CSCI315 – Operating Systems Design

Department of Computer Science

Bucknell University

Process Synchronization Introduction

Ch 6.1-6.3

This set of notes is based on notes from the textbook authors, as well as L. Felipe Perrone, Joshua Stough, and other instructors.
Xiannong Meng, Fall 2021.

Two Examples

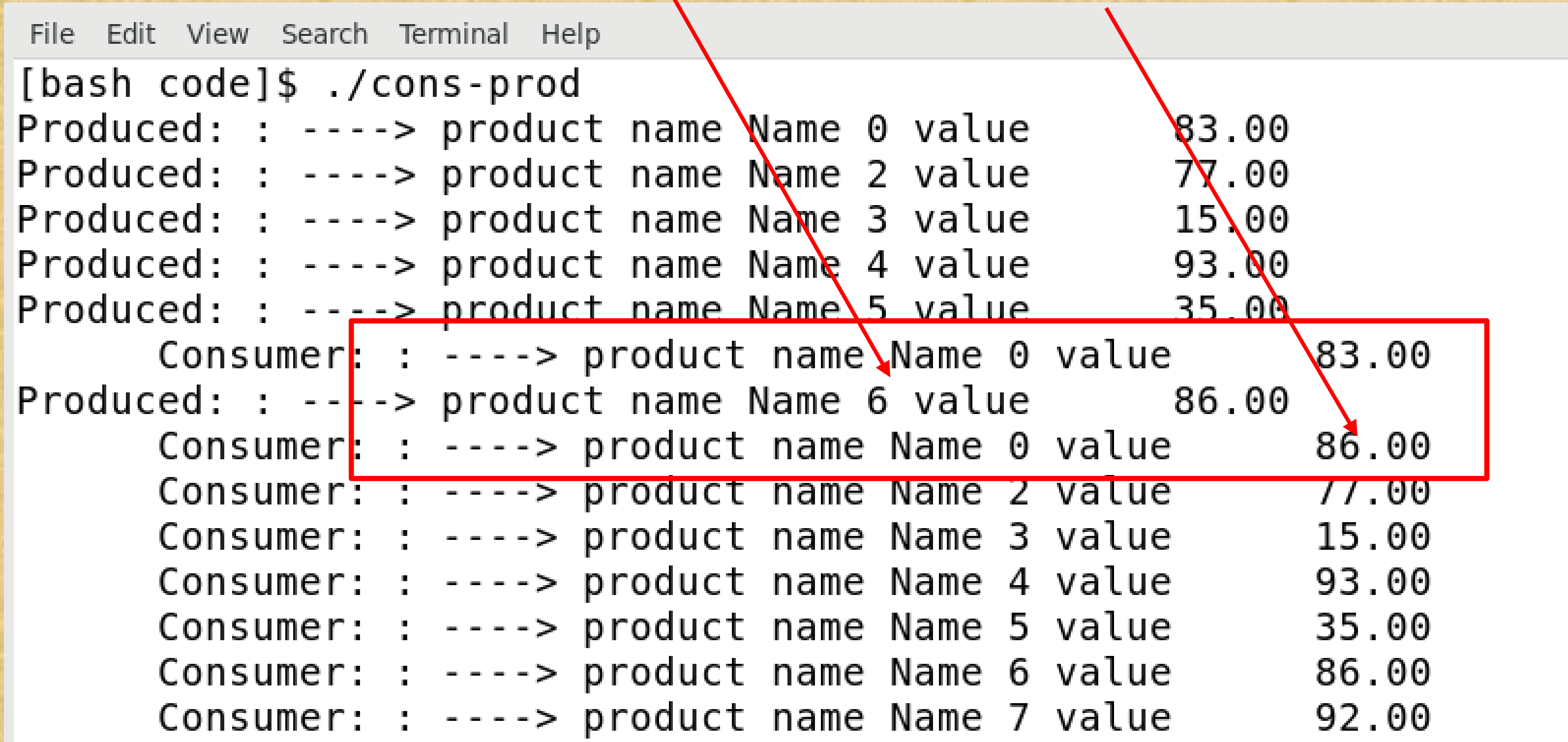
- Multiple threads increment a shared variable leading to incorrect results
  - http://www.eg.bucknell.edu/~cs315/F2021/meng/code/synch/trd-share.c
- Multiple threads share a string buffer (read/write) leading to incorrect results (consuming items not in the order of producing)
  - http://www.eg.bucknell.edu/~cs315/F2021/meng/code/synch/consumer-producer-wosynch.c

Who stole the two counts from me?!!

```
[xmeng@polaris thread]$ ./trd-share
main() reporting that all 5000 threads have terminated
v should be 5000, it is 4998
[xmeng@polaris thread]$
```

Consumer-Producer Problem

Incorrect result …



```
[bash code]$ ./cons-prod
Produced: : ----> product name Name 0 value      83.00
Produced: : ----> product name Name 2 value      77.00
Produced: : ----> product name Name 3 value      15.00
Produced: : ----> product name Name 4 value      93.00
Produced: : ----> product name Name 5 value      35.00
     Consumer: : ----> product name Name 0 value      83.00
Produced: : ----> product name Name 6 value      86.00
     Consumer: : ----> product name Name 0 value      86.00
     Consumer: : ----> product name Name 2 value      77.00
     Consumer: : ----> product name Name 3 value      15.00
     Consumer: : ----> product name Name 4 value      93.00
     Consumer: : ----> product name Name 5 value      35.00
     Consumer: : ----> product name Name 6 value      86.00
     Consumer: : ----> product name Name 7 value      92.00
```

Process Synchronization

- Processes work together to solve problems.
- They need to coordinate with each other in order to accomplish a task.
- Without coordination, things can go wrong as we saw in the last two examples. Many other scenarios lead to similar problems.

Race Condition

A **race condition** is where the outcome of the execution depends on the particular order in which the threads[note] access the shared data.

Note: in this context, we will use the term process and thread interchangeably.

We have seen this phenomenon in our thread discussion

```
[xmeng@polaris thread]$ ./trd-share
main() reporting that all 5000 threads have terminated
v should be 5000, it is 4998
[xmeng@polaris thread]$
```

The Synchronization Problem

- Concurrent access to shared data may result in data inconsistency.

- Maintaining data consistency requires mechanisms to ensure the “orderly” execution of cooperating processes.

Producer-Consumer
Race Condition

The **Producer** does:

```
while (1) {
    while (count == BUFFER_SIZE)
        ; // buffer full, wait
    // produce an item and put in buffer at “in”
    buffer[in] = make_item();
    in = (in + 1) % BUFFER_SIZE;
    counter++;
}
```

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Producer-Consumer

Race Condition

The **Consumer** does:

```
while (1) {
   while (count == 0)
      ; // buffer empty, wait
   item =  buffer[out];
   out = (out + 1) % BUFFER_SIZE;
   counter--;
   // consume the item
}
```

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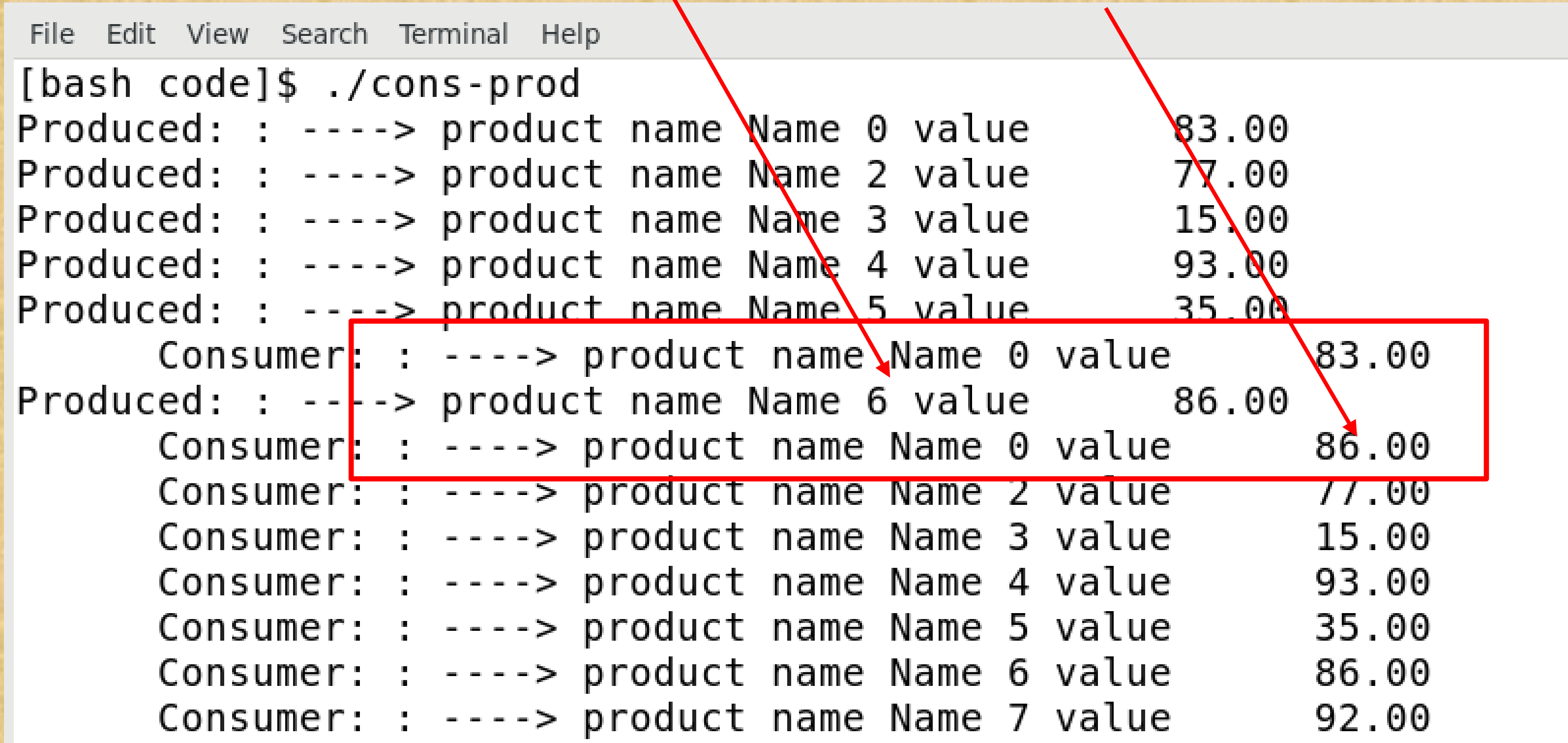
Consumer-Producer
Race Condition

Incorrect result …



```
[bash code]$ ./cons-prod
Produced: : ----> product name Name 0 value     83.00
Produced: : ----> product name Name 2 value     77.00
Produced: : ----> product name Name 3 value     15.00
Produced: : ----> product name Name 4 value     93.00
Produced: : ----> product name Name 5 value     35.00
     Consumer: : ----> product name Name 0 value     83.00
Produced: : ----> product name Name 6 value     86.00
     Consumer: : ----> product name Name 0 value     86.00
     Consumer: : ----> product name Name 2 value     77.00
     Consumer: : ----> product name Name 3 value     15.00
     Consumer: : ----> product name Name 4 value     93.00
     Consumer: : ----> product name Name 5 value     35.00
     Consumer: : ----> product name Name 6 value     86.00
     Consumer: : ----> product name Name 7 value     92.00
```

Producer-Consumer
Race Condition

- `count++` (in producer) could be implemented as

```
lw t0, 0(s0)        # load memory content at s0 to t0
addi t0, t0, 1      # increment t0 by 1
sw t0, 0(s0)        # store content in t0 to memory at s0
```

- `count--` (in consumer) could be implemented as

```
lw t1, 0(s0)        # load memory content at s0 to t1
subi t1, t1, 1      # decrement t1 by 1
sw t1, 0(s0)        # store content in t1 to memory at s0
```

- Consider this execution interleaving when count == 5:

```
Step 0: producer execute lw t0, 0(s0)      # t0 == 5
Step 1: producer execute addi t0, t0, 1    # t0 == 6
Step 2: consumer execute lw t1, 0(s0)      # t1 == 5
Step 3: consumer execute subi t1, t1, 1    # t1 == 4
Step 4: producer execute sw t0, 0(s0)      # count == 6
Step 5: consumer execute sw t1, 0(s0)      # count == 4, incorrect!
```

The Critical-Section Problem

- It turns out that the **consumer-producer problem** is one particular problem in a general category of problems called ***the critical-section problem:***
  - A collection of collaborating processes, each of which has a segment of code (***critical section***) that accesses some common data. To ensure the correctness of the result, only one process can enter its critical section to access the shared data at any time.
  - The ***critical-section problem*** is to design a protocol that ensures the correctness of the result under such a condition.

The Critical-Section Problem

Solution Requirements

1. **Mutual Exclusion** - If process P_i is executing in its critical section, then no other processes can be executing in their critical sections.

2. **Progress** - If no process is executing in its critical section and there exist some processes that wish to enter their critical section, then the selection of the processes that will enter the critical section next cannot be postponed indefinitely.

3. **Bounded Waiting** - A bound must exist on the number of times that other processes are allowed to enter their critical sections after a process has made a request to enter its critical section and before that request is granted. (Assume that each process executes at a nonzero speed. No assumption concerning relative speed of the **N** processes.)

Typical Process P_i

```
do {
  entry section
      critical section
  exit section
      remainder section
} while (TRUE);
```

OpenMP Code Example

```
int main(int argc, char *argv[])    {
    /* sequential code */
    int v = 0;
    #pragma omp parallel shared(v)
   {
          #pragma omp critical (addv)
        {
                    v ++;
          }
          printf("I am a parallel region\n");
    }
    /* sequential code */
     printf("value of v = %d\n", v);
    return 0;
}
```

How To Synchronize Processes?

- OpenMP provides a nice solution for programmers.
- But how are they implemented? How do we approach a synchronization problem in general?
- There could be hardware solution to this problem as well. We are concentrating on software solutions for now.

Peterson’s Solution

for a 2-process case

Shared variables

```
int turn;
boolean flag[2];
```

```
turn: status
flag[2]: intension
```

```
do {
   flag[i] = TRUE; // i 0 or 1
   turn = j;       // j 0 or 1
   while (flag[j] && turn == j);
          critical section
   flag[i] = FALSE;
          remainder section
} while (TRUE);
```

Peterson’s Solution

Process 0

Shared variables

```
int turn;
boolean flag[2];
```

turn: status

flag[2]: intension

```
do {
   flag[0] = TRUE;
   turn = 1;
   while (flag[1] && turn == 1);
         critical section
   flag[0] = FALSE;
         remainder section
} while (TRUE);
```

Peterson's Solution

Process 1

Shared variables

```
int turn;
boolean flag[2];
```

turn: status
flag[2]: intension

```
do {
  flag[1] = TRUE;
  turn = 0;
  while (flag[0] && turn == 0);
        critical section
  flag[1] = FALSE;
        remainder section
} while (TRUE);
```

Limitation to Peterson’s Solution

- Strict order of execution
- Variable updates (**turn** and **flag**) could still be problematic