data_tructures(&algorithms, lecture07)

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Plan

Queue ADT

Introduction, queue operation, queue application

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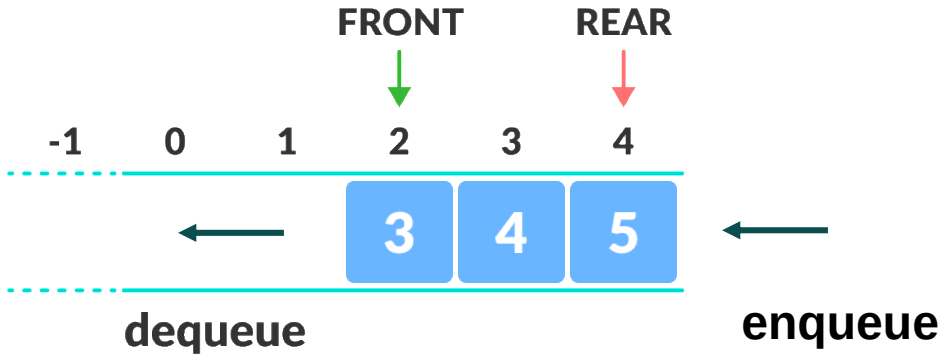
Queue ADT

Introduce Queue data structure, some operations

What Is A Queue

- A linear data structure that can be accessed in both begins and ends for storing and retrieving data
- A queue is a First In, First Out (FIFO) data structure



Operations On Queue

- clear: clear the queue
- is empty: check if a queue is empty
- enqueue: put element on the rear of the queue
- dequeue: take the element on the top out of the queue
- front: get first element without removing it
- rear: get last element without removing it
- size: get size of the queue

Applications Of Queue

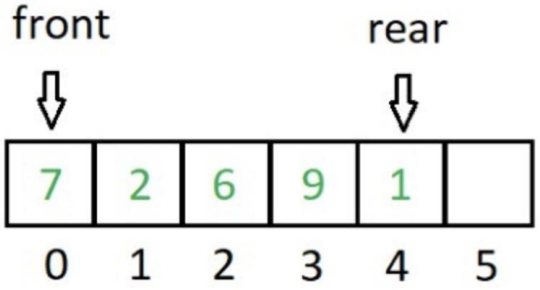
- Any kind of waiting list
- Operating System:
  - CPU scheduling
  - Disk scheduling
  - Shared resources between processes
- Traverse in tree / graph data structures
- Turned-base games
- Alt-Tab in Windows
- …

Array Implementation

Implement Queue by Array, Circular Queue

Queue Interface By Array

- Need global variables
- 2 indicators run forward
- Queue size is fixed
- Number of enqueue is limited



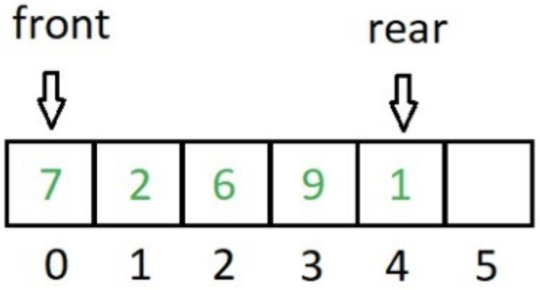

```
#define QUEUE_SIZE 100

extern int front;
extern int rear;
extern int queue[];

void clear_queue(void);
int is_empty(void);
int is_full(void);
void enqueue(const int n);
int dequeue(void);
int size(void);
void overflow(char* msg);
```

Queue Implementation By Array

- is_empty: when front = -1
- is_full: when rear runs to the end of array
- enqueue: need to check full queue before, then increase rear and assign new item to new rear position
- dequeue: need to check empty queue before, then increase front and return the item at old front
- size: distance between front vs rear

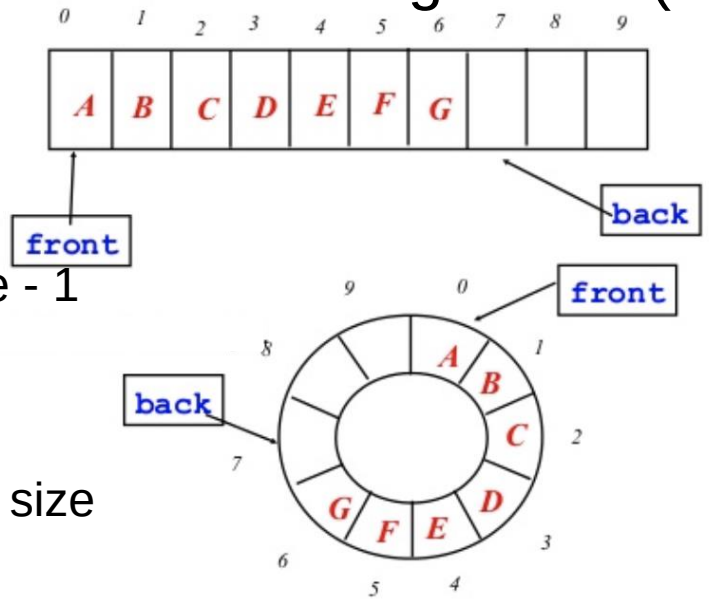


Queue Implementation By Array

- Number of enqueue is fixed
  - => When dequeue, if queue has only one item, clear queue to reset front & rear to -1
  - => Implement circular queue
- Size is fixed
  - => Using dynamic array and grow size if queue is full

Circular Queue By Array

- Main idea: front & rear run forward but go back (if possible) to 0 index.
  - is_empty: front = -1
  - is_full:
    - front = 0, rear = max size - 1
    - front = rear + 1
  - Using modulo to go back
    - front = (front + 1) % max size
  - real size:
    - if (front < rear): rear – front + 1
    - else: max size - (front - rear - 1)



Example: Queue of messages

- Simulation of sending message. Commands:
  - +message: enqueue message
    - When the queue is full, all messages will be sent
  - -: dequeue a message to send
  - a: Sending all messages by dequeue one by one
  - q: Quit simulation, all messages will be sent

- Using Circular Queue will support unlimited enqueue operation, still having full condition

Example: Queue of messages

- Queue: array of char pointers in heap memory
- Enqueue

```
Check if queue is full
Else
    If queue is empty front = 0
    Increase rear (go back if needed)
    Add message to rear position
```

- Dequeue

```
Check if message is empty
Else
    Get message at front
    If there is one message, clear queue
    Else increase front (go back if needed)
```

Example: Queue of messages

- Running simulation

```
Message sending simulation
>> +hello
Saved hello
>> +world
Saved world
>> +stack and queue
Saved stack and queue
>> -
Sending hello ...
>> +good bye
Saved good bye
>> a
Sending world ...
Sending stack and queue ...
Sending good bye ...
>> q
No message to send!
Program ended with exit code: 0
```

Linked List Implementation

Implement Queue by Linked List

LinkedList vs Queue

- Queue is Linked List with limited operations and/or other interfaces

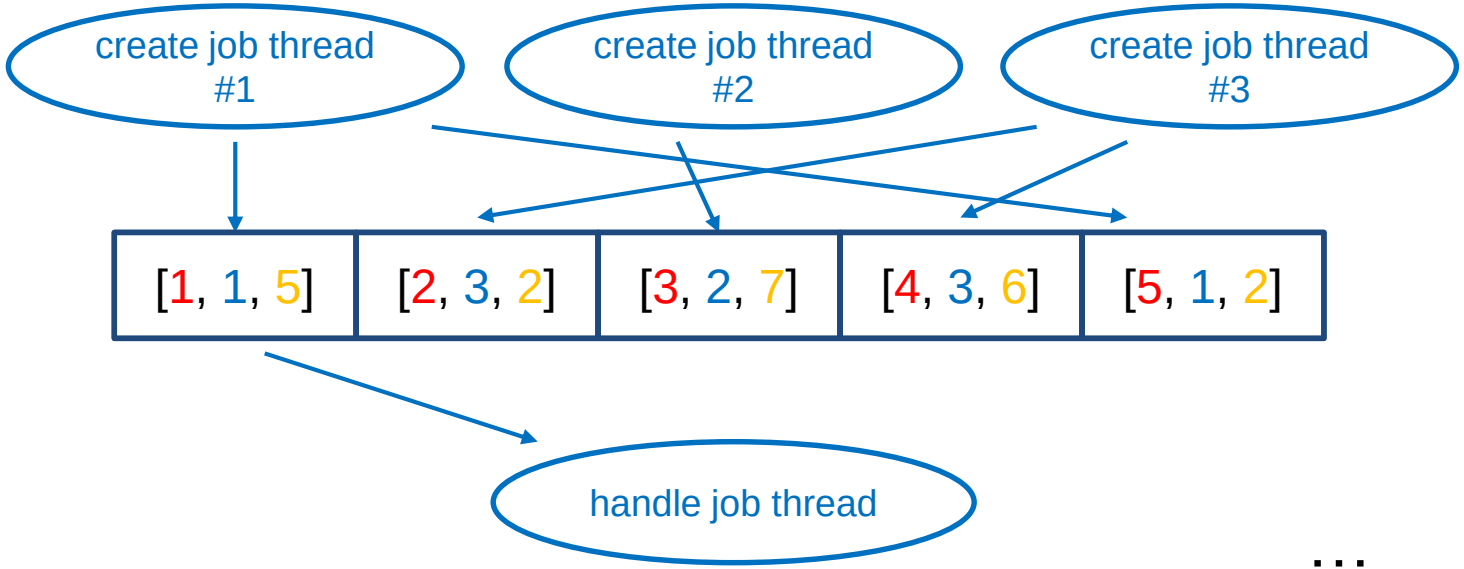
Linked List	Queue
Add to end	Enqueue
Remove from head	Dequeue
Clear list	Clear queue
Is empty	Is empty
Get size	Get size
	To array
	Front / Rear

Example: Queue of Jobs

- Simulation a queue of jobs
  - A job has an id, agent id (who creates this job) and duration (in seconds)
  - Several threads will create jobs in parallel and store them in a job queue
  - A thread will get job from that queue to execute it
  - Shared resources: queue of jobs and number of jobs

Example: Queue of Jobs

- Simulation a queue of jobs



Example: Queue of Jobs

- Implement queue of jobs
  - Job data

```
typedef struct
{
    int job_id;
    int agent_id;
    int duration; // in second
} job_data;
```

Job node in LL

```
typedef struct str_job job;

struct str_job
{
    job_data data;
    job* next;
};
```

Example: Queue of Jobs

- Implement queue of jobs
  - Enqueue operation

```
void enqueue(job** jobs_queue, job_data ajob)
{
    job* j = create_job(ajob);

    if (is_empty(*jobs_queue)) *jobs_queue = j;
    else
    {
        job* rear = *jobs_queue;
        while (rear->next != NULL) rear = rear->next;
        rear->next = j;
    }
}
```

Example: Queue of Jobs

- Implement queue of jobs
  - Dequeue operation

```
job_data dequeue(job** jobs_queue)
{
    if (is_empty(*jobs_queue))
    {
        printf("Jobs queue is empty!");
        exit(1);
    }
    else
    {
        job* j = *jobs_queue;
        *jobs_queue = j->next;
        job_data data = j->data;
        free(j);
        return data;
    }
}
```

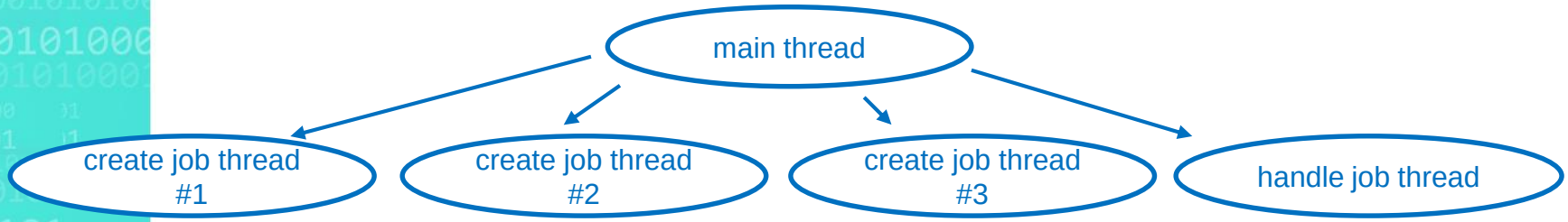
Example: Queue of Jobs

- Implement parallel threads
  - pthread_create: create a new thread to run in parallel

```
pthread_create(&tid, NULL, handle_jobs, NULL);
```

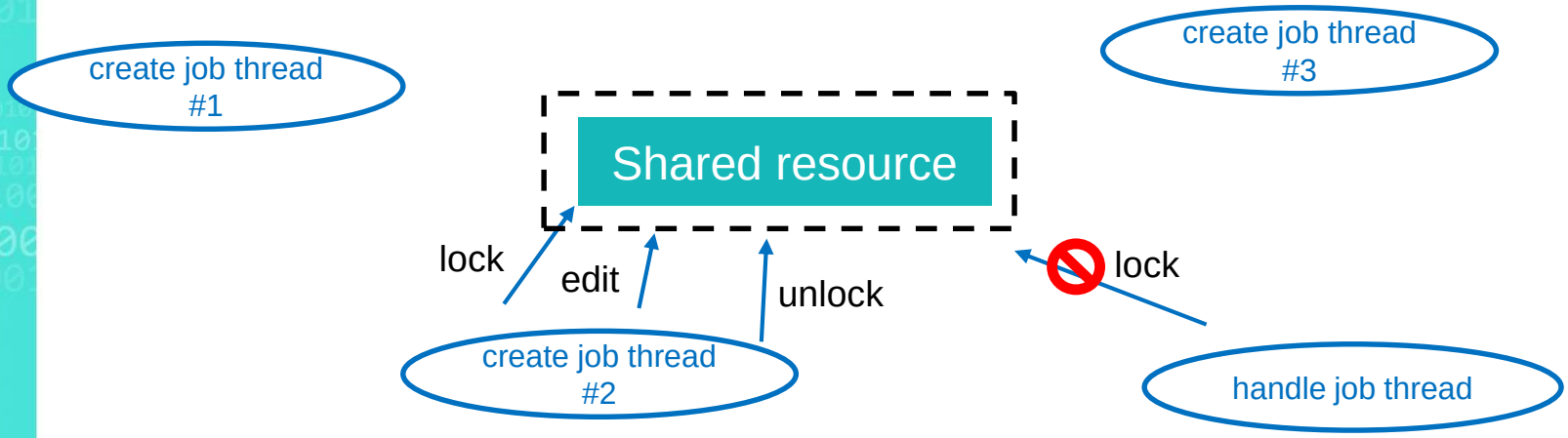
thread structure — thread attribute — callback function — arguments

  - pthread_exit: terminate a thread
  - sleep: to make current thread idle for a while



Example: Queue of Jobs

- Shared resources
  - pthread_mutex_t locker: declare a locker to lock shared resource
  - pthread_mutex_init(&locker,NULL): initialize the locker
  - pthread_mutex_lock(&locker): lock global resources
  - pthread_mutex_unlock(&locker): unlock global resources



Example: Queue of Jobs

- Putting all together
  - main thread

```
// init locker
pthread_mutex_init(&locker,NULL);

// create threads to generate jobs in parallel
for (int agent_id = 1; agent_id <= NAGENTS; agent_id++)
    pthread_create(&tid, NULL, generate_jobs, (void*)agent_id);
// create thread to handle generated jobs
pthread_create(&tid, NULL, handle_jobs, NULL);
```

Example: Queue of Jobs

- Putting all together
  - create job thread

```
int agent_id = (int) threadid;
for (int i = 1; i <= NJOBS; i++)
{
    pthread_mutex_lock(&locker); // lock the locker

    // increase number of jobs
    // create job data based on agent id, number of jobs
    // enqueue job data

    pthread_mutex_unlock(&locker); // unlock the locker

    sleep(rand() % WAIT_TIME);
}
pthread_exit(NULL);
```

Example: Queue of Jobs

- Putting all together
  - handle job thread

```
Endless loop
    Lock the locker
    If jobs queue is empty and no more jobs in future
        Quit handle thread
    Else If queue is not empty
        Handle a job
    Else
        Wait for a job
```

Example: Queue of Jobs

- Putting all together

```
Agent id 1 create job 1
Number of waiting jobs: 1
Handle job 1 of agent 1 in 4s
Agent id 2 create job 2
Agent id 3 create job 3
Agent id 2 create job 4
Agent id 2 create job 5
Agent id 1 create job 6
Agent id 3 create job 7
Number of waiting jobs: 6
Handle job 2 of agent 2 in 0s
Number of waiting jobs: 5
Handle job 3 of agent 3 in 0s
Number of waiting jobs: 4
Handle job 4 of agent 2 in 4s
```

Priority Queue

Introduce Priority Queue and how to implement it

What is Priority Queue?

- Same as a normal queue but …
  - Each element has a priority
  - Elements with higher priority will be dequeued before elements with lower priority
  - Elements with same priority will be dequeued in the order of enqueuing

> "**All animals are equal, but some animals are more equal than others**"
>
> *George Orwell – Animal Farm*

Example of Priority Queue

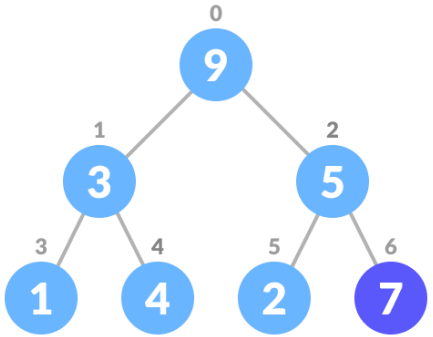
- Enqueue following pairs (key, priority)
  - (1, 1), (2, 1), (3, 2), (4, 1), (5, 2), (6, 3), (7, 1)
- Actual queue in building:
  - (1, 1)
  - (1, 1), (2, 1)
  - (3, 2), (1, 1), (2, 1)
  - (3, 2), (1, 1), (2, 1), (4, 1)
  - (3, 2), (5, 2), (1, 1), (2, 1), (4, 1)
  - (6, 3), (3, 2), (5, 2), (1, 1), (2, 1), (4, 1)
  - (6, 3), (3, 2), (5, 2), (1, 1), (2, 1), (4, 1), (7, 1)

Priority Queue by Array

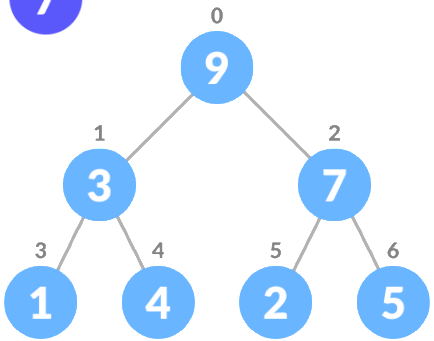
- Enqueue algorithm:
  - Insert new element at the rear
  - If priority of new element is greater than the one ahead then move it up until it's less than or equal
    - (3, 2), (1, 1), (2, 1), (4, 1)
    - (3, 2), (1, 1), (2, 1), (4, 1), (5, 2)
    - (3, 2), (1, 1), (2, 1), (5, 2), (4, 1)
    - (3, 2), (1, 1), (5, 2), (2, 1), (4, 1)
    - (3, 2), (5, 2), (1, 1), (2, 1), (4, 1)
  - Complexity:
    - Enqueue: O(n)
    - Dequeue: O(1)

Priority Queue by Heap

- Enqueue algorithm:
  - Insert new element at the end of the heap

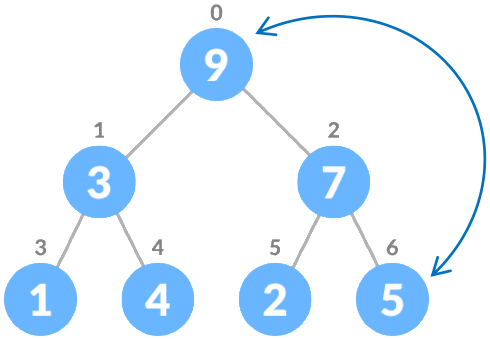


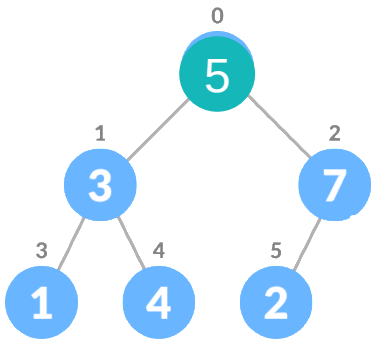
  - Heapify the whole tree

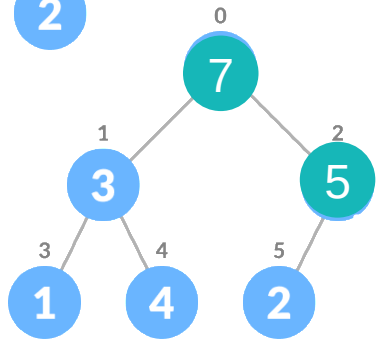


Priority Queue by Heap

- Dequeue algorithm:
  - Swap the root with the last element then remove it







  - Heapify the whole tree
  - Complexity:
    - Enqueue: O(logn)
    - Dequeue: O(logn)

Priority Queue by Heap

- Implement Priority Queue by Heap

```
typedef struct
{
    int key;
    int priority;
    int order;
} element;
```

```
extern int qsize;

void swap(element *a, element *b);
void print_queue(element* queue);
void heapify(element* queue, int i);
void enqueue(element* queue, element e);
element dequeue(element* queue);
int greater(element a, element b);
int is_empty(void);
```

Fix unstable characteristics of heap

Priority Queue by Heap

- Implement PriorityQueue by Heap

```
void heapify(element* queue, int i)
{
    int left = 2 * i + 1;
    int right = 2 * i + 2;
    int imax = i;

    if (left < qsize && greater(queue[left], queue[imax]))
        imax = left;
    if (right < qsize && greater(queue[right], queue[imax]))
        imax = right;

    if (imax != i)
    {
        swap(&queue[i], &queue[imax]);
        heapify(queue, imax);
    }
}
```

Priority Queue by Heap

- Implement Priority Queue by Heap

```
int greater(element a, element b)
{
    // First compare by priority
    // Then compare by order if same priority
}
```

```
void enqueue(element* queue, element e)
{
    // Add e to the end of the queue
    // Heapify the whole tree bottom-up
}
```

```
element dequeue(element* queue)
{
    // Get first element, save into e
    // Swap first element and last element
    // Heapify the new tree (exclude last element)
    // Return e
}
```