (2,-1) (6,-1) (3,-1)
-----------------------------------------------------------------------------
Page not Found: 0 (Page Fault)
Inserted Page: 0
Current Cache
(0,-1) (8,16) (5,-1) (7,15) (2,-1) (6,-1) (3,-1)
-----------------------------------------------------------------------------
Page not Found: 9 (Page Fault)
Inserted Page: 9
Current Cache
(9,18) (0,-1) (8,16) (5,-1) (7,15) (2,-1) (6,-1) (3,-1)
-----------------------------------------------------------------------------
Page not Found: 1 (Page Fault)
Inserted Page: 1
Current Cache
(1,19) (9,18) (0,-1) (8,16) (5,-1) (7,15) (2,-1) (6,-1) (3,-1)
```

```
-----------------------------------------------------------------------------
Found Page: 7
Current Cache
(1,19) (9,18) (0,-1) (8,16) (5,-1) (7,-1) (2,-1) (6,-1) (3,-1)
-----------------------------------------------------------------------------
Found Page: 8
Current Cache
(1,19) (9,18) (0,-1) (8,17) (5,-1) (7,-1) (2,-1) (6,-1) (3,-1)
-----------------------------------------------------------------------------
Found Page: 8
Current Cache
(1,19) (9,18) (0,-1) (8,-1) (5,-1) (7,-1) (2,-1) (6,-1) (3,-1)
-----------------------------------------------------------------------------
Found Page: 9
Current Cache
(1,19) (9,-1) (0,-1) (8,-1) (5,-1) (7,-1) (2,-1) (6,-1) (3,-1)
-----------------------------------------------------------------------------
Found Page: 1
Current Cache
(1,-1) (9,-1) (0,-1) (8,-1) (5,-1) (7,-1) (2,-1) (6,-1) (3,-1)
-----------------------------------------------------------------------------
Total Page Faults: 12
```