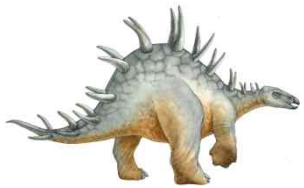
Chapter 6: Process Synchronization

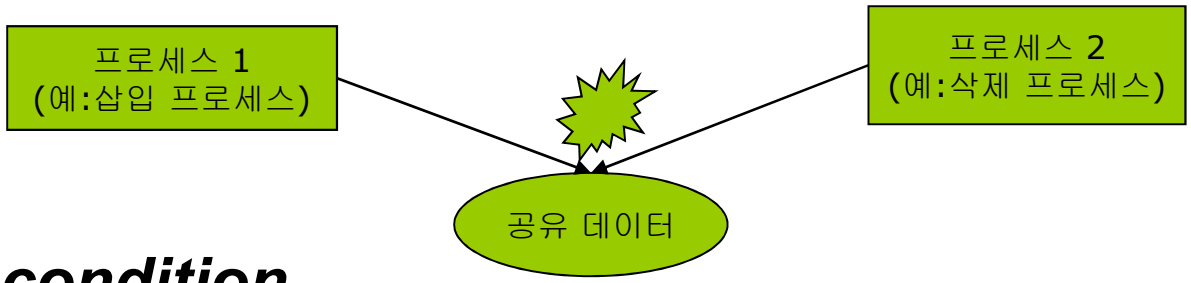
Module 6: Process Synchronization

- Background
- The Critical-Section Problem
- Peterson's Solution
- Synchronization Hardware
- Semaphores
- Classic Problems of Synchronization
- Monitors
- Synchronization Examples
- Atomic Transactions



Background

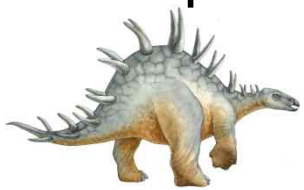
- *Concurrent access* to *shared data* may result in data *inconsistency*.



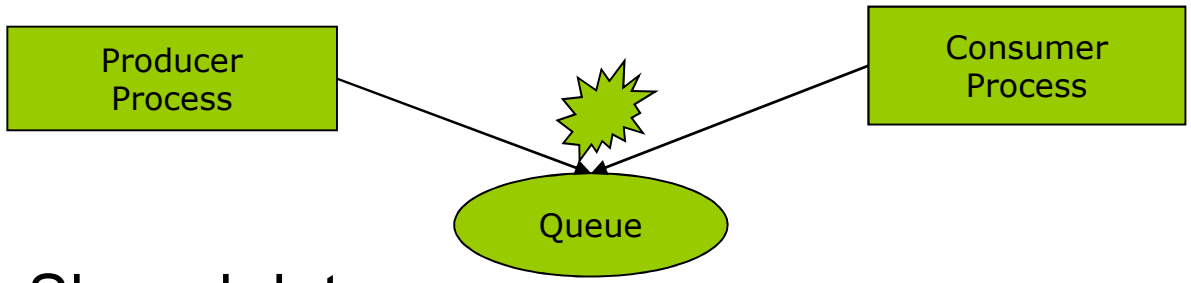
- ***Race condition***
  - The situation where several processes access and manipulate shared data concurrently.
  - The final value of the shared data
  - depends upon which process finishes last.

- To prevent race conditions,

  concurrent processes must be *synchronized*.

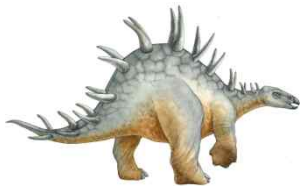


Background : Queue!



- Shared data

```
#define BUFFER_SIZE 10
typedef struct {
   . . .
} item;
item buffer[BUFFER_SIZE];
int in = 0;
int out = 0;
int counter = 0;
```



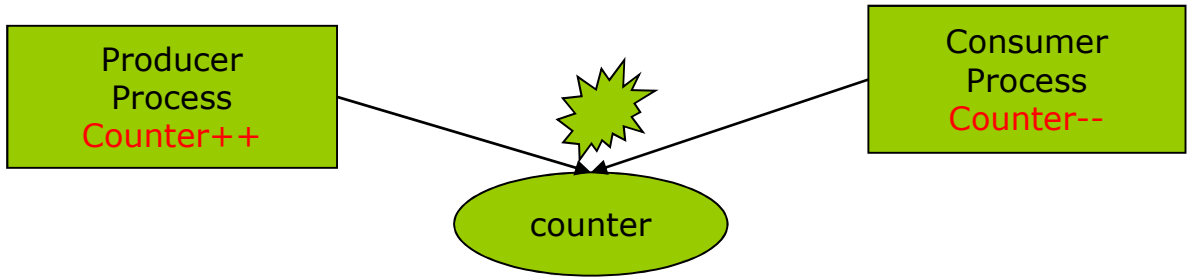
Background : Queue!

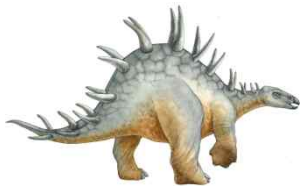
- Producer process

```
item nextProduced;

while (1) {
        while (counter == BUFFER_SIZE)
                ; /* do nothing */
        buffer[in] = nextProduced;
        in = (in + 1) % BUFFER_SIZE;
        counter++;
}
```

- Consumer process

```
item nextConsumed;

while (1) {
        while (counter == 0)
                ; /* do nothing */
        nextConsumed = buffer[out];
        out = (out + 1) % BUFFER_SIZE;
        counter--;
}
```





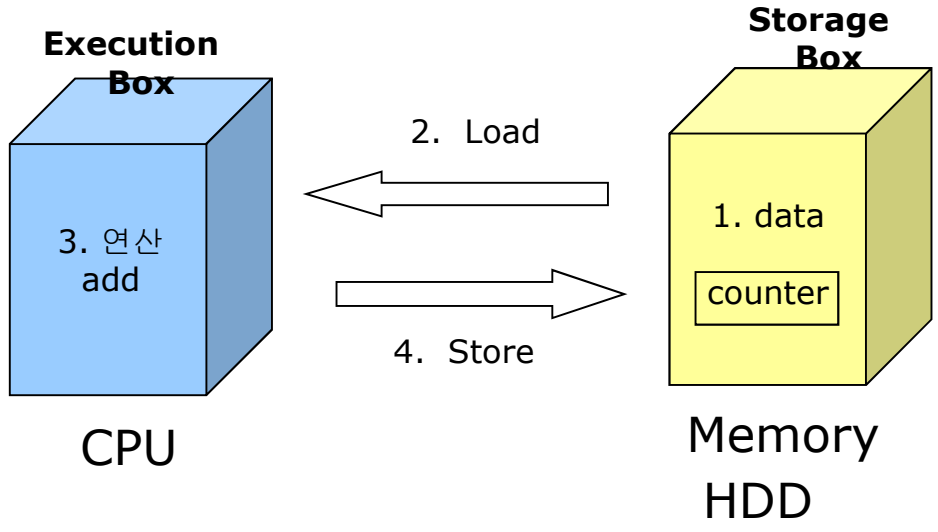
Bounded Buffer

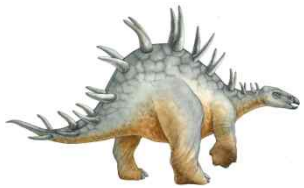
- 문제점 :
  counter++;
  counter--;

Atomic operation means an operation that completes in its entirety without interruption.

Atomic한 연산으로 보이지만, 실제는 Atomic하지 않다!

- Counter++ is Not Atomic!





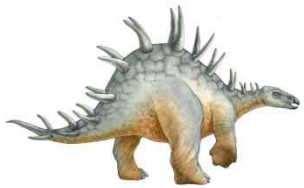
Bounded Buffer

- count++ could be implemented as

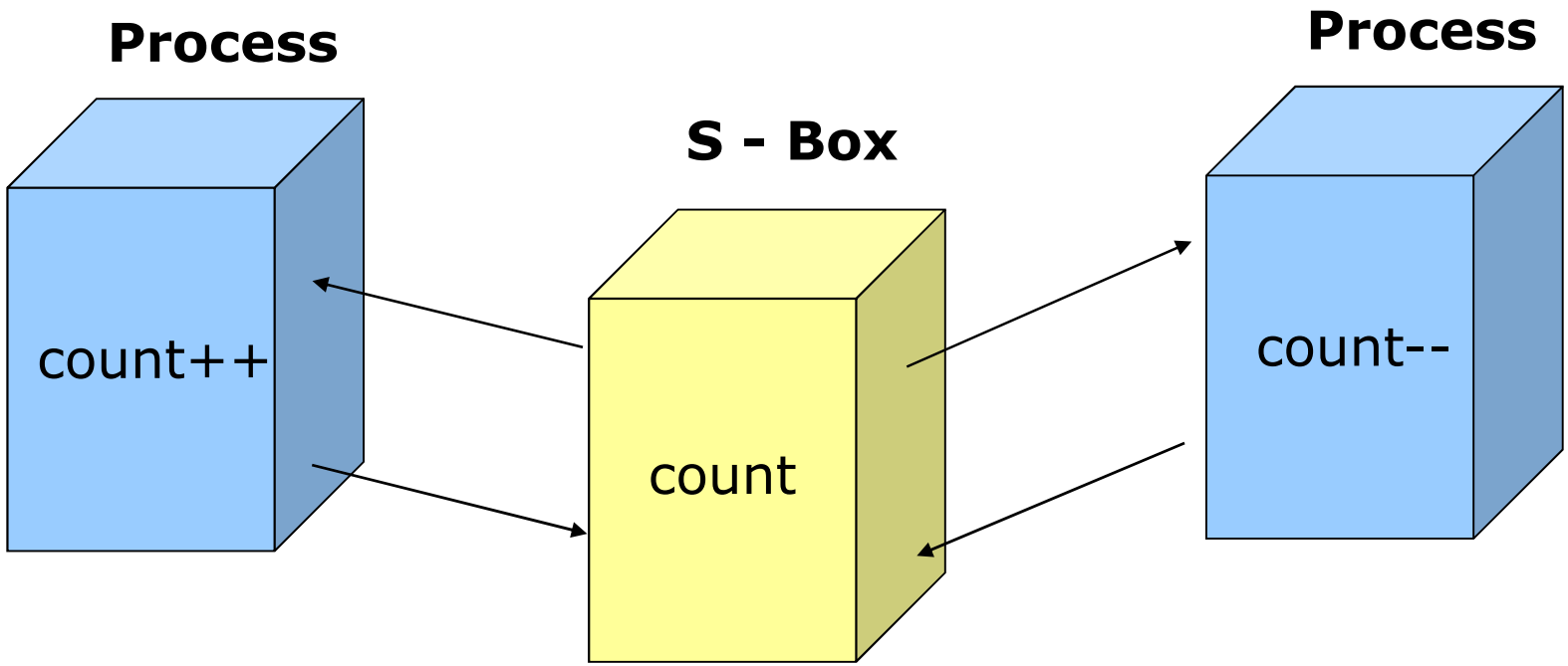
```
register1 = count                (LOAD   R1, COUNT)
register1 = register1 + 1        (ADD    R1, 1)
count = register1                (STORE  R1, COUNT)
```

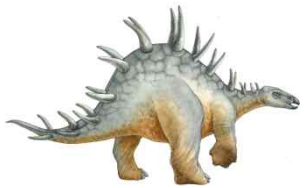
- count-- could be implemented as

```
register2 = count                (LOAD   R2, COUNT)
register2 = register2 - 1        (SUB    R2, 1)
count = register2                (STORE  R2, COUNT)
```



Bounded Buffer : 동시 수행!!

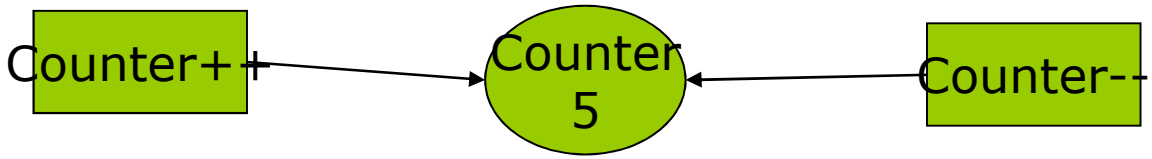




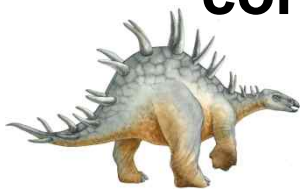
Bounded Buffer

- Consider this execution interleaving with "count = 5" initially:

S0: producer execute register1 = count {register1 = 5}
S1: producer execute register1 = register1 + 1 {register1 = 6}
S2: consumer execute register2 = count {register2 = 5}
S3: consumer execute register2 = register2 - 1 {register2 = 4}
S4: producer execute count = register1 {count = 6 }
S5: consumer execute count = register2 {count = 4}

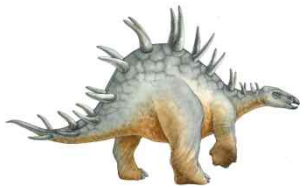


- The value of count may be either 4 or 6, where the correct result should be 5.



The Critical-Section Problem(임계구역문제)

- *n* processes all competing to use some shared data
- Each process has a code segment, called *critical section*, in which the shared data is accessed.
- Problem – ensure that when one process is executing in its critical section, no other process is allowed to execute in its critical section.

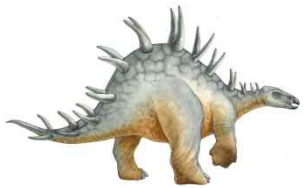


Critical-Section 문제 해결의 충족조건

1. **Mutual Exclusion**. 한 프로세스가 임계 구역을 실행 중일 때, 다른 어떤 프로세스도 임계 구역을 실행할 수 없다

2. **Progress**. 임계 구역을 실행하는 프로세스가 없고 여러 개의 프로세스들이 임계 구역에 들어오고자 하는 상황에서는, 반드시 하나의 프로세스를 선택하여 진입시키는 올바른 결정 기법이 있어야 하고, 이러한 결정은 무한정 미루어져서는 안 된다.

3. **Bounded Waiting**. 한 프로세스가 임계 구역에 대한 진입 요청 후부터 요청의 수락까지의 기간 내에, 다른 프로세스가 임계 구역을 실행할 수 있는 회수에는 제한이 있어야 한다.
   - Assume that each process executes at a nonzero speed
   - No assumption concerning relative speed of the *n* processes.



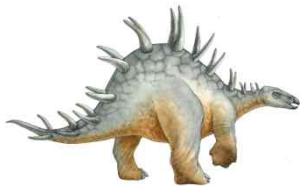
Critical-Section Problem

1. Race Condition - When there is concurrent access to shared data and the final outcome depends upon order of execution.

2. Critical Section - Section of code where shared data is accessed.

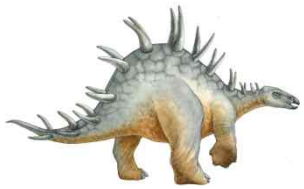
3. Entry Section - Code that requests permission to enter its critical section.

4. Exit Section - Code that is run after exiting the critical section



Structure of a Typical Process

```
while (true) {
        entry section
            critical section
        exit section
            remainder section
}
```

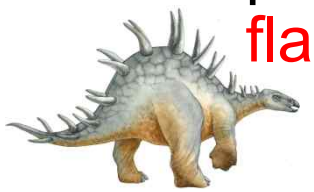


Peterson's Solution

- Two process solution
- Assume that the LOAD and STORE instructions are atomic; that is, cannot be interrupted.

- The two processes share two variables:
  - int turn;
  - Boolean flag[n]

- Turn : The variable turn indicates whose turn it is to enter the critical section.
- Flag : The flag array is used to indicate if a process is ready to enter the critical section. flag[i] = true implies that process P_i is ready!

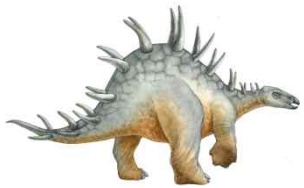


Peterson's Solution

- Combined shared variables of algorithms 1 and 2.
- Process P_i

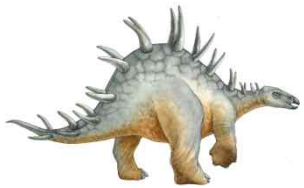
```
do {
    flag [i]:= true; /* My intention is to enter ….    */
    turn = j; /* Set to his turn-빠를수록 양보 */
    while (flag [j] and turn = j) ;/* wait only if …*/
        critical section
    flag [i] = false;
        remainder section
} while (1);
```

- Problems
  - Busy Waiting! *(계속 CPU와 memory 를 쓰면서 wait)*
  - *Software 적인 해결책은 느림*



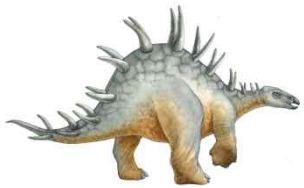
Critical Section Using Locks

```
while (true) {
        acquire lock

            critical section

        release lock

            remainder section
}
```



Synchronization Hardware

- Many systems provide hardware support for critical section code
- Uniprocessors – could disable interrupts
  - Currently running code would execute without preemption
  - Generally too inefficient on multiprocessor systems
    - Operating systems using this not broadly scalable
- Modern machines provide special atomic hardware instructions
    - Atomic = non-interruptible
  - Either test memory word and set value
  - Or swap contents of two memory words



Synchronization Hardware

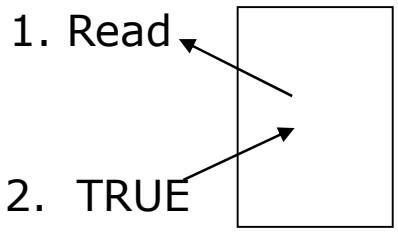
상호배제(Multual Exclusion)의 구현

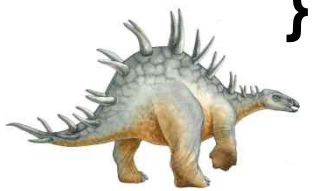
- Lock에 대한 testAndSet를 CPU의 명령어로 제공 (atomic instruction)

- Test and modify the content of a word atomically

```
boolean TestAndSet(boolean *target) {
   boolean rv =*target;
   *target = true;

   return rv;
}
```

TestAndSet(a)





Mutual Exclusion with Test-and-Set

상호배제(Multual Exclusion)의 구현

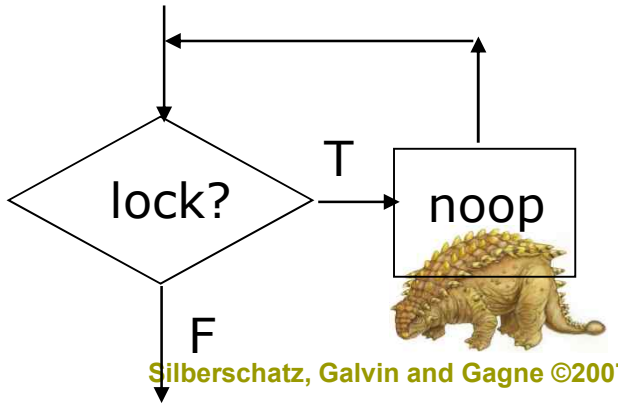
- Shared data:

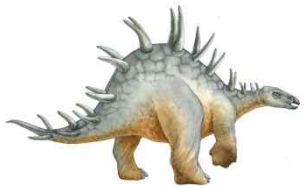
  boolean lock = false;

- Process P_i

```
do {
   while (TestAndSet(&lock)) ;
      critical section
   lock = false;
      remainder section
}
```

while(cond) do { };



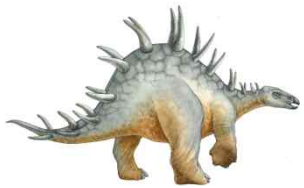


Synchronization Hardware : Swap 이용

상호배제(Multual Exclusion)의 구현

- Atomically swap two variables.
  - swap 명령은 CPU에서 지원할 경우가 많음

```
void Swap(boolean *a, boolean *b) {
   boolean temp = *a;
   *a = *b;
   *b = temp;
}
```



Mutual Exclusion with Swap

상호배제(Multual Exclusion)의 구현

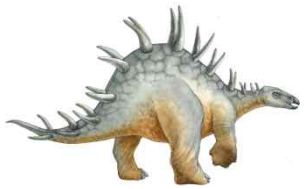
- Shared data (initialized to **false**):

```
boolean lock = false ;
boolean waiting[n];
```

- Process P_i

```
do {
    key = true; /* My intention */
    while (key == true)
            Swap(&lock,&key);

        critical section

    lock = false;
        remainder section
} while( true );
```

bounded waiting
문제는 어떻게 해결?



상호배제와 한정된 대기조건을 만족하는 lock

상호배제(Multual Exclusion)+한정된 대기(Bounded Waiting)

```
repeat
    waiting[i] := true;
    key := true;
    while waiting[i] and key do
            key := Test-and-Set(lock);
    waiting[i] := false;
            // 임계 구역
    j := i+1 mod n;
    while (j ≠ i) and (not waiting[j]) do
            j :=  j+1 mod n;
    if j = i then lock := false
            else waiting[j] := false;
            잔류 구역
until false;
```

process의 순서대로 lock을 줌

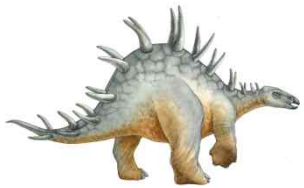
다른 프로세스가 요청 후 기다리고 있는지 차례로 검사

요청 후 기다리고 있는 프로세스가 하나도 없으면...

만약 있다면, lock을 풀지 않은 채로 대기 중인 프로세스를 임계 구역으로 진입시킴

Semaphores

- 소프트웨어 해결 및 Test-and-Set 등은 모두 “busy waiting” 알고리즘
- 임계 구역 진입 시 이미 다른 프로세스가 진입해 있으면 busy-waiting loop 실행 -> 타임 슬라이스 낭비
- 세마포어 (Dijkstra) : block/wakeup 알고리즘
  - 진입 불가능 시에는 대기 상태로 전환
  - 임계 구역을 진출하는 프로세스가 대기 프로세스를 준비 상태로 깨워줌



Semaphores

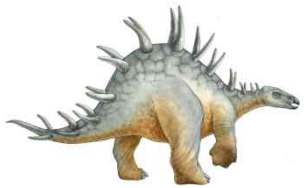
- Synchronization tool that does not require busy waiting.
- Semaphore *S* – integer variable
- can only be accessed via two indivisible (atomic) operations

wait (*S*):

```
while S≤ 0 do no-op;
  S--;
```

signal (*S*):

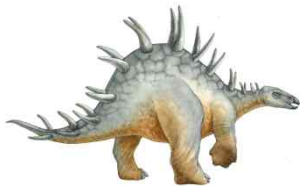
```
S++;
```



Critical Section of *n* Processes

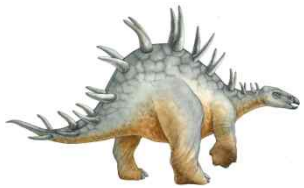
- Shared data:
  semaphore mutex; //initially *mutex* = 1
- Process *Pi:*

```
do {
    wait(mutex);

       critical section

    signal(mutex);

   remainder section
} while (1);
```



Semaphores 사용 예

```
Semaphore Printer;
  init(Printer, 3);
        :
 ----------------------
  wait (Printer);
 ----------------------
     use a printer;
 -----------------
  signal (Printer);
 -----------------
     remainder section;
```

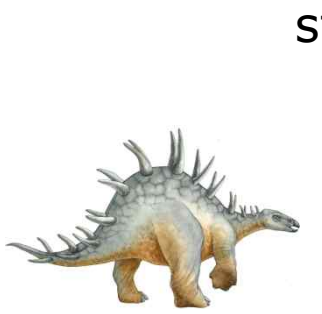


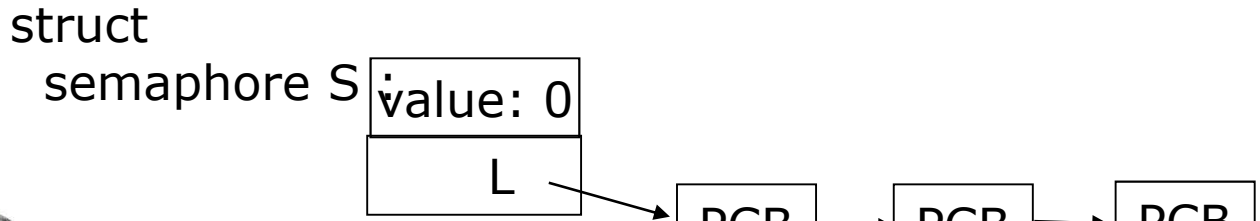
Semaphore Implementation

- Define a semaphore as a record

```
typedef struct {
   int value;
   struct process *L;
} semaphore;
```

- Assume two simple operations:
  - **block** kernel suspends the process that invoked P(S) itself.
    Put this process' PCB into wait queue (semaphore)
  - **wakeup(P)** V(S) resumes the execution of a blocked process **P**.
    (Put this process' PCB into ready queue)





Implementation

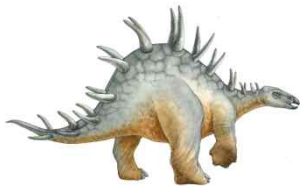
- Semaphore operations now defined as

wait(semaphore *S):

```
S->value--;
if (S->value < 0) {
        add this process to S->L;
        block();
}
```

signal(semapore *S):

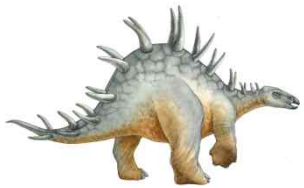
```
S->value++;
if (S->value <= 0) {
        remove a process P from S->L;
        wakeup(P);
}
```



Semaphore in Java

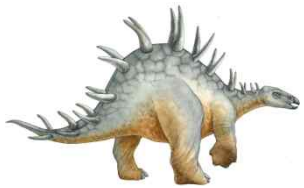
- Java SE5, SE6에서 기본 지원
  - url : http://java.sun.com/javase/6/docs/api/java/util/concurrent/Semaphore.html

```
Semaphore S = new Semaphore();

S.acquire();

   // critical section

S.release();

   // remainder section
```



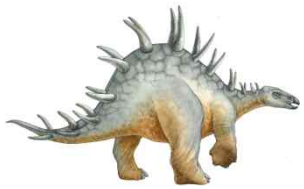
Semaphore in Java : example

```
public class Worker implements Runnable
{
    private Semaphore sem;
    private String name;

    public Worker(Semaphore sem, String name) {
       this.sem = sem;
       this.name = name;
    }

    public void run() {
       while (true) {
          sem.acquire();
          MutualExclusionUtilities.criticalSection(name);
          sem.release();
          MutualExclusionUtilities.remainderSection(name);
       }
    }
}
```



Semaphore in Java : example

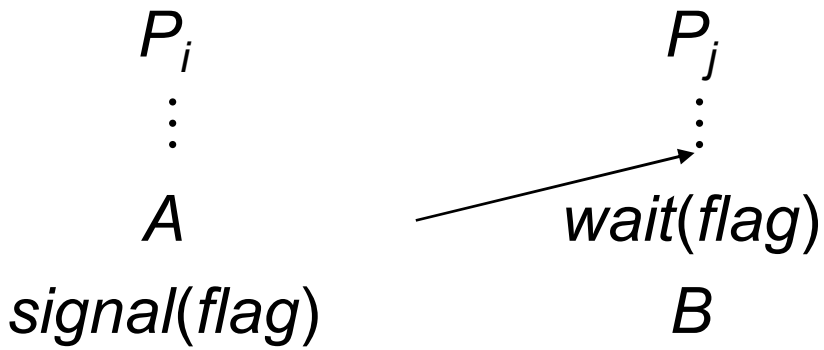
```
public class SemaphoreFactory
{
    public static void main(String args[]) {
       Semaphore sem = new Semaphore(1);
       Thread[] bees = new Thread[5];

       for (int i = 0; i < 5; i++)
          bees[i] = new Thread(new Worker
             (sem, "Worker " + (new Integer(i)).toString() ));

       for (int i = 0; i < 5; i++)
          bees[i].start();
    }
}
```

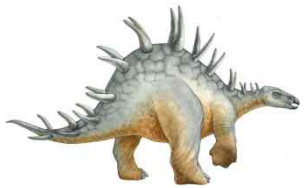


Semaphore as a General Synchronization Tool

프로세스 **Sync**를 위해 **Semaphore** 사용하기

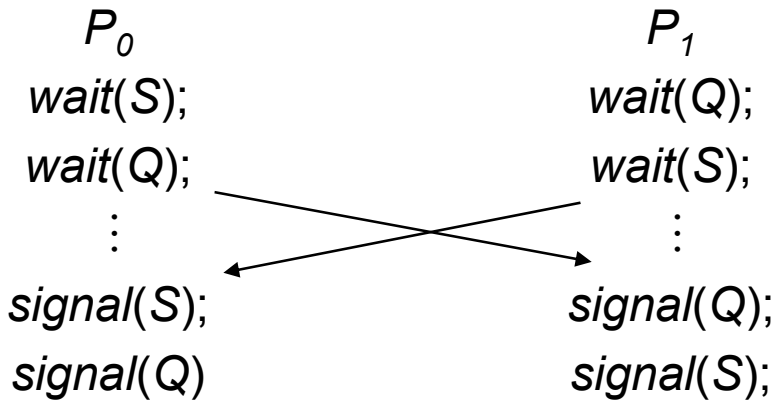
- Execute *B* in P_j only after *A* executed in P_i
- Use semaphore *flag* initialized to 0
- Code:



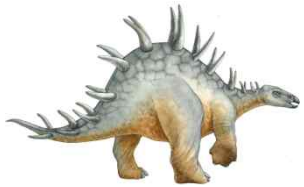


Deadlock and Starvation

- **Deadlock** – two or more processes are waiting indefinitely for an event that can be caused by only one of the waiting processes.
- Let *S* and *Q* be two semaphores initialized to 1

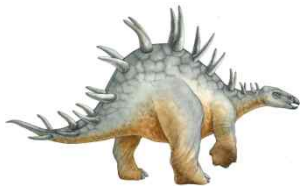


- **Starvation** – indefinite blocking. A process may never be removed from the semaphore queue in which it is suspended.



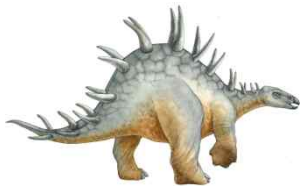
Two Types of Semaphores

- *Counting* semaphore – integer value can range over an unrestricted domain.
- *Binary* semaphore – integer value can range only between 0 and 1; can be simpler to implement.
- Can implement a counting semaphore *S* as a binary semaphore.

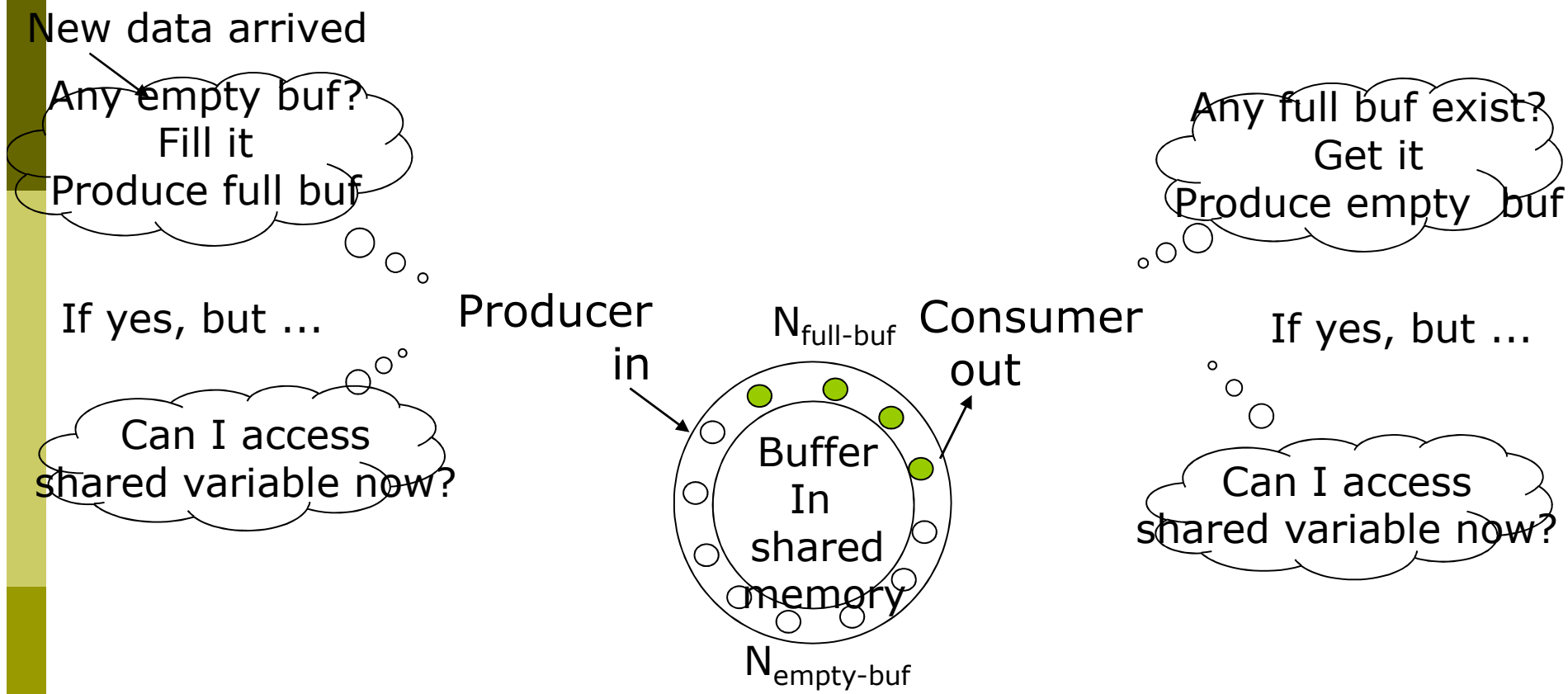


Classical Problems of Synchronization

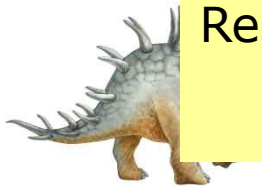
- Bounded-Buffer Problem
- Readers and Writers Problem
- Dining-Philosophers Problem



Bounded-Buffer Problem



Shared variable:	buf, count	==>	Need binary semaph
Resource count:	# of full buf # of empty buf	==>	Need integer semaph



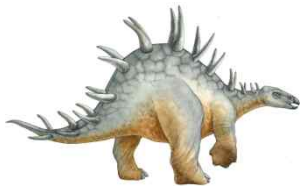
Bounded-Buffer Problem

- Shared data

  semaphore full, empty, mutex;

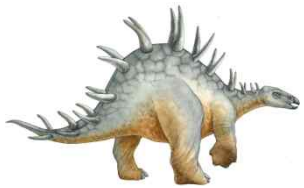
  Initially:

  full = 0, empty = n, mutex = 1



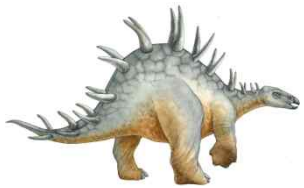
Bounded-Buffer Problem Producer Process

```
do {
        …
    produce an item in nextp
        …
    wait(empty);
    wait(mutex);
        …
    add nextp to buffer
        …
    signal(mutex);
    signal(full);
} while (1);
```



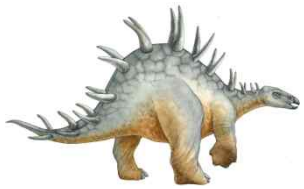
Bounded-Buffer Problem Consumer Process

```
do {
    wait(full)
    wait(mutex);
        …
    remove an item from buffer to nextc
        …
    signal(mutex);
    signal(empty);
        …
    consume the item in nextc
        …
} while (1);
```



Bounded-Buffer : Java 구현 예

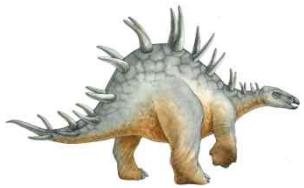
```
public class BoundedBuffer implements Buffer
{
    private static final int BUFFER_SIZE = 5;
    private Object[] buffer;
    private int in, out;
    private Semaphore mutex;
    private Semaphore empty;
    private Semaphore full;

    public BoundedBuffer() {
       // buffer is initially empty
       in = 0;
       out = 0;
       buffer = new Object[BUFFER_SIZE];

       mutex = new Semaphore(1);
       empty = new Semaphore(BUFFER_SIZE);
       full = new Semaphore(0);
    }

    public void insert(Object item) {
       // Figure 6.9
    }

    public Object remove() {
       // Figure 6.10
    }
}
```



Bounded-Buffer : Java 구현 예

insert() Method

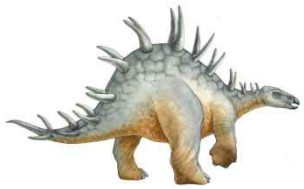
```
public void insert(Object item) {
    empty.acquire();
    mutex.acquire();

    // add an item to the buffer
    buffer[in] = item;
    in = (in + 1) % BUFFER_SIZE;

    mutex.release();
    full.release();
}
```



Bounded-Buffer : Java 구현 예

remove() Method

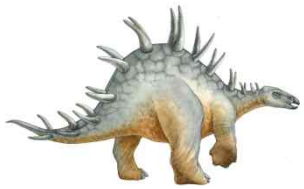
```
public Object remove() {
    full.acquire();
    mutex.acquire();

    // remove an item from the buffer
    Object item = buffer[out];
    out = (out + 1) % BUFFER_SIZE;

    mutex.release();
    empty.release();

    return item;
}
```



Bounded-Buffer : Java 구현 예

- The structure of the producer process

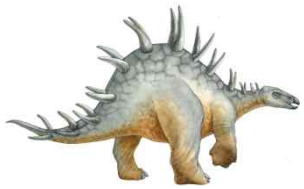
```
public class Producer implements Runnable
{
   private Buffer buffer;

   public Producer(Buffer buffer) {
      this.buffer = buffer;
   }

   public void run() {
      Date message;

      while (true) {
         // nap for awhile
         SleepUtilities.nap();
         // produce an item & enter it into the buffer
         message = new Date();
         buffer.insert(message);
      }
   }
}
```



Bounded-Buffer : Java 구현 예

- The structure of the consumer process

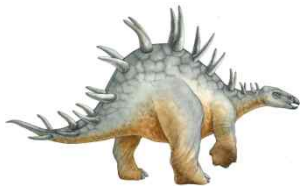
```
public class Consumer implements Runnable
{
   private Buffer buffer;

   public Consumer(Buffer buffer) {
      this.buffer = buffer;
   }

   public void run() {
      Date message;

      while (true) {
         // nap for awhile
         SleepUtilities.nap();
         // consume an item from the buffer
         message = (Date)buffer.remove();
      }
   }
}
```



Bounded-Buffer : Java 구현 예

- The Factory

```
public class Factory
{
    public static void main(String args[]) {
       Buffer buffer = new BoundedBuffer();

       // now create the producer and consumer threads
       Thread producer = new Thread(new Producer(buffer));
       Thread consumer = new Thread(new Consumer(buffer));

       producer.start();
       consumer.start();
    }
}
```



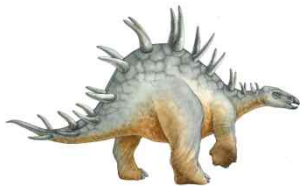
Readers-Writers Problem

- Shared data

  semaphore mutex, wrt;

  Initially

  mutex = 1, wrt = 1, readcount = 0



Readers-Writers Problem Writer Process

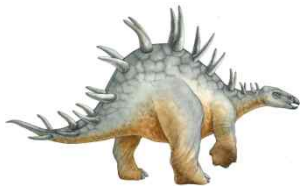
wait(wrt);

...

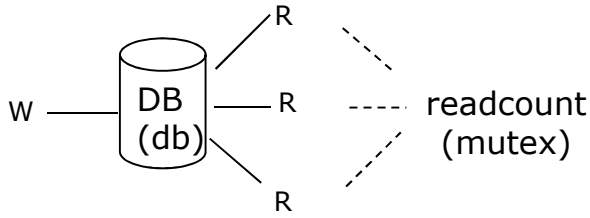
writing is performed

...

signal(wrt);



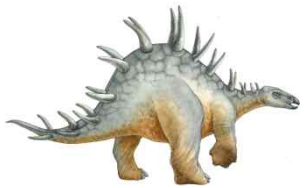
Readers-Writers Problem Reader Process




```
wait(mutex);
readcount++;
if (readcount == 1)
        wait(wrt);
signal(mutex);
        …
   reading is performed
        …
wait(mutex);
readcount--;
if (readcount == 0)
   signal(wrt);
signal(mutex):
```

다른 프로세스가 쓰는 중이면 기다림

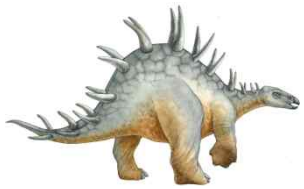
읽기 카운트를 증가 시키는중에 다른 프로세스가 Readcount를 증가시키지 못하도록 함



Readers-Writers Problem : Java 구현 예

Interface for read-write locks

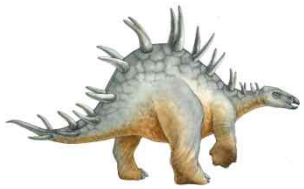
```
public interface RWLock
{
   public abstract void acquireReadLock();
   public abstract void acquireWriteLock();
   public abstract void releaseReadLock();
   public abstract void releaseWriteLock();
}
```



Readers-Writers Problem : Java 구현 예

Methods called by writers.

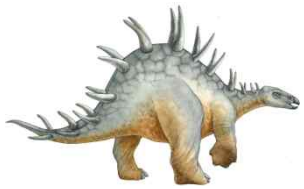
```
public void acquireWriteLock() {
   db.acquire();
}

public void releaseWriteLock() {
   db.release();
}
```



Readers-Writers Problem : Java 구현 예

- The structure of a writer process

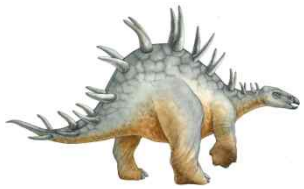
```
public class Writer implements Runnable
{
    private RWLock db;

    public Writer(RWLock db) {
       this.db = db;
    }

    public void run() {
       while (true) {
          // nap for awhile
          SleepUtilities.nap();

          db.acquireWriteLock();

          // you have access to write to the database
          SleepUtilities.nap();

          db.releaseWriteLock();
       }
    }
}
```



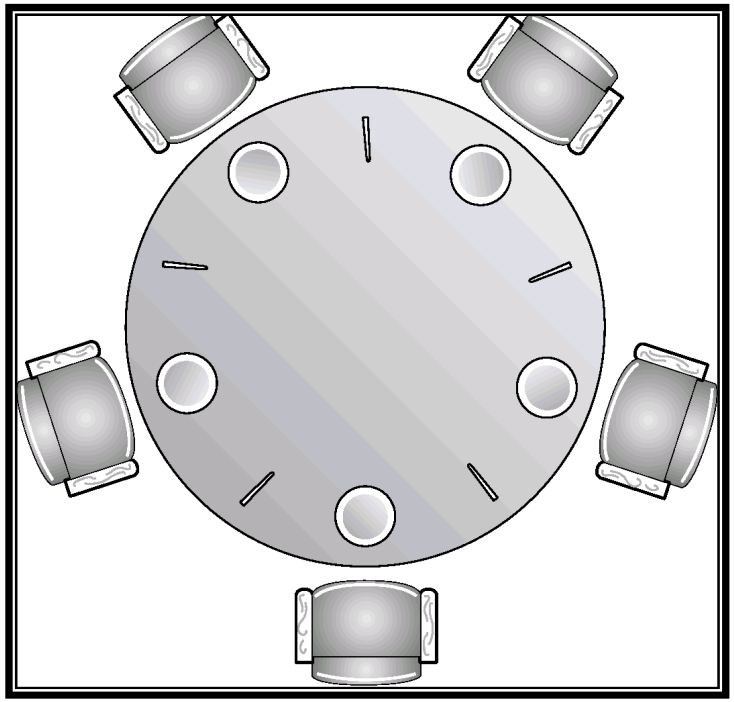
Readers-Writers Problem : Java 구현 예

- The structure of a reader process

```
public class Reader implements Runnable
{
    private RWLock db;

    public Reader(RWLock db) {
       this.db = db;
    }

    public void run() {
       while (true) {
          // nap for awhile
          SleepUtilities.nap();

          db.acquireReadLock();

          // you have access to read from the database
          SleepUtilities.nap();

          db.releaseReadLock();
       }
    }
}
```



Dining-Philosophers Problem



- Shared data

  semaphore chopstick[5];

  Initially all values are 1

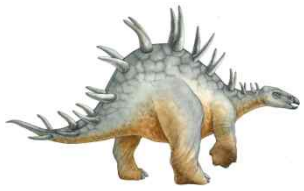
Dining-Philosophers Problem

- Philosopher *i*:

```
do {
   wait(chopstick[i])
   wait(chopstick[(i+1) % 5])
      …
      eat
      …
   signal(chopstick[i]);
   signal(chopstick[(i+1) % 5]);
      …
      think
      …
} while (1);
```

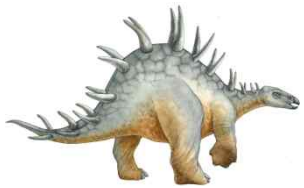
왼쪽 숫가락과
오른쪽 숫가락을
모두 확보하면
Critical section In!

왼쪽 숫가락과
오른쪽 숫가락을
모두 반납!



Semaphores의 문제점

- Difficult to code
- Difficult to prove correctness
  - ** errors are not reproducible
  - ** error are observed rarely
- Requires voluntary cooperation
- Single misuse affect entire system



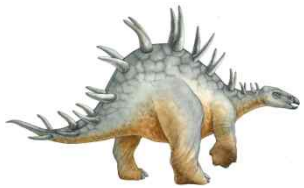
Critical Regions

- High-level synchronization construct
- A shared variable ***v*** of type ***T***, is declared as:

  v: shared T
- Variable ***v*** accessed only inside statement

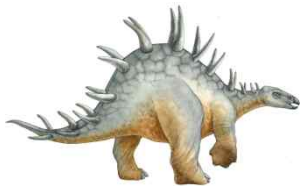
  region v when B do S

  where ***B*** is a boolean expression.
- While statement ***S*** is being executed, no other process can access variable ***v***.



Critical Regions

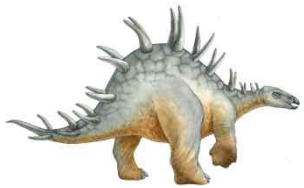
- Regions referring to the same shared variable exclude each other in time.
- When a process tries to execute the region statement, the Boolean expression *B* is evaluated. If *B* is true, statement *S* is executed. If it is false, the process is delayed until *B* becomes true and no other process is in the region associated with *v*.



Example – Bounded Buffer

- Shared data:

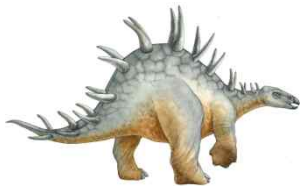
```
struct buffer {
    int pool[n];
    int count, in, out;
}
```



Bounded Buffer Producer Process

- Producer process inserts **nextp** into the shared buffer

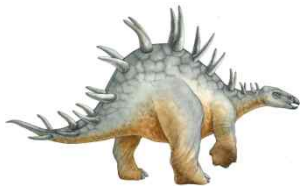
```
region buffer when( count < n) {
        pool[in] = nextp;
        in:= (in+1) % n;
        count++;
}
```



Bounded Buffer Consumer Process

- Consumer process removes an item from the shared buffer and puts it in **nextc**

```
region buffer when (count > 0) {
    nextc = pool[out];
    out = (out+1) % n;
    count--;
}
```



Implementation region *x* when *B* do *S*

- Associate with the shared variable *x*, the following variables:

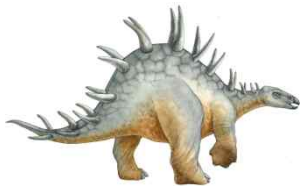
  semaphore mutex, first-delay, second-delay;
  int first-count, second-count;

- Mutually exclusive access to the critical section is provided by **mutex**.

- If a process cannot enter the critical section because the Boolean expression **B** is false, it initially waits on the **first-delay** semaphore; moved to the **second-delay** semaphore before it is allowed to reevaluate *B*.

Implementation

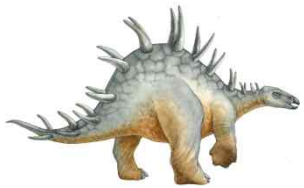
- Keep track of the number of processes waiting on **first-delay** and **second-delay**, with **first-count** and **second-count** respectively.
- The algorithm assumes a FIFO ordering in the queuing of processes for a semaphore.
- For an arbitrary queuing discipline, a more complicated implementation is required.



Monitors

- High-level synchronization construct that allows the safe sharing of an abstract data type among concurrent processes.

```
monitor monitor-name
{
    shared variable declarations
    procedure body P1 (…) {
        . . .
    }
    procedure body P2 (…) {
        . . .
    }
    procedure body Pn (…) {
        . . .
    }
    {
        initialization code
    }
}
```



Monitors

- To allow a process to wait within the monitor, a **condition** variable must be declared, as

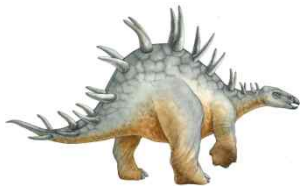
  condition x, y;

- Condition variable can only be used with the operations **wait** and **signal**.
  - The operation

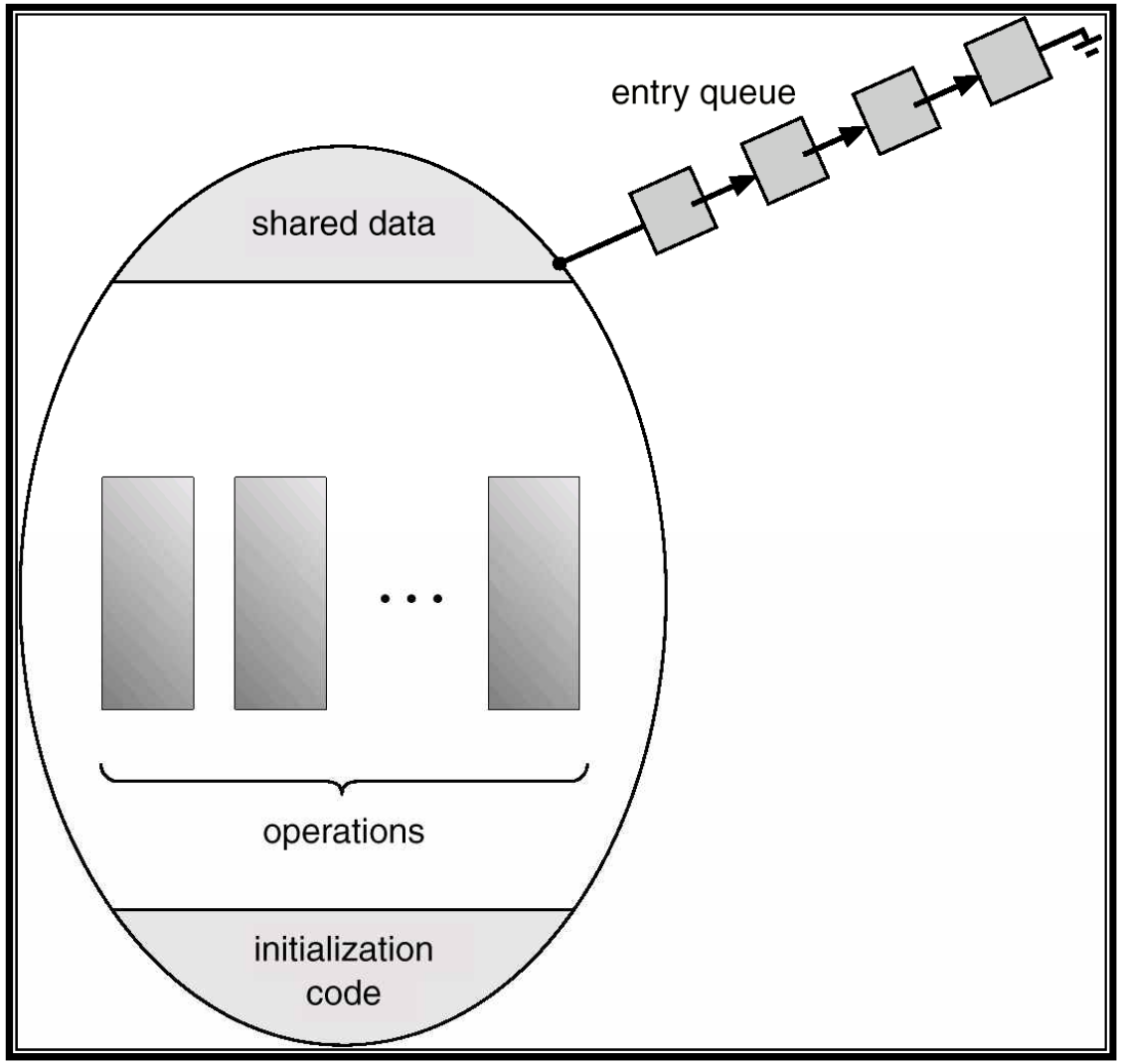
    x.wait();

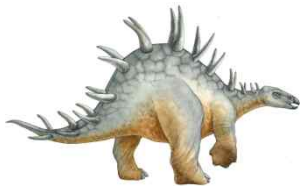
    means that the process invoking this operation is suspended until another process invokes

    x.signal();
  - The **x.signal** operation resumes exactly one suspended process. If no process is suspended, then the **signal** operation has no effect.

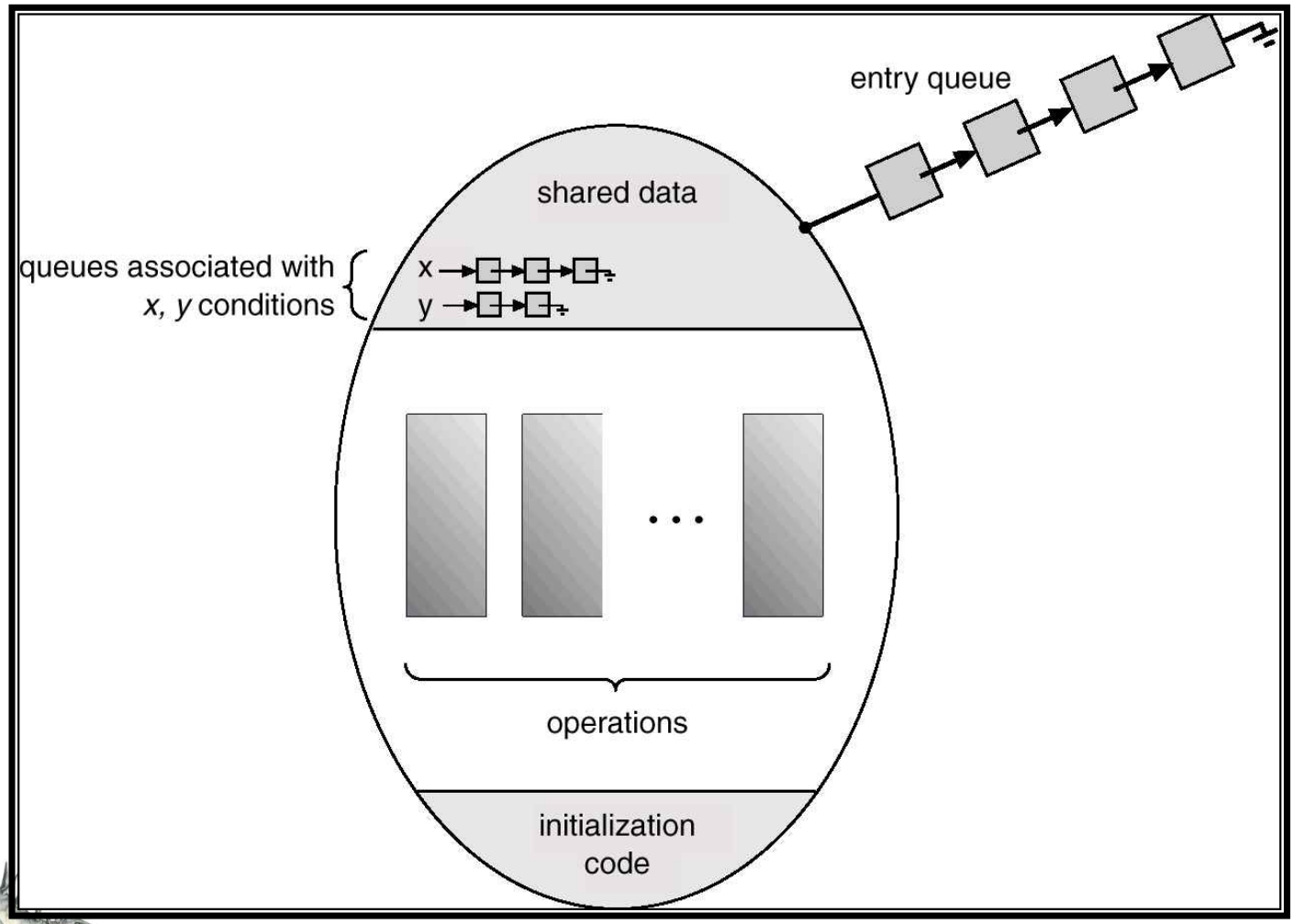


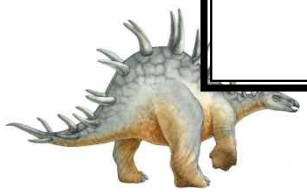
Schematic View of a Monitor





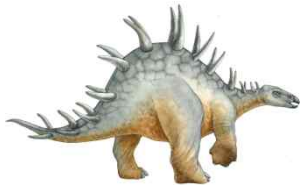
Monitor With Condition Variables





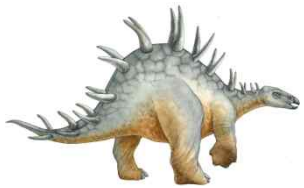
Dining Philosophers Example

```
monitor dp
{
  enum {thinking, hungry, eating} state[5];
  condition self[5];
  void pickup(int i)                    // following slides
  void putdown(int i)     // following slides
  void test(int i)              // following slides
  void init() {
       for (int i = 0; i < 5; i++)
                state[i] = thinking;
  }
}
```



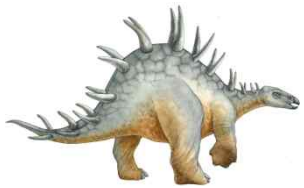
Dining Philosophers

```
void pickup(int i) {
        state[i] = hungry;
        test[i];
        if (state[i] != eating)
                self[i].wait();
}

void putdown(int i) {
        state[i] = thinking;
        // test left and right neighbors
        test((i+4) % 5);
        test((i+1) % 5);
}
```



Dining Philosophers

```
void test(int i) {
    if ( (state[(I + 4) % 5] != eating) &&
      (state[i] == hungry) &&
      (state[(i + 1) % 5] != eating)) {
        state[i] = eating;
        self[i].signal();
    }
}
```



Monitor Implementation Using Semaphores

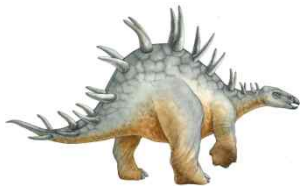
- Variables

```
semaphore mutex;  // (initially  = 1)
semaphore next;   // (initially  = 0)
int next-count = 0;
```

- Each external procedure ***F*** will be replaced by

```
wait(mutex);
    …
  body of F;
    …
if (next-count > 0)
  signal(next)
else
  signal(mutex);
```

- Mutual exclusion within a monitor is ensured.



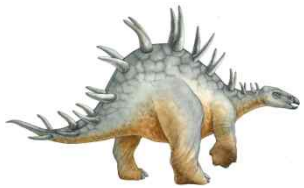
Monitor Implementation

- For each condition variable ***x***, we have:

```
semaphore x-sem; // (initially = 0)
int x-count = 0;
```

- The operation **x.wait** can be implemented as:

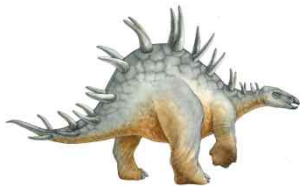
```
x-count++;
if (next-count > 0)
    signal(next);
else
    signal(mutex);
wait(x-sem);
x-count--;
```



Monitor Implementation

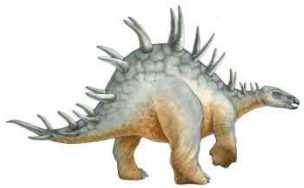
- The operation **x.signal** can be implemented as:

```
if (x-count > 0) {
    next-count++;
    signal(x-sem);
    wait(next);
    next-count--;
}
```



Monitor Implementation

- *Conditional-wait* construct: **x.wait(c);**
  - **c** – integer expression evaluated when the **wait** operation is executed.
  - value of **c** (a *priority number*) stored with the name of the process that is suspended.
  - when **x.signal** is executed, process with smallest associated priority number is resumed next.
- Check two conditions to establish correctness of system:
  - User processes must always make their calls on the monitor in a correct sequence.
  - Must ensure that an uncooperative process does not ignore the mutual-exclusion gateway provided by the monitor, and try to access the shared resource directly, without using the access protocols.



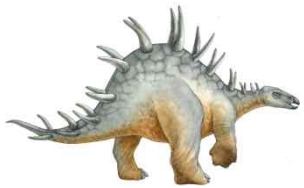
Java 5.0 Synchronization

```
public class SyncTest {
 List<String> values = new ArrayList<String>();

 public void test() {
  Thread writeThread = new Thread() {
   public void run() {
    while(true) {
     for(int i = 0; i < 10; i++) {
      add("Val" + i);
     }
     try {
       Thread.sleep(50);
     } catch (InterruptedException e) {
     }
    }
   }
  };

  Thread readThread = new Thread() {
   public void run() {
    while(true) {
     print();
     try {
       Thread.sleep(100);
     } catch (InterruptedException e) {
       e.printStackTrace();
     }
    }
   }
  };

  writeThread.start();
  readThread.start();
 }

 public void add(String value) {
  values.add(value);
 }

 public void print() {
  for(String value: values) {
   System.out.println(value);
  }
 }

 public static void main(String[] args) {
  (new SyncTest()).test();
 }
}
```

공유 데이터

공유 데이터를 이용하는 쓰레드

Synchronized 를 사용하지 않을 경우 문제를 발생시키는 예

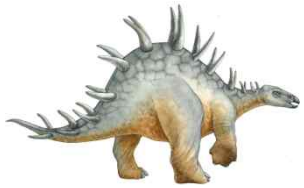


Java 5.0 Synchronization

- Synchronized를 이용한 동기화

```
public synchronized void add(String value) {
  values.add(value);
}

public synchronized void print() {
  for(String value: values) {
    System.out.println(value);
  }
}
```

  - Synchronized를 이용하여 메소드를 배타적으로 수행함
  - 배타적으로 수행하므로 Once Write Many Read 의 경우 성능에 영향을 미칠수 있음

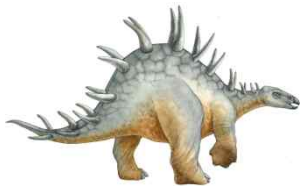


Java 5.0 Synchronization

- ReadWriteLock을 이용한 Synchronization

```
List<String> values = new ArrayList<String>();
final ReentrantReadWriteLock lock = new ReentrantReadWriteLock();

public void add(String value) {
   lock.writeLock().lock();
   try {
     values.add(value);
   } finally {
     lock.writeLock().unlock();
   }
 }

 public void print() {
   lock.readLock().lock();
   try {
     for(String value: values) {
       System.out.println(value);
     }
   } finally {
     lock.readLock().unlock();
   }
 }
```

Deadlock의 문제점 내포



Java 5.0 Synchronization

- ReadWriteLock에서 Deadlock의 회피
  - 일정시간동안 lock을 얻지 못하면 Exception 발생

```
public void print() {
  try {
    if(lock.readLock().tryLock(100, TimeUnit.MILLISECONDS)) {
      try {
        for(String value: values) {
          System.out.println(value);
        }
      } finally {
        lock.readLock().unlock();
      }
    } else {
      System.out.println("Lock Timeout");
    }
  } catch (InterruptedException e) {
    e.printStackTrace();
  }
}
```