Lecture 13

Synchronization

이재진

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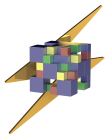

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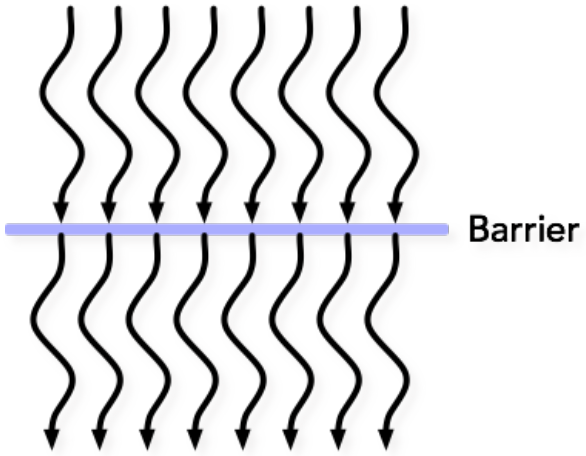
동기화가 필요한 이유

- 스레드 간 또는 프로세스 간 실행되는 순서를 정하기 위해
- 상호배제(Mutual Exclusion)를 달성하기 위해

Barrier

- Barrier가 있는 지점에 도달한 스레드는 실행을 중단하고 다른 모든 스레드가 같은 배리어에 도달하기를 기다린 다음 실행을 계속함
- 같은 함수(코드)를 동시에 실행할 때 흔하게 이용됨
  - SPMD

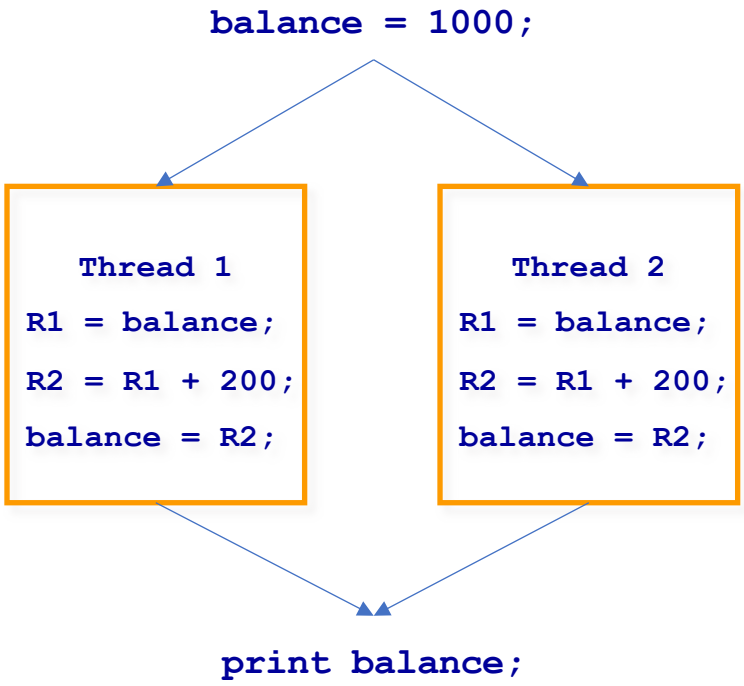



```
work_on_my_problem();
Barrier();
get_result_from_others();
Barrier();
```

```
if (my_id == 0) {
    work(); //초기화
    barrier();
} else {
    barrier();
}
…
```

Data Race

- 두 스레드가 변수 balance를 공유
- R1과 R2는 각 스레드에 대해 로컬 변수



Data Race (cont'd)

시간

Thread 1	Thread 2	Balance
R1 = balance (1000)		1000
R2 = R1 + 200 (1200)		1000
balance = R2 (1200)		1200
	R1 = balance (1200)	1200
	R2 = R1 + 200 (1400)	1200
	balance = R2 (1400)	1400

Data Race (cont'd)

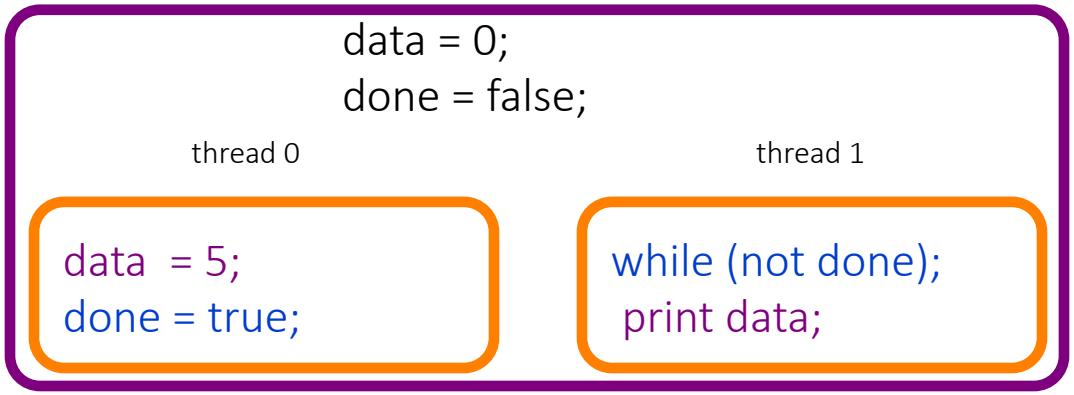
시간

Thread 1	Thread 2	Balance
R1 = balance (1000)		1000
	R1 = balance (1000)	1000
	R2 = R1 + 200 (1200)	1000
R2 = R1 + 200 (1200)		1000
balance = R2 (1200)		1200
	balance = R2 (1200)	1200

Data Race (cont'd)

- 데이터 레이스가 일어나는 조건
  - 두 개 이상의 스레드가 같은 메모리 위치를 엑세스하고
  - 그 중 하나의 스레드가 그 위치에 쓰기를 하고,
  - 그 위치가 동기화에 의해 보호되지 않을 때
- 엑세스 순서가 비결정적(non-deterministic)
  - 실행 될 때마다 다른 결과가 출력될 수 있음
- 어떤 데이터 레이스는 의도적으로 사용
  - 비지 웨이트(busy-wait) 동기화
  - Lock-free 알고리즘
- 하지만 보통의 경우, 데이터 레이스는 버그

비지 웨이트(Busy Wait) 동기화



Thread Safety

- 두 개 이상의 스레드가 어떤 함수를 동시에 호출했을 때 그 함수가 항상 올바르게 동작하면 그 함수를 Thread Safe 하다고 함
  - Thread-safe library

아토미시티(Atomicity)

- 한 묶음의 연산들이 아토믹(atomic)하다는 것은 모든 연산이 다 수행되거나 하나도 수행되지 않는 것을 의미(all or nothing)
  - 부분적인 수행으로 인한 결과를 볼 수 없음

상호배제(Mutual Exclusion)

- 항상 많아야 하나의 스레드만 어떤 코드부분를 실행할 수 있을 때 그 코드부분이 상호배제(mutual exclusion)적으로 실행된다고 함

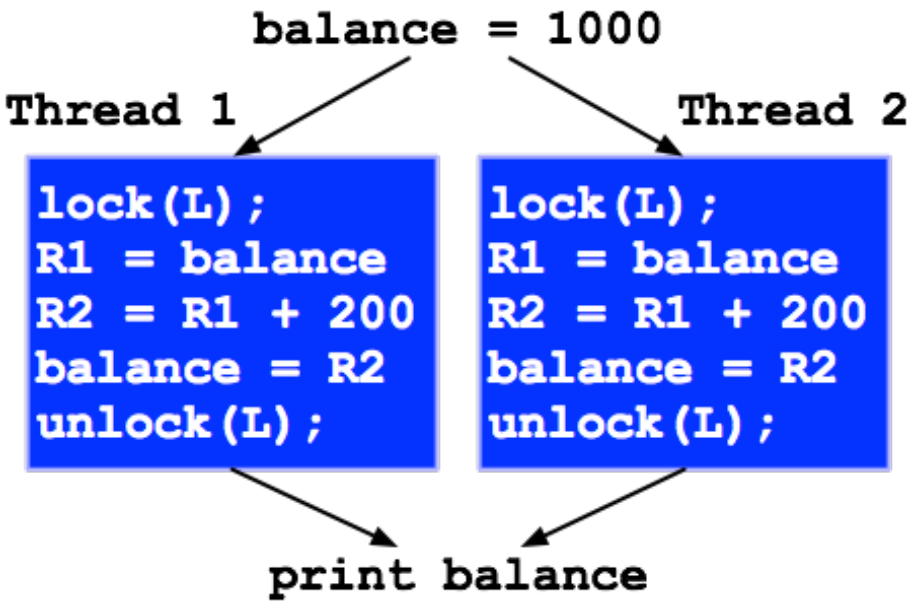
- 상호배제에 의해 atomicity를 보장할 수 있음

- 어떤 코드부분을 동기화로 보호하여 아토믹하게 실행할 때 그 코드부분을 크리티컬 섹션(critical section)이라고 함

Lock

- Atomicity를 보장하기 위해 사용
- 록 변수(lock variable)는 두 개의 상태(state)를 가짐
  - 록이 걸림(locked)과 록이 걸리지 않음(unlocked)
- 두 개의 함수 - lock(L)과 unlock(L)
  - 하나의 스레드가 록 변수 L에 록을 걸고자 할 때 먼저 록이 걸려있는지 확인
  - 록이 걸려 있으면 록을 건 스레드가 록을 풀어주기를 기다린 후 록을 검
- 스레드를 이용한 병렬 프로그램의 동기화에 이용

Lock의 예


balance = 1000
Thread 1
Thread 2
lock(L);
R1 = balance
R2 = R1 + 200
balance = R2
unlock(L);
lock(L);
R1 = balance
R2 = R1 + 200
balance = R2
unlock(L);
print balance

Spinlocks

- A thread requesting a lock does not release CPU but rather spins constantly checking the lock until it is released
  - The thread proceeds as soon as the lock is released
  - May save time for locks that are held for short time
    - No context switching
  - The thread wastes CPU cycles spinning
  - Cannot be used on uniprocessor systems

- Sleeplock
  - A thread requesting a lock blocks and is put back on the ready queue only when the lock is released
  - Can be used on uniprocessor
  - Saves CPU time on locks held long

Spinlocks (contd.)

- Two while loops avoid performance degradation due to frequent memory accesses by test_and_set
  - test_and_set always go to memory

```
void lock(bool *L)
{
  while (test_and_set(L) {
    while (*L){};
  }
}

void unlock(bool *L)
{
    *L = 1;
}
```

Pros and Cons of Locks

- Easy to understand and use
- However,
  - Deadlock
  - Priority inversion
  - Expensive

Priority Inversion

- Only one processor
- Thread T1 has a higher priority than thread T2
- T1 is not ready
- T2 is scheduled and enters its critical section
- T1 becomes ready
- The scheduler suspends T2 and schedules T1
- When T1 tries to enter its critical section, it waits for T2 to release the lock (waits forever)

- Solutions exist
  - Disable preemption while holding a lock
  - Priority inheritance
  - ...

Semaphores

- A semaphore, S, is a variable that can take only nonnegative integer values
- Manipulated by two special atomic operations, called P and V
  - S is atomically incremented or decremented
  - P(S)
    - If S > 0, then P decrements S and returns
    - Otherwise, P suspends the calling thread until S becomes nonzero and the thread is restarted by a V operation performed by another thread
    - After restarting, P decrements S and returns
  - V(S)
    - V increments S by one
    - If there are any threads blocked in a P waiting for S, V restarts exactly one of these threads
- To schedule shared resources
- A thread suspended on a semaphore no longer executes instructions checking variables in a busy-wait loop

Binary Semaphores vs. Counting Semaphores

- Binary semaphores
  - Its value is initially 1 and always 0 or 1

- Counting (general) semaphores
  - Its value can be any integer greater than or equal to 0
  - Represents a resource with many units available
    - The initial value is usually the number of resources

세마포어를 이용한 상호배제

- Initially, S = 1

```
void T0()
{
  while (1) {
S00: non-critical-section;
S01: P(S);
S02: critical-section;
S03: V(S);
  }
}
```

```
void T1()
{
  while (1) {
S10: non-critical-section;
S11: P(S);
S12: critical-section;
S13: V(S);
  }
}
```

An Atomic Counter with Semaphores

```
sem_t m;
int   count;
void count_thread(int id)
{
  /* compute the portion of the array that this thread needs to work on */
  /* array_length: the size of the array                                */
  /* n: the number of threads                                           */

  int private_count = 0;
  int length = array_length/n;
  int start = id*length;

  for (int i=start; i < start+length; i++){
    if (array[i] == 7)
    {
      private_count++;
    }
  }

  sem_wait(m);    /* P(m) */
  count += private_count;
  sem_post(m);    /* V(m) */
}
```

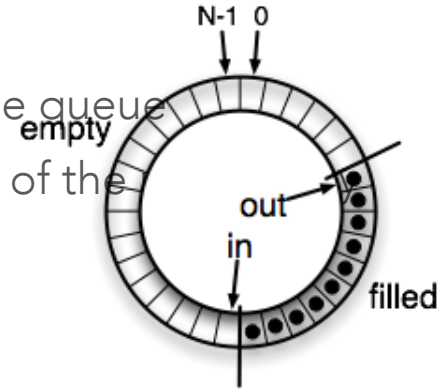
Producers and Consumers

- There are two types of threads
  - Producers - these threads create a data element that is then sent to the consumers
  - Consumers - upon receipt of a data element, these threads perform some computation with the data element

- Assume a single producer and a single consumer

Single-Producer and Single-Consumer

- Circular buffer
  - A circular queue
    - Implemented with an array
    - The index is computed modulo the length of the array
  - For asynchronous communication
  - The producer appends a data element to the tail of the queue
  - The consumer removes a data element from the head of the queue

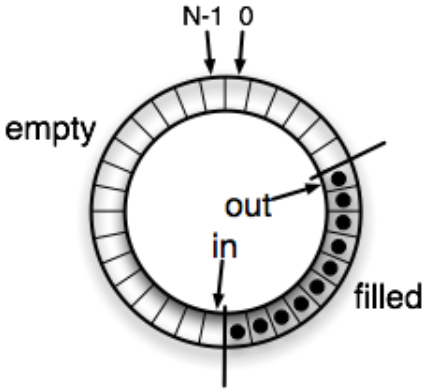


- The consumer does not try to remove an element from an empty buffer

- The producer does not append to a full buffer

Single-Producer and Single-Consumer (contd.)

- buffer is an array of length N
  - in = 0
  - out = 0
- elements and slots are general semaphores
  - elements = 0
  - slots = N




```
void producer() {
  while(1) {
    data = produce();
    P(slots);
    buffer(in) = data;
    in = (in + 1) mod N;
    V(elements);
  }
}
```

```
void consumer() {
  while(1) {
    P(elements);
    data = buffer(out);
    out = (out + 1) mod N;
    V(slots);
    consume(data);
  }
}
```

Single-Producer and Single-Consumer (cont'd)

- buffer is an array of length N
  - in = 0, out = 0, count = 0
- S is a binary semaphore
  - S = 1
- not_full and not_empty are binary semaphores
  - not_full = 0, not_empty = 0

```
void producer() {
  int lcount = 0;
  while(1) {
    data = produce();
    if (lcount == N) P(not_full);
    buffer(in) = data;
      P(S);
      count = count + 1;
      lcount = count;
      V(S);
      if (lcount == 1) V(not_empty);
      in = (in + 1) mod N;
    }
  }
```

```
void consumer() {
  int lcount = 0;
  while(1) {
    if (lcount == 0) P(not_empty);
    data = buffer(out);
    P(S);
    count = count - 1;
    lcount = count;
      V(S);
      if (lcount == N-1) V(not_full);
      out = (out + 1) mod N;
      consume(data);
    }
  }
```

Non-blocking Synchronization

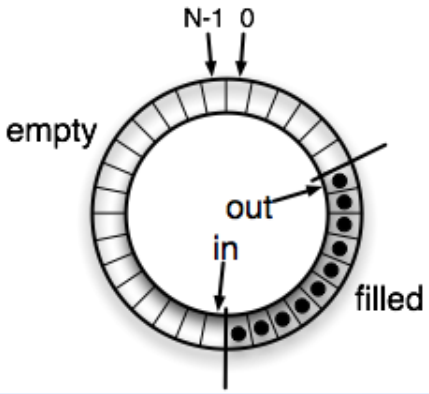
- An algorithm is non-blocking if the suspension of one or more threads will not stop the potential progress of the other threads
- Blocking a thread is undesirable
  - When blocked, cannot accomplish anything
  - Coarse-grained locking
    - Reduces opportunities of parallelism
  - Fine-grained locking
    - Increases overhead
- Many non-blocking synchronization algorithms exist in these days
  - Hard to understand though

Advantages of Non-blocking Synchronization

- No deadlocks
- No priority inversion
- Does not suffer performance degradation from
  - Context switching
  - Page faults
  - Cache misses

Non-blocking Single-Producer and Single-Consumer

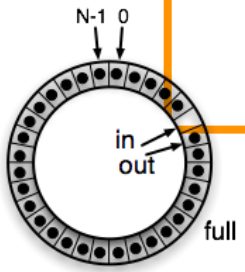
- Producer updates in
- Consumer updates out
- Without a non-blocking algorithm, either the the entire queue is locked or the shared variables in and out are locked between the producer and consumer to guarantee correctness
- Assume atomic assignments
- No synchronization for the shared variables in and out or the entire queue

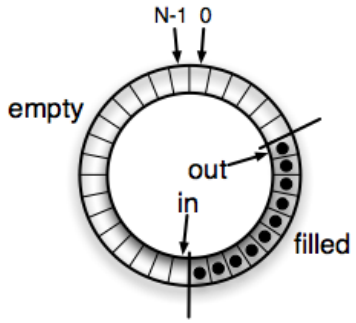


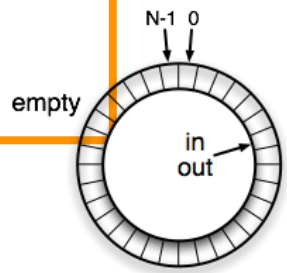
Non-blocking Single-Producer and Single-Consumer (cont'd)

```
Producer

while (...) {
  while ( true ) {
    Pin = in;
    Pout = out;
    if ((Pin + 1) mod N ≠ Pout)
      /* full ? */
      break;
  }
  ... /* produce */
  Pin = ... ;
  in = Pin;
  ...
}
```

```
Consumer

while (...) {
  while ( true ) {
    Cin = in;
    Cout = out;
    if (Cin ≠ Cout)
      /* empty? */
      break;
  }
  ... /* consume */
  Cout = ... ;
  out = Cout;
  ...
}
```

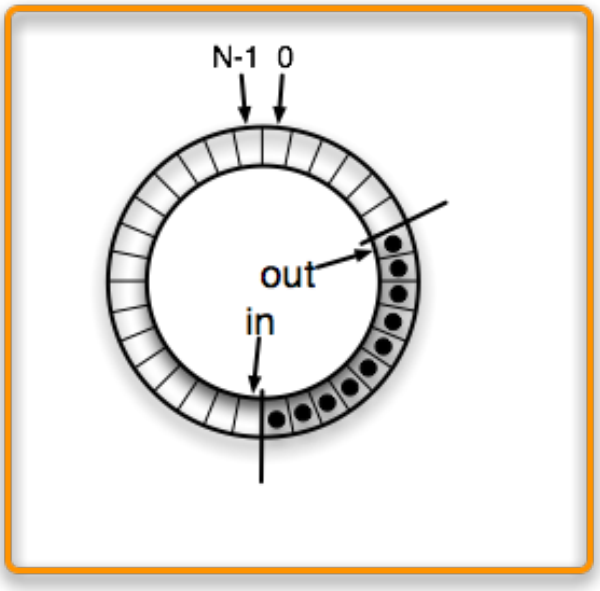






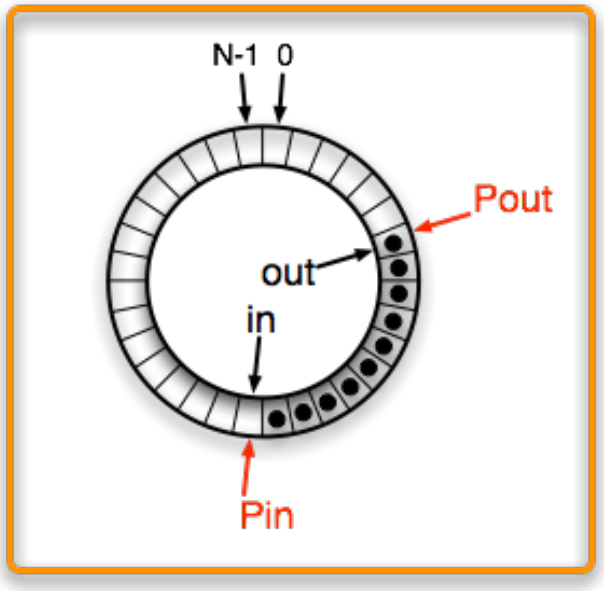
Non-blocking Single-Producer and Single-Consumer (cont'd)

```
Producer

while (...) {
  while ( true ) {
    Pin = in;
    Pout = out;
    if ((Pin + 1) mod N ≠ Pout)
      break;
  }
  ... /* produce */
  Pin = ... ;
  in = Pin;
  ...
}
```



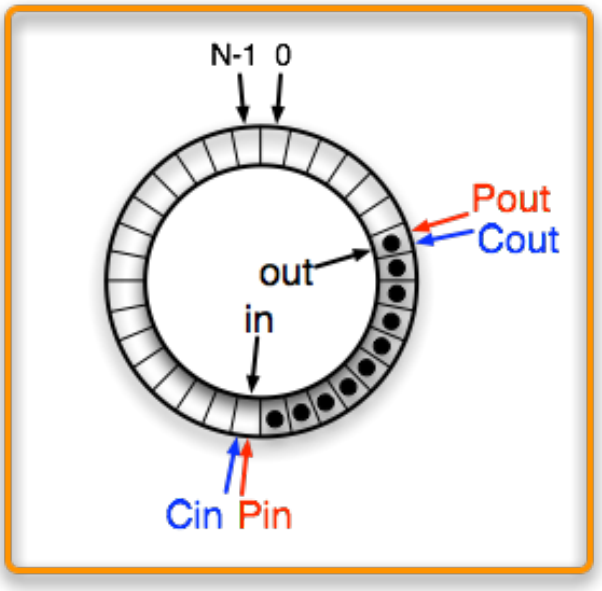
Non-blocking Single-Producer and Single-Consumer (cont'd)

```
Producer

while (...) {
  while ( true ) {
    Pin = in;
    Pout = out;
    if ((Pin + 1) mod N ≠ Pout)
      break;
  }
  ... /* produce */
  Pin = ... ;
  in = Pin;
  ...
}
```



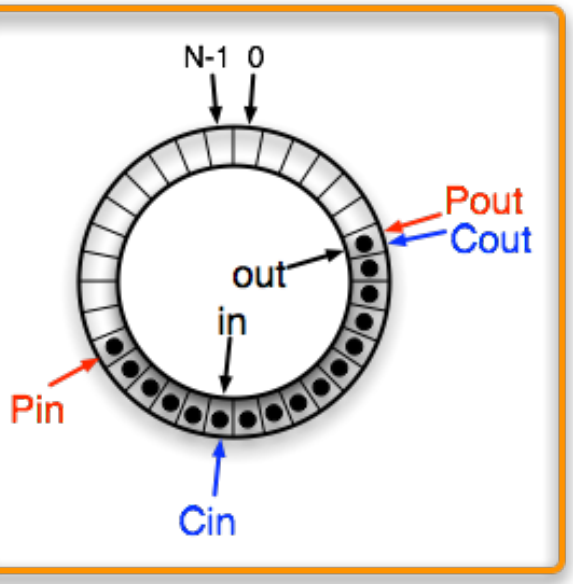
Non-blocking Single-Producer and Single-Consumer (cont'd)

```
Consumer

while (...) {
  while ( true ) {
    Cin = in;
    Cout = out;
    if (Cin ≠ Cout)
      break;
  }
  ... /* consume */
  Cout = ... ;
  out = Cout;
  ...
}
```



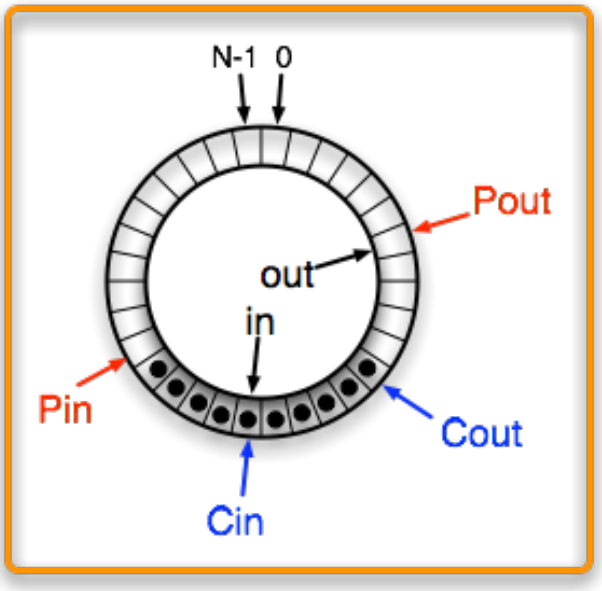
Non-blocking Single-Producer and Single-Consumer (cont'd)

```
Producer

while (...) {
  while ( true ) {
    Pin = in;
    Pout = out;
    if ((Pin + 1) mod N ≠ Pout)
      break;
  }
  ... /* produce */
  Pin = ... ;
  in = Pin;
  ...
}
```



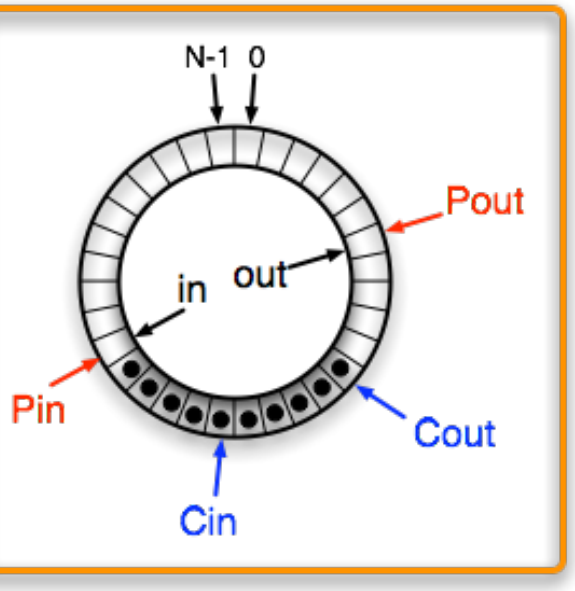
Non-blocking Single-Producer and Single-Consumer (cont'd)

```
Consumer

while (...) {
  while ( true ) {
    Cin = in;
    Cout = out;
    if (Cin ≠ Cout)
      break;
  }
  ... /* consume */
  Cout = ... ;
  out = Cout;
  ...
}
```



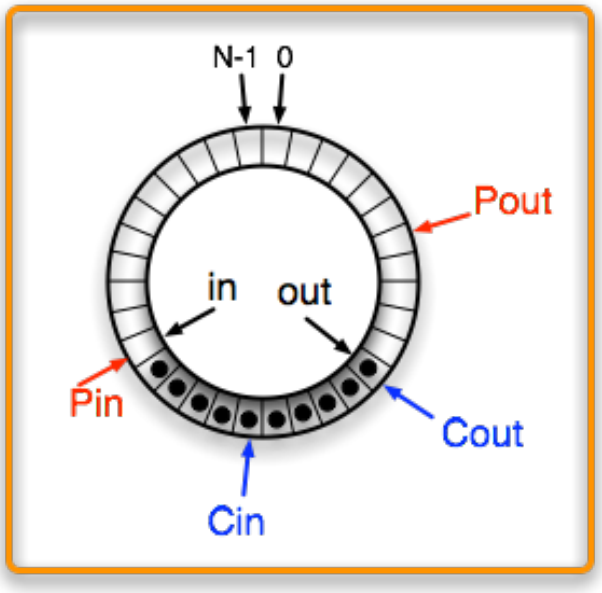
Non-blocking Single-Producer and Single-Consumer (cont'd)

```
Producer

while (...) {
  while ( true ) {
    Pin = in;
    Pout = out;
    if ((Pin + 1) mod N ≠ Pout)
      break;
  }
  ... /* produce */
  Pin = ... ;
  in = Pin;
  ...
}
```

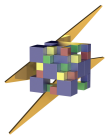


Non-blocking Single-Producer and Single-Consumer (cont'd)

```
Consumer

while (...) {
  while ( true ) {
    Cin = in;
    Cout = out;
    if (Cin ≠ Cout)
      break;
  }
  ... /* consume */
  Cout = ... ;
  out = Cout;
  ...
}
```



병렬화 시 고려사항



병렬화 시 고려할 점

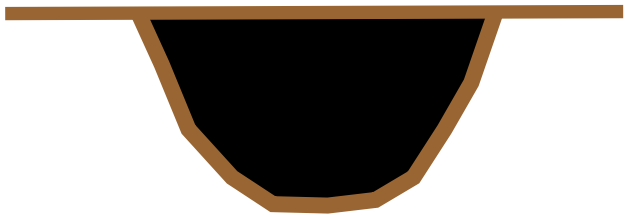
- 프로그램에 든 병렬성의 양
  - Amdahl의 법칙
  - 순차실행을 할 수 밖에 없는 부분에 의해 Speedup이 결정됨
- 로캘리티
  - 될 수 있으면 로컬 데이터를 이용하여 계산하는 것이 좋음(캐쉬를 잘 이용하도록)
  - 스레드나 프로세스 간 데이터의 이동에 시간이 걸림

병렬화 시 고려할 점 (cont'd)

- Load balance
  - 각 스레드 또는 프로세스가 같은 양의 일을 하도록 일을 분배하는 것이 중요
  - 전체 실행 시간은 가장 늦게 일을 끝내는 스레드나 프로세스에 의해 결정됨
- 병렬화 오버헤드
  - 스레드나 프로세스를 시작하는 비용
  - 통신 비용
  - 동기화 비용
  - 병렬화를 위한 가외의 계산

삽질하기

- 지름이 50cm, 깊이가 50cm인 구덩이를 파는 경우



순차(sequential) 프로그래밍의 경우

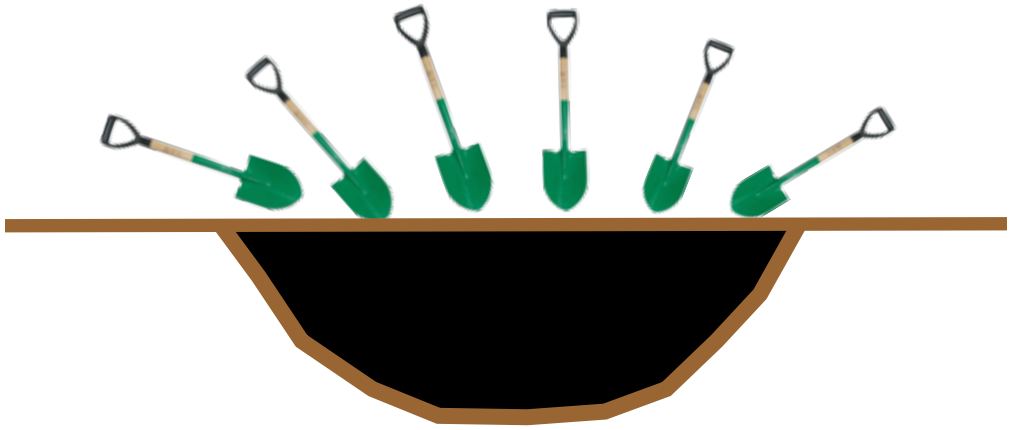
- 한 사람이 삽질하는 경우

병렬(parallel) 프로그래밍의 경우

- 여러 명이 삽질하는 경우

병렬(parallel) 프로그래밍의 경우(cont'd)

- 지름이 3m, 깊이가 1.5m인 구덩이를 파는 경우



확장성

- Scalability
- 더 많은 프로세서가 있으면 성능이 향상됨을 일컬음
- 하지만 프로세서의 수가 증가할 수록 병렬화 오버헤드가 증가하기 때문에 달성하기 어려움

- Weak scalability vs. strong scalability