



```
#include <stdlib.h>
#include <string.h>
#include <ctype.h>

#define MAXPAROLA 30
#define MAXRIGA 80

int main(int argc, char *argv[])
{
    int freq[MAXPAROLA]; /* vettore di contatori
delle frequenze delle lunghezze delle parole */
    char riga[MAXRIGA];
    int i, inizio, lunghezza;
    FILE * f;

    for(i=0; i<MAXPAROLA; i++)
        freq[i]=0;

    if(argc != 2)
    {
        fprintf(stderr, "ERRORE, serve un parametro con il nome del file\n");
        exit(1);
    }
    f = fopen(argv[1], "r");
    if(f==NULL)
    {
        fprintf(stderr, "ERRORE, impossibile aprire il file %s\n", argv[1]);
        exit(1);
    }

    while( fgets( riga, MAXRIGA, f ) != NULL )
```

Synchronization

Synchronization protocols with semaphores

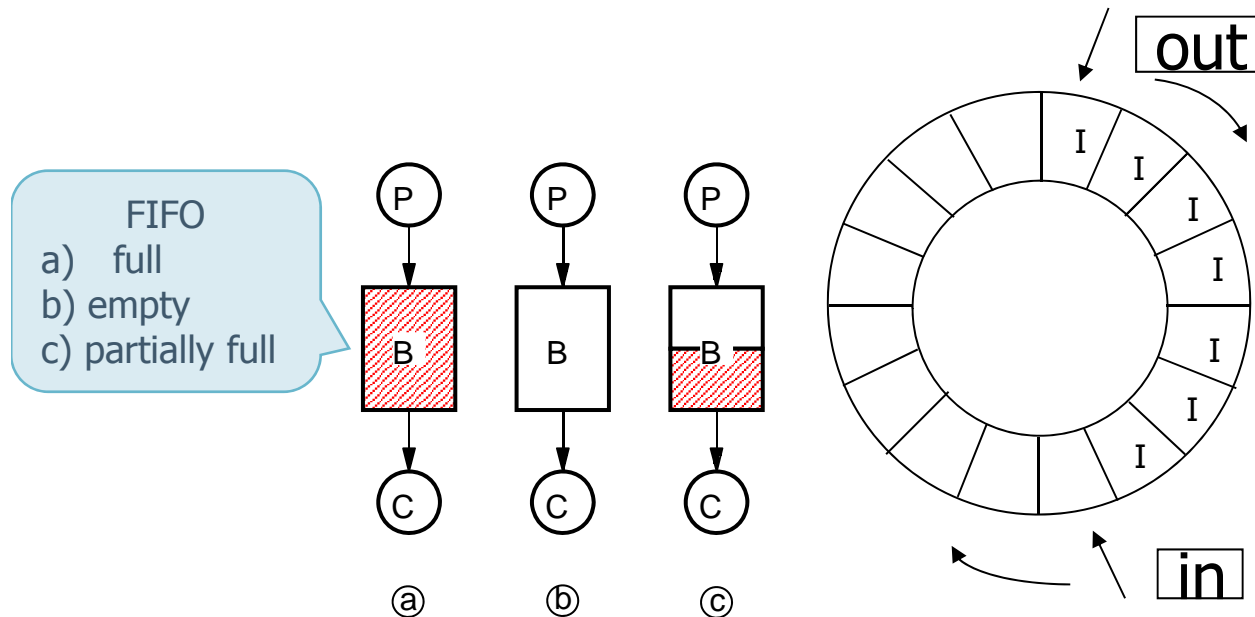
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Producer & Consumer with limited memory buffer

- Uses a circular buffer of size **MAX** for storing the produced elements to be consumed
- The circular buffer implements a FIFO (First-In First-Out) queue



Access functions

```
#define MAX ...  
...  
int buffer[MAX];  
int in, out;  
...  
void init () {  
    in = 0;  
    out = 0;  
}
```

```
void enqueue (int val) {  
    queue[in] = val;  
    in=(in+1)%MAX;  
    return;  
}
```

```
int dequeue (int *val) {  
    *val=queue[out];  
    out=(out+1)%MAX;  
    return;  
}
```

Concurrent access

number of full elements
number of empty elements

1 Producer
1 Consumer

```
init (full, 0);  
init (empty, MAX);
```

```
Producer () {  
    Message m;  
    while (TRUE) {  
        produces (m);  
        wait (empty);  
        enqueue (m);  
        signal (full);  
    }  
}
```

```
Consumer () {  
    Message m;  
  
    while (TRUE) {  
        wait (full);  
        m = dequeue ();  
        signal (empty);  
        consumes (m);  
    }  
}
```

Considerations

- ❖ The solution is symmetric (dual)
- ❖ Producers and consumers **operate** on different indexes of the buffer, thus they can operate **in concurrency**
 - As long as the queue is not full or empty
 - Otherwise either a producer or a consumer is blocked
- ❖ The solution can be easily extended more than one producer and consumer process
 - Two producers or two consumers should instead act in mutual exclusion to protect their index (**in** or **out**, respectively)

Producers & Consumers

P Producers
C Consumers

For Mutual Exclusion among
Producers (Consumers)

```
init (full, 0);  
init (empty, MAX);  
init (MEp, 1);  
init (MEc, 1);
```

```
Producer () {  
    Message m;  
    while (TRUE) {  
        produces m;  
        wait (empty);  
        wait (MEp);  
        enqueue (m);  
        signal (MEp);  
        signal (full);  
    }  
}
```

```
Consumer () {  
    Message m;  
    while (TRUE) {  
        wait (full);  
        wait (MEc);  
        m = dequeue ();  
        signal (MEc);  
        signal (empty);  
        consumes m;  
    }  
}
```

Readers & Writers

- ❖ Sharing a database between two sets of concurrent threads
 - One class of such threads is called **Reader threads**
 - Readers are allowed access the database in concurrency
 - One class of such threads is called **Writer threads**
 - Writers must access the database is in Mutual Exclusion
 - with other Writers
 - with Readers

Readers & Writers

- ❖ There are two versions of the problem
 - Reader priority
 - Writer priority

Readers & Writers

- ❖ When a Writer is writing in the database, several Readers and Writers processes can be blocked outside their CSs waiting the end of the write operation
- ❖ Readers precedence
 - At the end of a writing operation, to give priority to the Readers means to favour the access of the waiting Readers rather than of the waiting Writers
- ❖ Writers precedence
 - At the end of a writing operation, to give priority to the Writers means to favour the access of the waiting Writers rather than of the waiting Readers

Readers & Writers

❖ Common objectives

- Respect the precedence protocol
- Comply with the Bernstein conditions
- Maximize concurrency

Readers priority

- ❖ Giving priority to the Readers means that
 - A Reader does not wait unless a Writer is writing
- ❖ Access protocol
 - While Readers are reading (they can access the database in concurrency), new Readers are allowed to read, and Writers are blocked
 - When the last Reader terminates, a waiting Writer can access the database

Readers priority

```
nR = 0;  
init (meR, 1); init (meW, 1);  
init (w, 1);
```

Reader

```
wait (meR);  
  nR++;  
  if (nR==1)  
    wait (w);  
signal (meR);  
...  
read  
...  
wait (meR);  
  nR--;  
  if (nR==0)  
    signal (w);  
signal (meR);
```

Writer

```
wait(meW)  
wait (w);  
...  
write  
...  
signal (w);  
signal(meW)
```

Analysis

❖ The solution uses

- A shared variable (**nR**) that counts the number of Readers inside their CS (reading)
- A Mutual Exclusion semaphore that protects variable **nR** (**meR**)
- A Mutual Exclusion semaphore (**w**) among Writers, or among Readers and Writers
- A Mutual Exclusion semaphore (**meW**) among Writers, (only writers can queue on this semaphore)

Analysis

- ❖ Writers are subject to starvation, since they can wait forever
 - More complex solutions are possible that avoid starvation of the Writers

Writers priority

- ❖ Giving priority to the Writers means
 - A Writer has priority over all Readers

- ❖ Access protocol
 - A Writer trying to enter its CS blocks **new** Readers, but the Readers that are inside their CS are allowed to complete their reading task

Writers priority

```
nR = nW = 0;  
init (w, 1); init (r, 1);  
init (meR, 1); init (meW, 1);
```

Reader

```
wait (r);  
wait (meR);  
nR++;  
if (nR == 1)  
wait (w);  
signal (meR);  
signal (r);  
...  
read  
...  
wait (meR);  
nR--;  
if (nR == 0)  
signal (w);  
signal (meR);
```

Writer

```
wait (meW);  
nW++;  
if (nW == 1)  
wait (r);  
signal (meW);  
wait (w);  
...  
write  
...  
signal (w)  
wait (meW);  
nW--;  
if (nW == 0)  
signal (r);  
signal (meW);
```


Analysis

❖ The solution uses

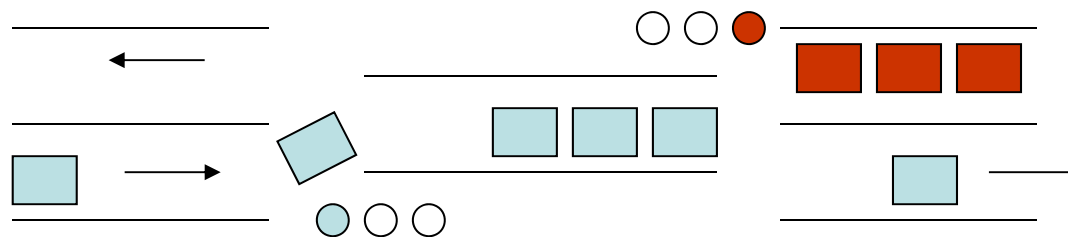
- Two shared variables (**nR** and **nW**) for counting the Readers inside their CS, and the Writers that need to write (one of them possibly writing)
- Two Mutual Exclusion semaphores (**meR** and **meW**) for protecting the variables **nR** and **nW**
- Two Mutual Exclusion semaphores (**r** and **w**) to enforce Readers and Writers to wait on different queues

❖ The Readers are subject to starvation, since they can wait forever

- More complex solutions are possible that avoid starvation for the Readers

Single lane tunnel

- ❖ A tunnel has a single lane, and cars can proceed only in alternate directions
- ❖ Access protocol
 - Enable any number of cars (threads) to proceed in the same direction
 - If there is traffic in one direction, block traffic in the opposite direction



Single lane tunnel

- ❖ Similar to the Readers & Writers problem, but for two sets of Readers
- ❖ Data structure
 - Two shared count variables (**n1** and **n2**), one for each travel direction
 - Two semaphores (**s1** and **s2**), one for each travel direction
 - A global semaphore wait (**busy**)
- ❖ In its basic implementation can result in starvation of cars in one direction

Solution

```
n1 = n2 = 0;  
init (s1, 1); init (s2, 1);  
init (busy, 1);
```

left2right

```
wait (s1);  
  n1++;  
  if (n1 == 1)  
    wait (busy);  
signal (s1);  
...  
Run (left to right)  
...  
wait (s1);  
  n1--;  
  if (n1 == 0)  
    signal (busy);  
signal (s1);
```

right2left

```
wait (s2);  
  n2++;  
  if (n2 == 1)  
    wait (busy);  
signal (s2);  
...  
Run (left to right)  
...  
wait (s2);  
  n2--;  
  if (n2 == 0)  
    signal (busy);  
signal (s2);
```