Konzepte objektorientierter Programmierung

– Lecture 8 –

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Wintersemester 04/05

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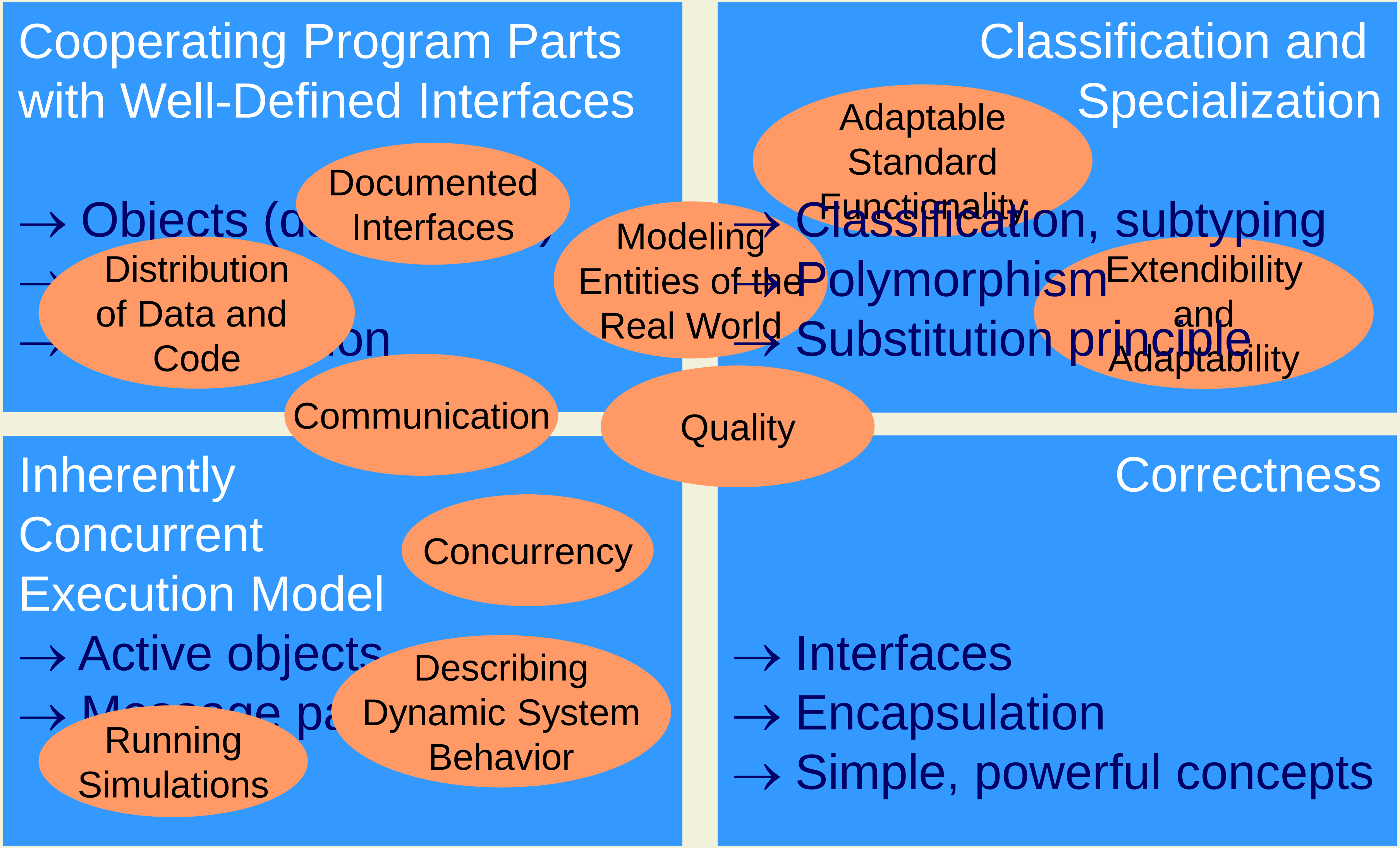
Meeting the Requirements



Cooperating Program Parts with Well-Defined Interfaces

→ Objects (d)

→

→ on

Classification and Specialization

→ Classification, subtyping

→ Polymorphism

→ Substitution principle

Inherently Concurrent Execution Model

→ Active objects

→ Message pa

Correctness

→ Interfaces

→ Encapsulation

→ Simple, powerful concepts

Documented Interfaces

Distribution of Data and Code

Modeling Entities of the Real World

Adaptable Standard Functionality

Extendibility and Adaptability

Communication

Quality

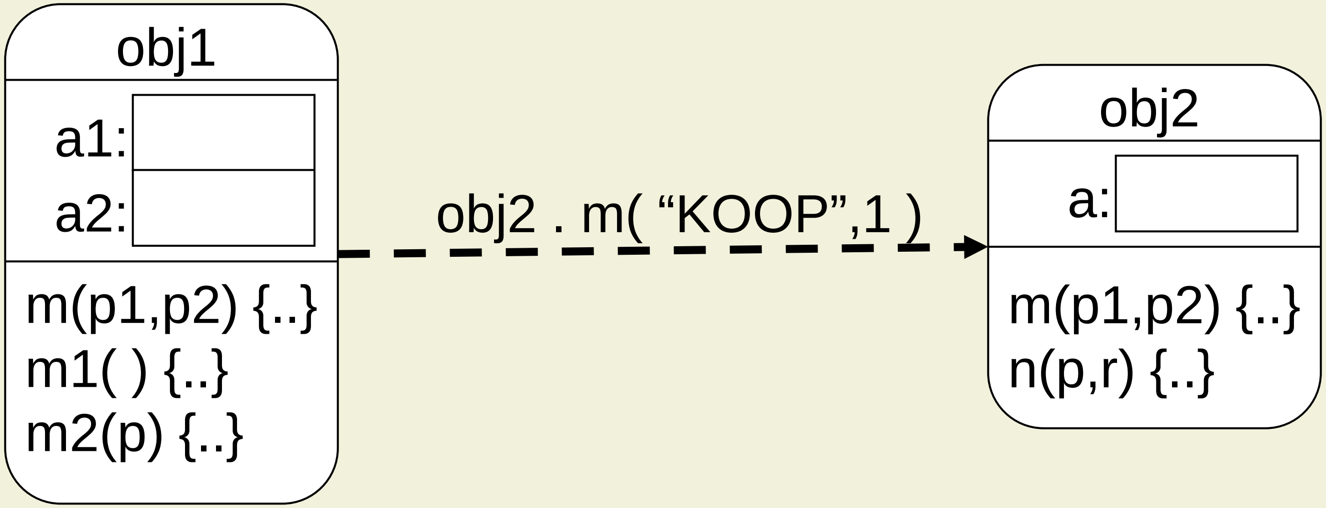
Concurrency

Describing Dynamic System Behavior

Running Simulations

The Object Model

- A software system is a set of cooperating objects
- Objects have state and processing ability
- Objects exchange messages



Agenda for Today

8. Concurrency

8.1 Threads

8.2 Synchronization

8.3 Active Objects

Objectives

- Object-oriented concurrency model
- Synchronization of objects and object structures

8. Concurrency

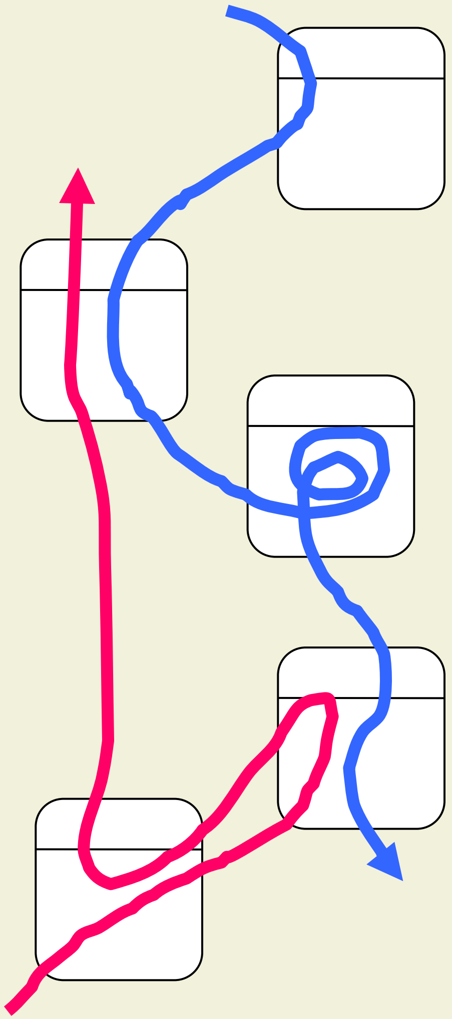
8.1 Threads

8.2 Synchronization

8.3 Active Objects

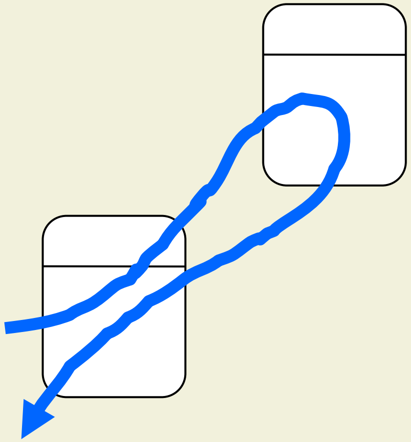
Threads

- Execution threads are **sequences of atomic actions** during a program execution
- Concurrent programs can have **more than one thread**
- Execution of threads can be **parallel** (on several processors) or **virtually parallel** (on one processor)
- A **scheduler** maps threads to processors

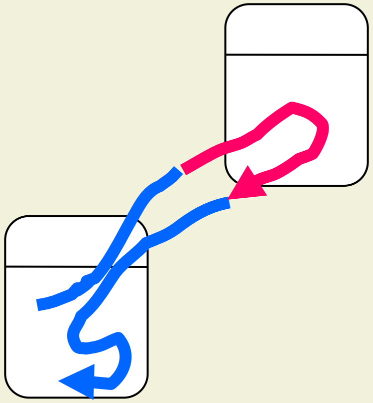


Concurrency in OO-Programs

- Passive objects
  - Threads **pass through different objects** (by method invocations)
  - **Several threads** executed **on one object** possible



- Active objects
  - **Each object has** its own **thread**
  - Upon method invocation, the thread of the target object serves the request
  - **At most one thread** executed on one object



Threads and Passive Objects

- Threads have to be created, started, synchronized, and controlled
- Threads are represented by special objects
- Method “start” starts new thread and returns immediately

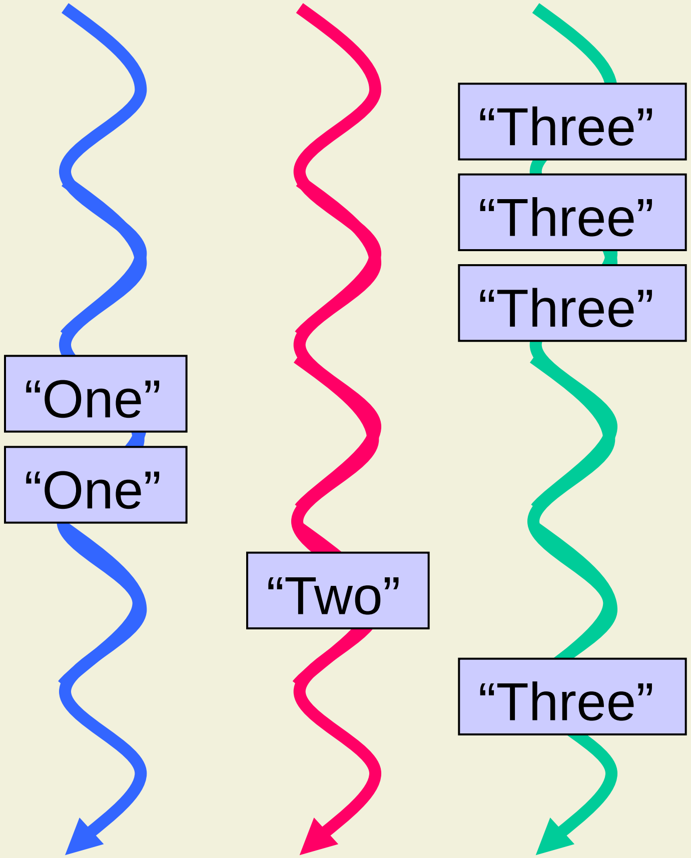
```
interface Runnable {
  void run( );
}
```

```
class Thread
        implements  Runnable {
  Thread( Runnable target )   { … }
  void run( )                 { … }
  native void start( );
  void interrupt( )           { … }
  …
}
```

Example

```
class Printer implements Runnable {
  String val;
  Printer( String s ) { val = s; }
  void run( ) {
    while( true )
      System.out.println( val );
  }
}
```

```
new Thread( new Printer( “One” ) ).start( );
new Thread( new Printer( “Two” ) ).start( );
new Thread( new Printer( “Three” ) ).start( );
```



8. Concurrency

8.1 Threads

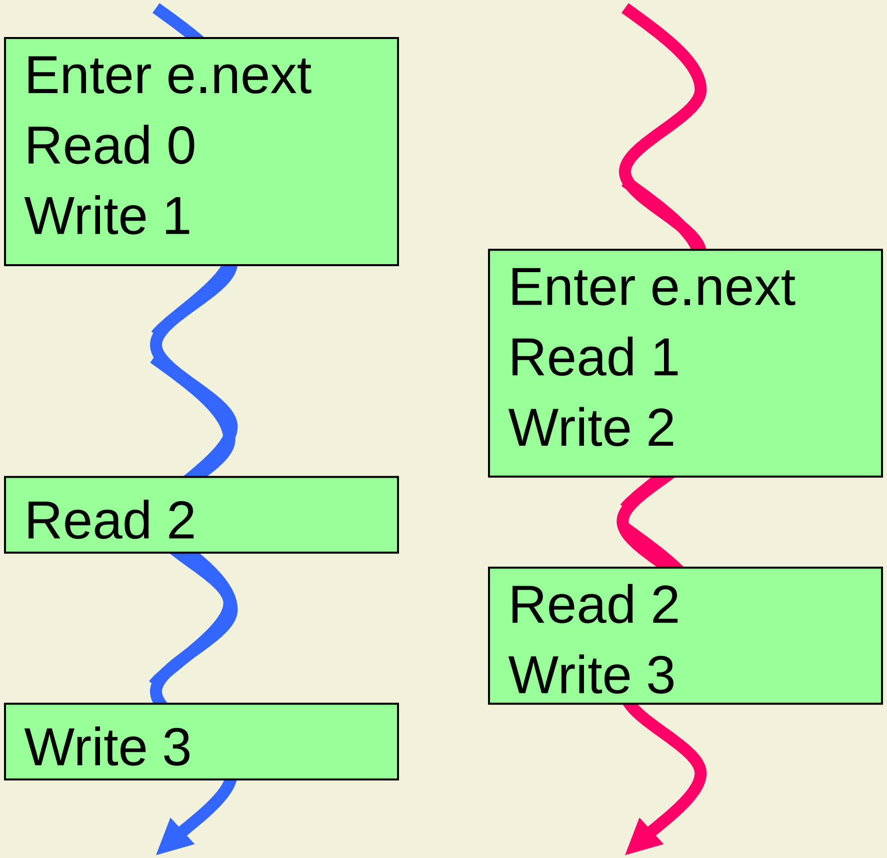
8.2 Synchronization

8.3 Active Objects

Data Races

- Access to **common resources** (e.g., variables) can lead to unwanted behavior
- Execution is divided into **critical** and non-critical **sections**
- Execution of **critical sections** should be **mutually exclusive**

```
class Even {
  private int x;
  void next( ) { x++; x++; }
}
```



Enter e.next
Read 0
Write 1

Enter e.next
Read 1
Write 2

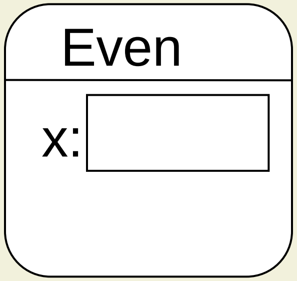
Read 2

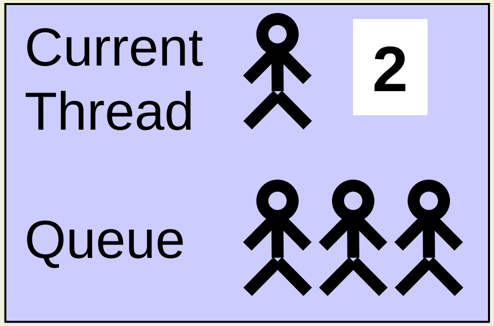
Read 2
Write 3

Write 3

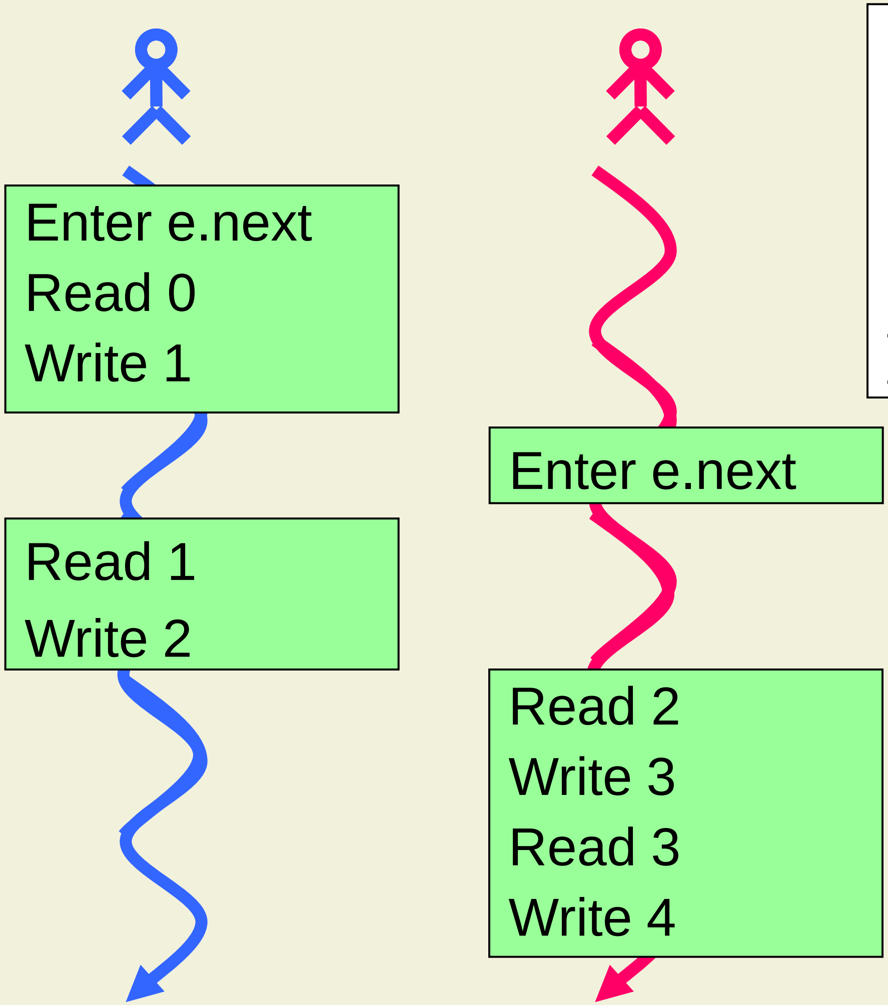
Object-Oriented Monitors

- Each object has a monitor
- Execution of synchronized methods requires lock of monitor
  - Lock is obtained upon invocation
  - Lock is released upon termination
  - Other threads have to wait
- Monitor keeps track of
  - Thread that has locked the monitor
  - Number of locks of this thread
  - Queue of blocked threads





Preventing Data Races



Enter e.next
Read 0
Write 1

Read 1
Write 2

Enter e.next

Read 2
Write 3
Read 3
Write 4

```
class Even {
  private int x;
  synchronized void next( )
      { x++; x++; }
}
```

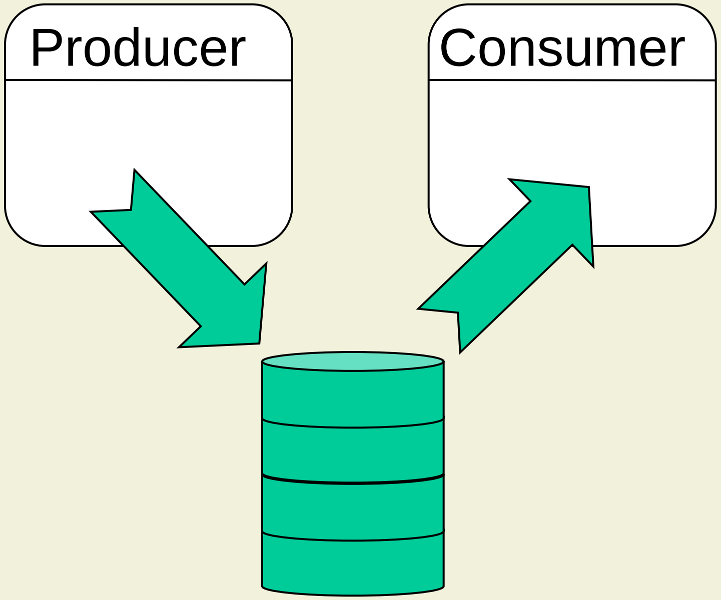
Even
x: 4

Current Thread 1

Queue

Cooperating Threads

- One thread has to wait until another thread has performed an action
- Wait condition usually depends on commonly used variables (occurs inside synchronized methods)



Producer-Consumer Example

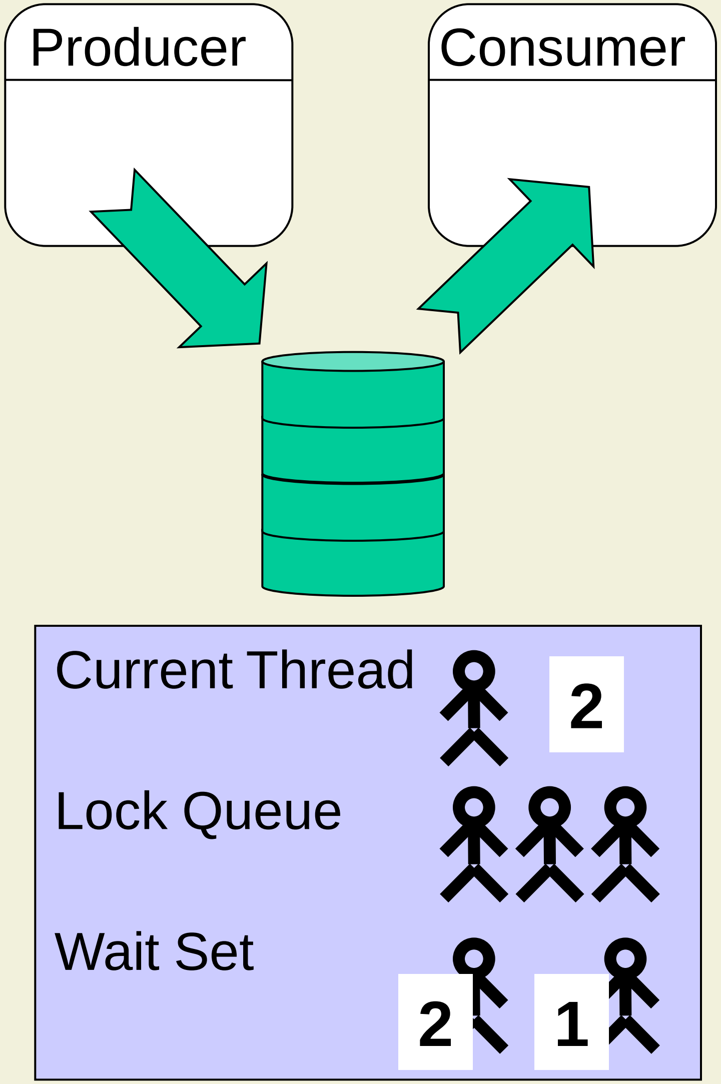
```
class Buffer {
  …
  synchronized boolean put( Prd p ) {
    if ( isFull( ) )       return false;
    …
    return true;
  }

 synchronized Prd get( ) {
    if ( isEmpty( ) )       return null;
    …
  }
}
```

```
class Producer extends Thread {
  Buffer buf;
  void run( ) {
    while ( true ) {
      Prd p = new Prd( );
      while( buf.put( p ) == false )
        sleep( 1000 );
    }
}
```

```
class Consumer extends Thread {
  Buffer buf;
  void run( )
    { // analogous }
}
```

Wait and Notify

- Wait operation
  - Can be applied if a thread has locked a monitor
  - Puts thread into wait state and adds thread to wait set
  - Releases lock
- Notify operation
  - Can be applied if a thread has locked a monitor
  - Chooses one thread from wait set and re-enables it for scheduling



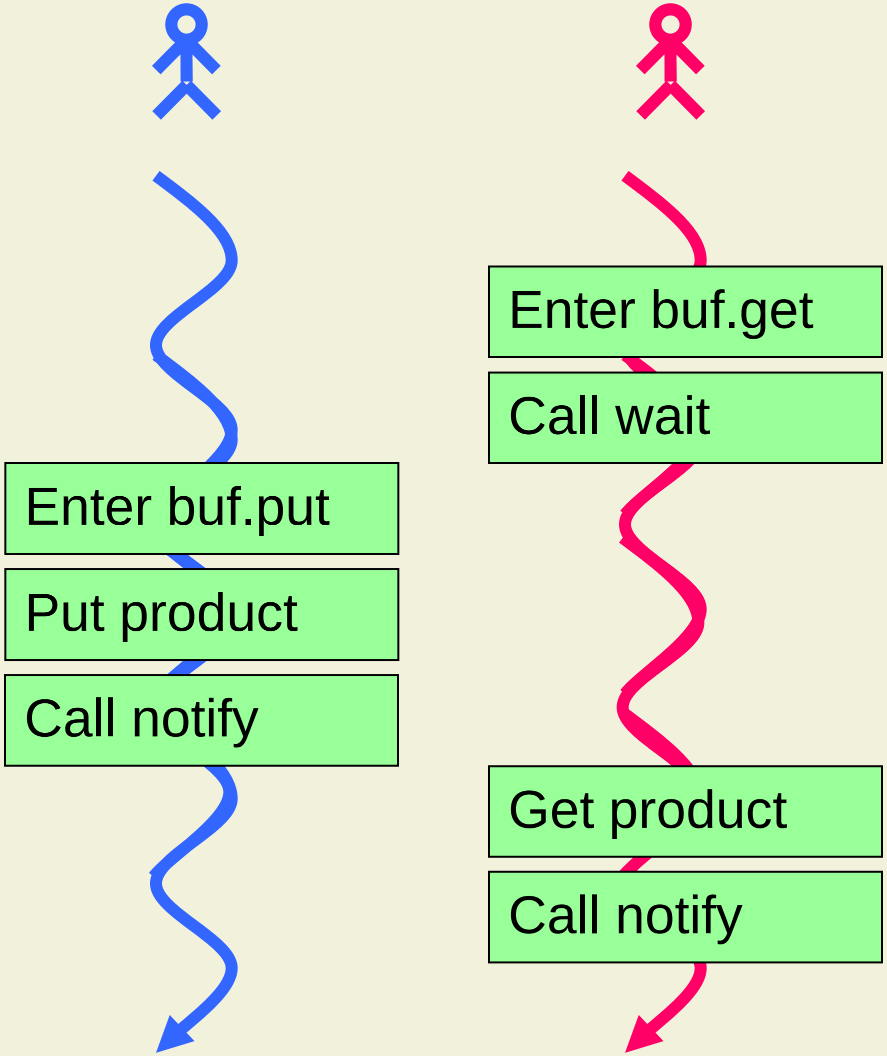
Producer-Consumer Example Revisited

```
class Buffer {
  …
  synchronized void put( Prd p ) {
    if ( isFull( ) )    wait( );
    …
    notify( );
  }

  synchronized Prd get ( ) {
    if ( isEmpty( ) )   wait( );
    …
    notify( );
  }
}
```

```
class Producer extends Thread {
  Buffer buf;
  void run( ) {
    while ( true )
      buf.put( new Prd( ) );
  }
}
```

```
class Consumer extends Thread {
  Buffer buf;
  void run( ) {
    while ( true )
    buf.get( );
  }
}
```

Producer-Consumer Example Revisited



Enter buf.put

Put product

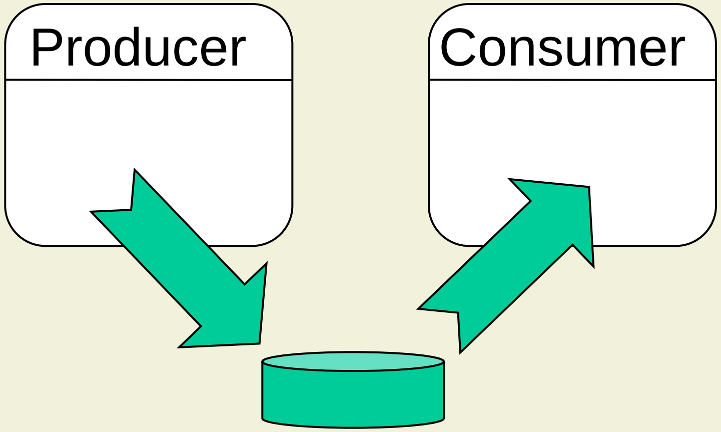
Call notify

Enter buf.get

Call wait

Get product

Call notify



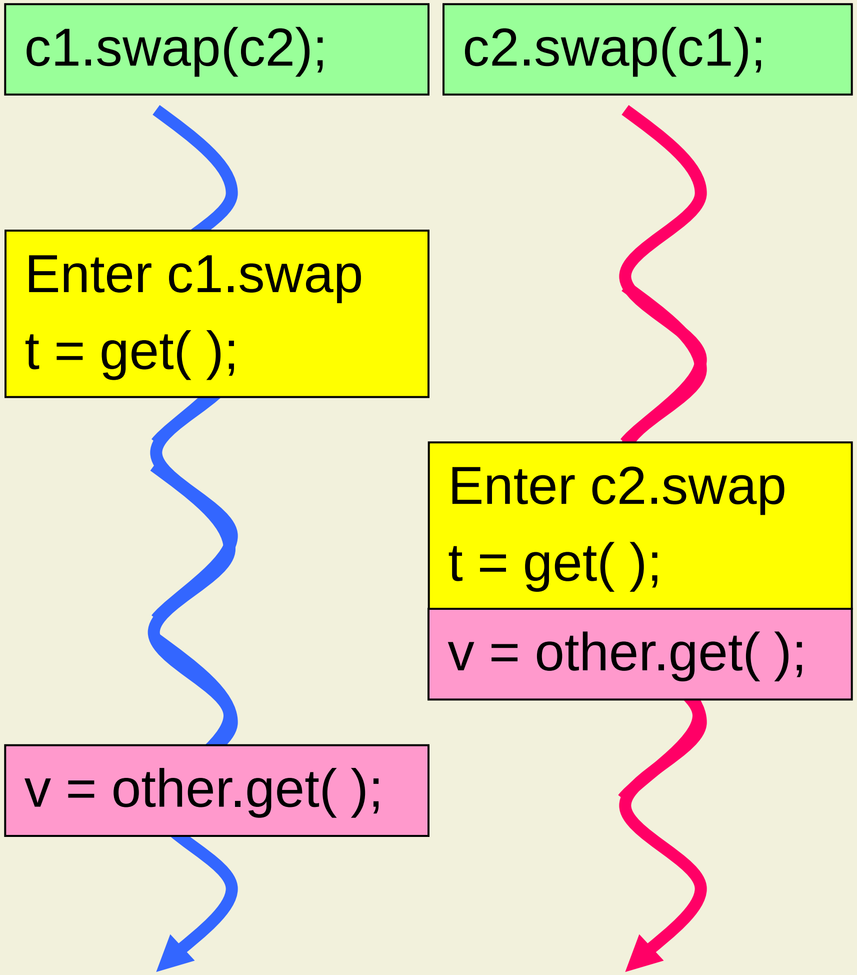
Current Thread	1
Lock Queue	
Wait Set	

Safety and Liveness

- Safety
  - **“Nothing bad ever happens”**
  - To perform method actions only when in consistent states
  - Achieved by mutual exclusion
- Liveness
  - **“Something eventually happens”**
  - Every called method should eventually execute
  - Avoiding deadlocks
  - Avoiding unfair scheduling (not guaranteed in Java)

Deadlock Example

```
class Cell {
  private long value;
  synchronized long get( )
    { return value; }
  synchronized void set( long v )
    { value = v; }
  synchronized void
          swap( Cell other ) {
    long t = get( );
    long v = other.get( );
    set( v );
    other.set( t );
  }
}
```



c1.swap(c2);

c2.swap(c1);

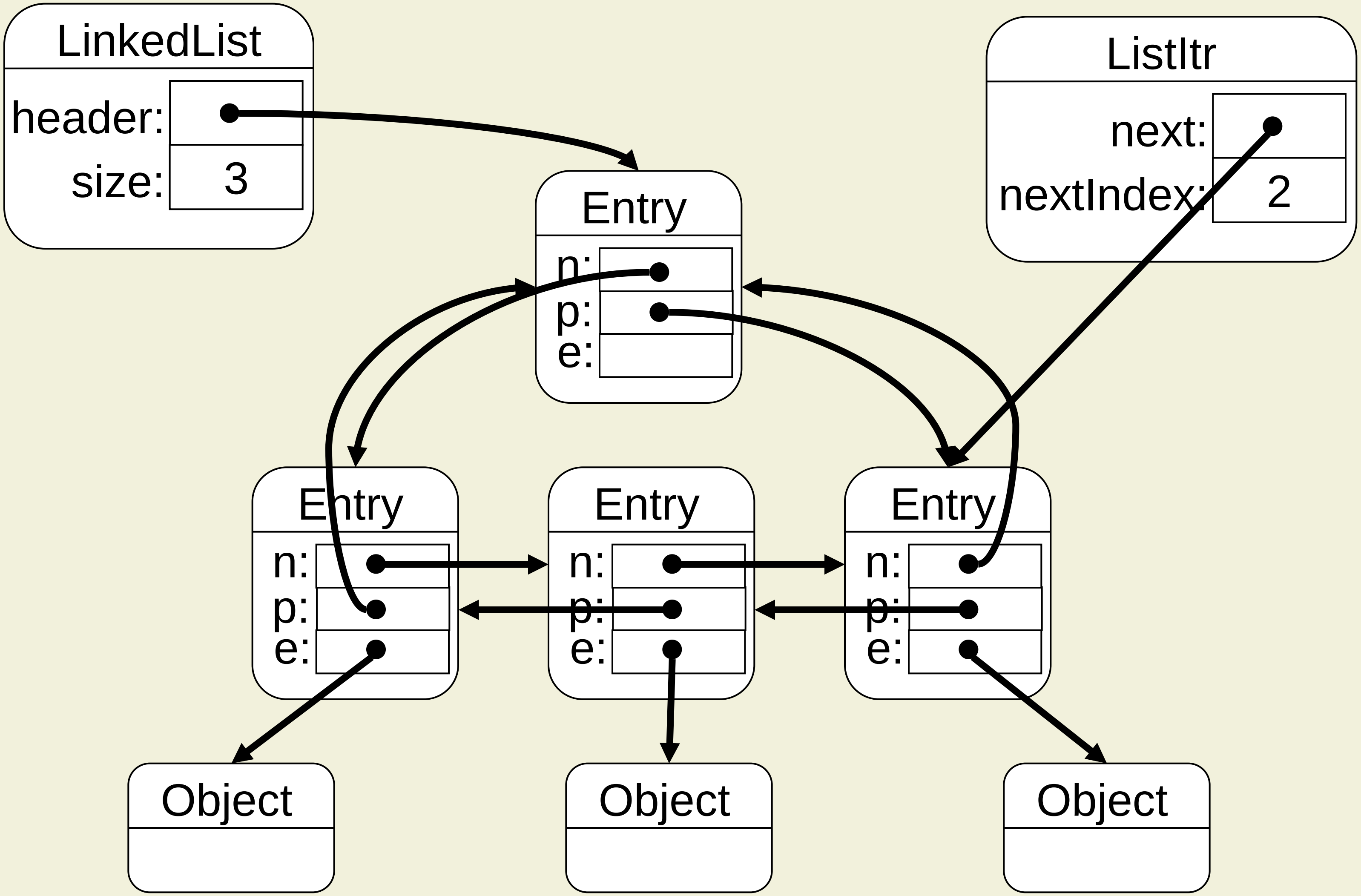
Enter c1.swap
t = get( );

Enter c2.swap
t = get( );

v = other.get( );

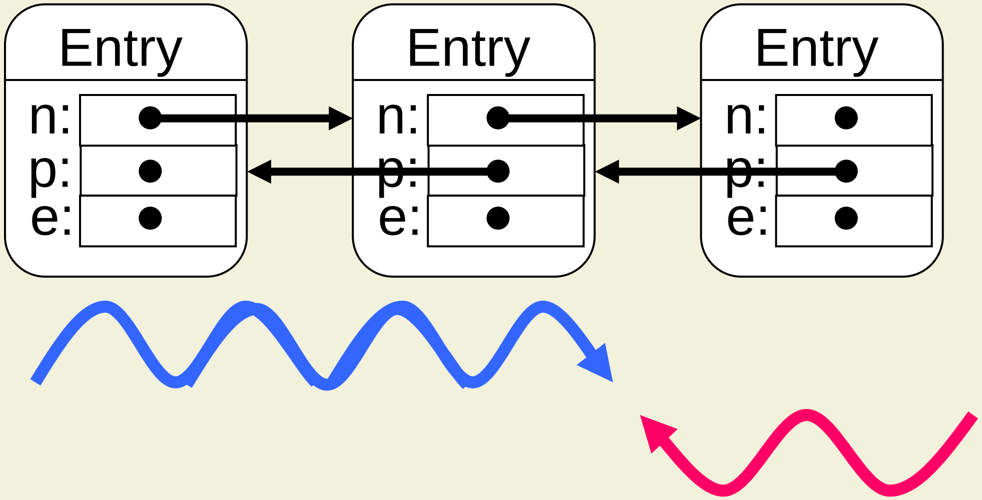
v = other.get( );

Synchronization with Object Structures



Synchronization on all Objects

- Possible solution: Make the methods of all representation objects **synchronized**
- Disadvantages
  - Direct attribute access must be synchronized separately
  - Might easily lead to deadlocks



Thread1: Traverses list from front to back

Thread2: Traverses list from back to front

Central Objects of Synchronization

- Possible guideline: To access data structure, **lock on one designated object** (e.g., the owner object) must be obtained
- Disadvantages
  - No concurrent operations on data structure
  - Clients might not follow the guideline (encapsulation!)

```
class LinkedList {
  Entry header;
  int size;
  synchronized void
           add(Object o ) { … }
}
```

```
class ListItr {
  Entry next;   int nextIndex;
  LinkedList theList;
  synchronized Object getVal( ) {
    synchronized( theList ) { … }
  }
}
```

Splitting Locks and Behavior

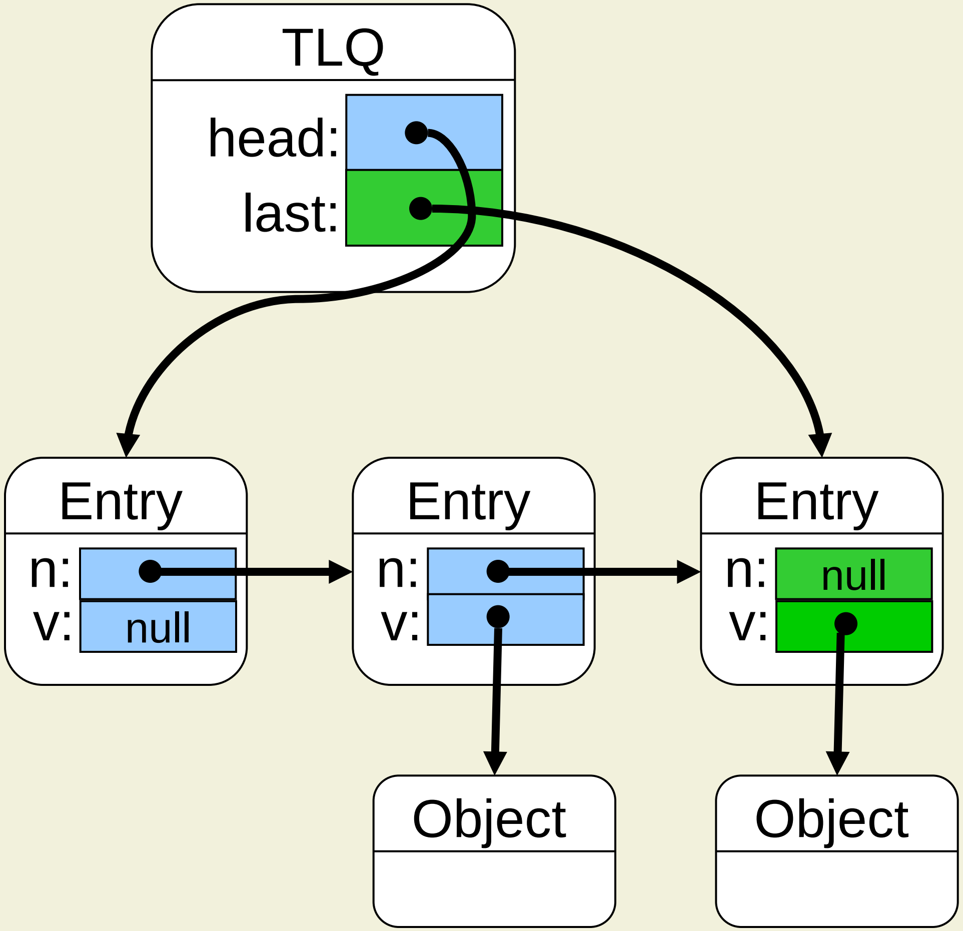
- Associate a helper object with an **independent subset of state and functionality**
- Delegate actions to helper via pass-through method
- grow and shift can execute simultaneously

```
class Shape {
  // size & location are independent
  int height = 0;
  int width = 0;
  synchronized void grow() {
      height++; width++;
  }

  Location l = new Location(0,0);
          // fully synchronized
  void shift() { l.moveBy( 1 1 ); }
          // Use l's synchronization
}
```

Concurrent Queue

- put works at the end of the list
- get works at the front of the list

- Operations can be synchronized on different locks



Concurrent Queue: Code

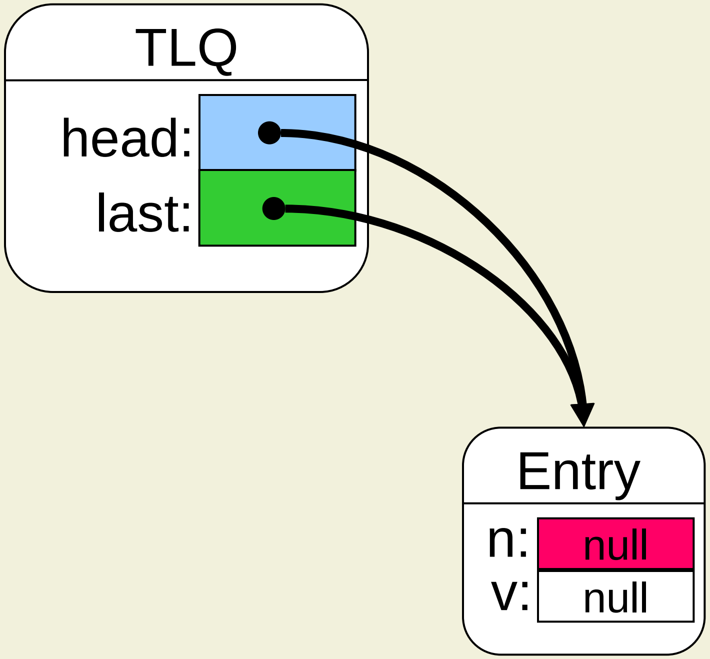
```
class Entry {
  Object value;
  Entry next = null;
  Entry( Object x ) { value = x; }
}
```

```
class TwoLockQueue {
  private Entry head =
                     new Entry( null );
  private Entry last = head;
  private Object lastLock =
                     new Object( );
```

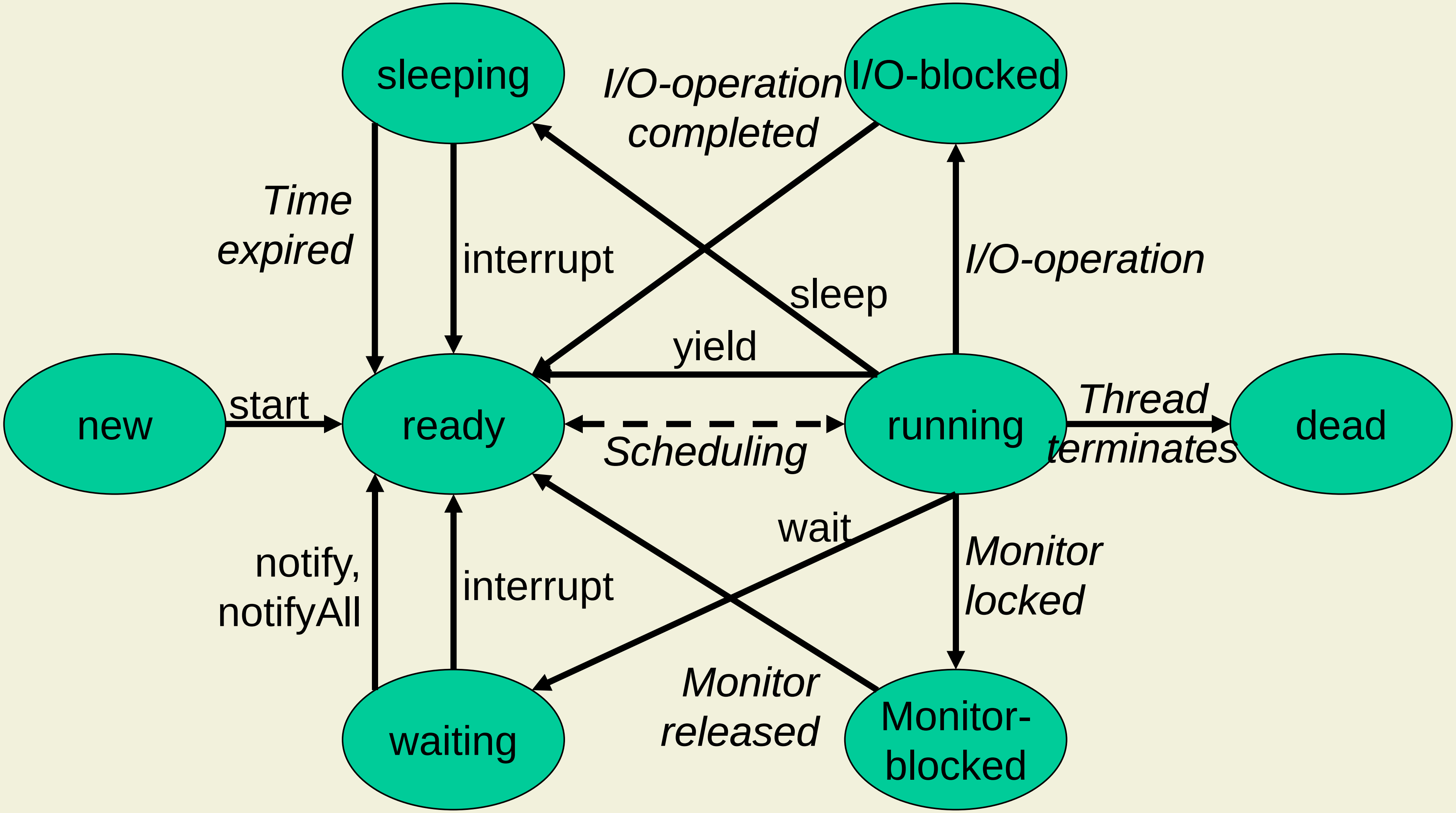
```
  void put( Object x ) {
    synchronized ( lastLock )
      { last = last.next = new Entry(x); }
  }
  synchronized Object get( ) {
    Object x = null;
    Entry first = head.next;
    if (first != null) {
      x = first.value; first.value = null;
      head = first;
    }
    return x;
} }
```

Concurrent Queue: Discussion

- put and get can run concurrently
- Java atomicity guarantees at only potential contention point
- Multiple puts and multiple gets disallowed



States of Java Threads



Summary: Object-Oriented Threads

- Threads are objects
    - Threads can be controlled by method invocations
    - Threads can be specialized by inheritance
- Each object has an associated monitor
    - Operations are inherited from Object (wait, notify, etc.)
    - Synchronization works well for individual objects, but is especially difficult for object structures
- Objects are passive
    - No real support for inherently concurrent object model

8. Concurrency

8.1 Threads

8.2 Synchronization

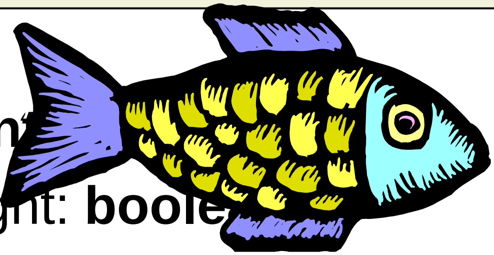
8.3 Active Objects

[This part is based on a guest lecture by
Emil Sekerinski, McMaster University]

Overview

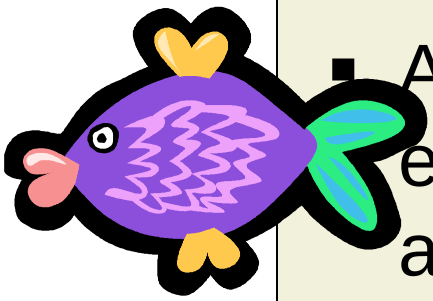
- Objects are a natural “unit” of concurrency
    - Objects can evolve independently and thus concurrently
    - Method calls allow for communication and synchronization
    - Creating an object potentially initiates a concurrent activity
- Model for active (autonomous) objects
    - Autonomous activity expressed by actions
    - Synchronization expressed by guards
- No threads

Actions: Fish Screen Saver



```
class Fish
  attr x, y: in
  attr up, rig t: boole
  initialization x, y, up, right := 0, 0, true, true
  action moveUp
    when y < H and up do y := y + 1
  action moveDow
    when y > 0 an   up do y := y – 1
  …
  action bounceU
    when y = H and up do up := false
  action bounceDo wn
    when y = 0 and ¬up do up := true
end
```

```
var f: Fish ;
for I := 1 to 10 do
  f := new Fish
```



- Actions are executed autonomously
- An action is executed only if its guard is true

Guarded Methods: Bounded Buffer

```
class BoundedBuffer
  attr b: array of Object
  attr in, out, n, max: integer
  initialization (m: integer)  in, out, n, max, b := 0, 0, 0, m, new Object[ m ]
  method put (x: Object)
    when n < max do in, b[ in ], n := ( in + 1 ) mod max, x, n + 1
  method get: Object
    when n > 0 do out, result, n := ( out + 1 ) mod max, b[ out ], n – 1
end
```

- Filtering from buffer in into out

```
x := in.get; if f( x ) then out.put( x )
```

- Execution may block at calls to guarded methods

Semaphore

```
class Semaphore
  attr n: integer
  initialization (m: integer)
    n := m
  method acquire
    when n > 0 do n := n – 1
  method release
    n := n + 1
end
```

- A semaphore s that allows m concurrent users of a resource

```
var s: Semaphore; s :=
new Semaphore (m)
```

- A user requiring semaphores s and t for a critical section

```
s.acquire; t.acquire;
… critical section ….;
s.release; t.release
```

Eager versus Lazy Computation

```
class Doubler
  attr x: integer
  method store (u: integer)
    x := 2 * u
  method retrieve: integer
    result := x
end
```

```
class LazyDoubler
  attr x: integer
  attr d: boolean
  initialization d := true
  method store (u: integer)
    x, d := u, false
  method retrieve: integer
    if ¬d then x, d := 2 * x, true;
    result := x
end
```

- Objects of class LazyDoubler can be used wherever objects of class Doubler are expected

Introducing Concurrency

```
class LazyDoubler
  attr x: integer
  attr d: boolean
  initialization d := true
  method store (u: integer)
    x, d := u, false
  method retrieve: integer
    if ¬d then x, d := 2 * x, true;
    result := x
end
```

```
class DelayedDoubler
  attr x: integer
  attr d: boolean
  initialization d := true
  method store (u: integer)
    x, d := u, false
  method retrieve: integer
    when d do result := x
  action double
    when ¬d do x, d := 2 * x, true
end
```

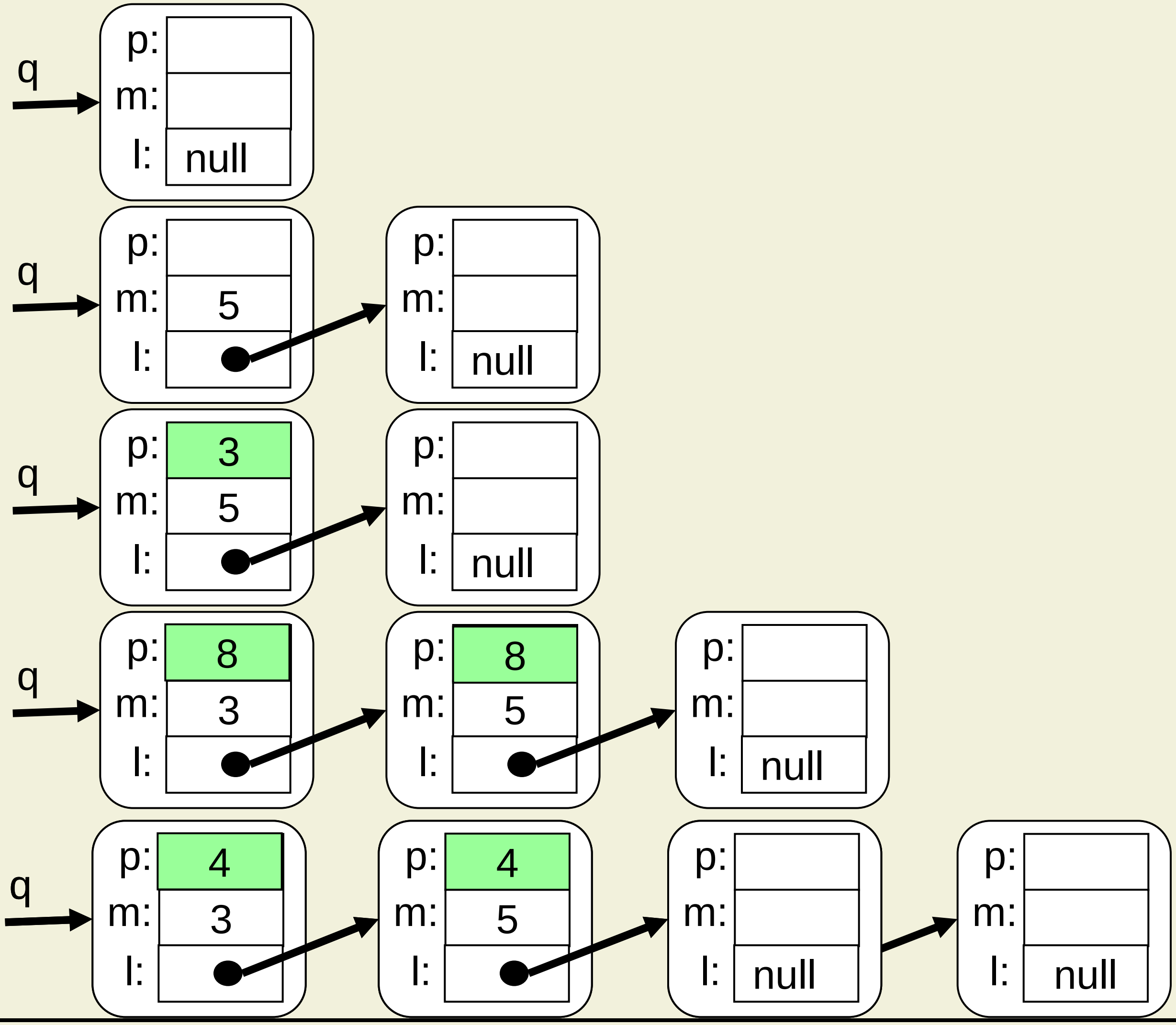
- Objects of class DelayedDoubler can be used wherever objects of class Doubler are expected

Introducing Concurrency in Subclasses

```
class Doubler
  attr x: integer
  method store (u: integer)
    x := 2 * u
  method retrieve: integer
    result := x
end
```

```
class DelayedDoubler
                       inherit Doubler
  attr d: boolean
  initialization d := true
  method store (u: integer)
    x, d := u, false
  method retrieve: integer
    when d do result := x
  action double
    when ¬d do x, d := 2 * x, true
end
```

Concurrent Priority Queue



q := **new** PQ

q.add(5)

q.add(3)

q.add(8)

q.add(4)

Concurrent Priority Queue: Code

```
class PriorityQueue
  attr m, p: integer
  attr l: PriorityQueue
  attr a: boolean
  initialization l, a := nil, false
  method add (e: integer)
    when ¬a do
      if l = nil then
        begin
          m := e; l := new PriorityQueue
        end
      else
        begin p := e ; a := true end
```

```
  action doAdd
    when a do
      begin
        if m < p then l.add (p)
        else
          begin
            l.add (m) ; m := p
          end;
          a := false
  method empty: boolean
    result := l = nil
end
```

Dining Philosophers

```
class Fork
  attr available: boolean
  initialization available := true
  method pickUp when available do available := false
  method putDown available := true
end
```

```
class Philosopher
  attr state: (thinking, hungry, eating, full)
  attr left, right: Fork
  initialization (l, r : Fork) state, left, right := thinking, l, r
  action gettingHungry when state = thinking do
    begin state := hungry; left.pickUp ; right.pickUp; state := eating end
  action gettingFull when state = eating do
    begin state := full; left.putDown ; right. putDown; state := thinking end
end
```

Dining Philosophers: Main Program

```
var fork := new Fork [ 5 ];
var philosopher := new Philosopher [ 5 ];
for i := 0 to 4 do
  fork [ i ] := new Fork ;
for j := 0 to 4 do
  philosopher [ j ] := new Philosopher ( fork [ j ], fork [ (j + 1) mod 5 ] )
```

Fairness through Strong Semaphores

```
class WeakBinarySemaphore
  attr a: boolean
  initialization a := true
  method acquire
    when a do a := false
  method release
    a := true
end
```

- If continuously several users try to acquire a weak semaphore, some may be delayed indefinitely

```
class StrongBinarySemaphore
  attr a: boolean
  attr q: seq of Object
  initialization a, q := true, <>
  method acquire( u: Object )
    begin q := q ° <u>;
    when a and u = head( q ) do
      a, q := false, tail( q )
  method release a := true
end
```

- The strong semaphore ensures a first-in first-out policy

Summary of Active Objects

- Language extensions
  - **No** construct for **threads**
  - Classes: attributes, methods, **actions**
  - **Guards** for synchronization: **when** b **do** S = **await** b S
- Goal: Bring the practice of concurrent object-oriented programming as close as possible to a simple model with a sound theory