COMP 322: Fundamentals of Parallel Programming

Lecture 20: Isolated statement (contd), Monitors, Actors

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https://wiki.rice.edu/confluence/display/PARPROG/COMP322

Acknowledgments

- Wikipedia – Spanning Tree
- Wolfram Mathworld – Spanning Tree
- Inside the Java Virtual Machine, Chapter 20: Thread Synchronization
  http://www.artima.com/insidejvm/ed2/threadsynch.html
- Concurrency Tutorial: Guarded Blocks
  http://docs.oracle.com/javase/tutorial/essential/concurrency/guardmeth.html
- "Actor-based Programming for Scalable Parallel and Distributed Systems", Gul Agha

  http://dl.dropbox.com/u/27020702/actors/Actors.pptx

Outline

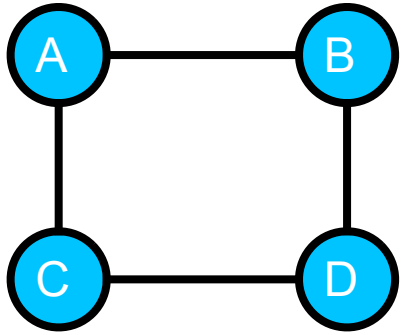
- Spanning Tree Example
- Monitors
- Actors

Spanning Tree

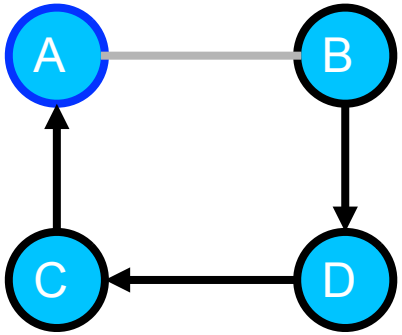
- A spanning tree, T, of a connected undirected graph G is
  - rooted at some vertex of G
  - defined by a parent map for each vertex
  - contains all the vertices of G, i.e. spans all vertices
  - contains exactly |v| - 1 edges
    - adding any other edge will create a cycle
  - contains no cycles (a tree!)
    - implies the edges involved in T is a subset of the edges in G

An Example Graph with 4 possible spanning trees rooted at vertex A

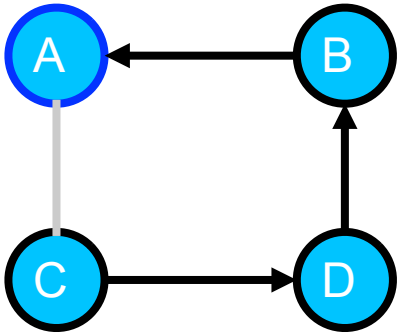
Example Graph:



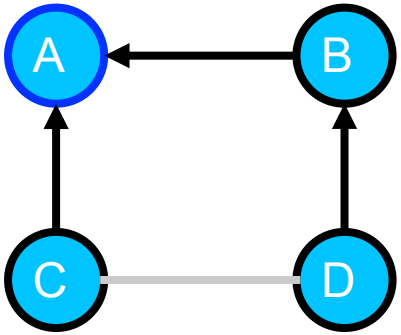
Spanning Trees:



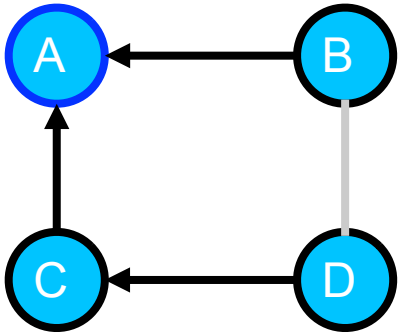
Vertex	Parent
A	null
B	D
C	A
D	C



Vertex	Parent
A	null
B	A
C	D
D	B



Vertex	Parent
A	null
B	A
C	A
D	B



Vertex	Parent
A	null
B	A
C	A
D	C

Parallel Spanning Tree Algorithm using isolated statement

```
1. class V  {
2.   V [] neighbors; // adjacency list for input graph
3.   AtomicReference parent; // output value of parent in spanning tree
4.   boolean tryLabeling(V n) {
5.     isolated if (parent == null) parent=n;
6.     return parent == n;
7.   } // tryLabeling
8.   void compute() {
9.     for (int i=0; i<neighbors.length; i++) {
10.      V child = neighbors[i];
11.      if (child.tryLabeling(this))
12.          async child.compute(); //escaping async
13.     }
14.  } // compute
15.} // class V
16.. . .
17.root.parent = root; // Use self-cycle to identify root
18.finish root.compute();
19.. . .
```


Parallel Spanning Tree Algorithm using object-based isolation

```
1. class V  {
2.   V [] neighbors; // adjacency list for input graph
3.   AtomicReference parent; // output value of parent in spanning tree
4.   boolean tryLabeling(V n) {
5.     isolated(this) if (parent == null) parent=n;
6.     return parent == n;
7.   } // tryLabeling
8.   void compute() {
9.     for (int i=0; i<neighbors.length; i++) {
10.      V child = neighbors[i];
11.      if (child.tryLabeling(this))
12.          async child.compute(); //escaping async
13.     }
14.  } // compute
15.} // class V
16.. . .
17.root.parent = root; // Use self-cycle to identify root
18.finish root.compute();
19.. . .
```


Parallel Spanning Tree Algorithm using java.util.concurrent.atomic.AtomicReference

```
1. class V  {
2.   V [] neighbors; // adjacency list for input graph
3.   AtomicReference parent; // output value of parent in spanning tree
4.   boolean tryLabeling(V n) {
5.     return parent.compareAndSet(null ,n);
6.
7.   } // tryLabeling
8.   void compute() {
9.     for (int i=0; i<neighbors.length; i++) {
10.      V child = neighbors[i];
11.      if (child.tryLabeling(this))
12.          async child.compute(); //escaping async
13.     }
14.  } // compute
15.} // class V
16.. . .
17.root.parent = root; // Use self-cycle to identify root
18.finish root.compute();
19.. . .
```


Performance trade-offs for Isolated, Object-based Isolated, and Atomic Variables

- Atomic variables have the best performance of all three cases
  - Limitations:
    - Body of critical section must match existing method in atomic variable's interface
    - Context-switching needs to be disabled in the middle of an atomic operation
- Standard isolated ("isolated-all") performs better than object-based isolated in low contention
  - HJ's standard isolated uses a single lock. The additional parallelism from object-based isolation does not make a measurable difference if contention is low, while the additional overhead for object-based isolation can be significant.
- Standard isolated ("isolated-all") performs better than object-based isolated in high contention on a single object
  - Object-based isolation incurs extra overhead but provides no extra benefit when contention is on a single object.
- Object-based isolation performs better than standard isolated ("isolated-all") if critical sections are distributed across a wide range of objects, there is sufficient contention to make standard isolated perform poorly, there isn't too much contention on a single object to limit object-based contention, and there is enough work in the isolated statement to justify the overhead
  - HJ's object-based isolation uses one global read-write lock, combined with built-in locks for all Java objects

Outline

- Spanning Tree Example
- Monitors
- Actors

Monitors --- an object-oriented approach to isolation

- A monitor is an object containing
  - some local variables (private data)
  - some methods that operate on local data (monitor regions)
- Only one task can be active in a monitor at a time, executing some monitor region
  - Analogous to a critical section
- Monitors can also be used for
  - Mutual exclusion
  - Cooperation

Mutual Exclusion with Monitors: an Analogy

- A building, many people can enter the building at the same time
  - Entering building == entering the monitor
  - Leaving building == exiting the mintor
- Special room which can be occupied **by a single person at a time**
- The room contains some data which can be used/modified
- People must queue up in the hall and compete to enter the room
  - Entering room == acquiring the monitor
  - Occupying the room == owning the monitor
  - Leaving room == releasing the monitor

Monitors Cooperation - Analogy

- Cooperation == waiting for some condition to be true before executing the monitor region
- Analogy:
  - A fastidious person will only work in the room if it is clean
  - If the room is unclean, he will move from the room to a waiting area, and wait for the room to become cleaner before trying to re-enter
  - Hopefully, a cleaner will come along, gain access to the room and clean it
  - Cleaner needs to notify people waiting after room is clean
    - We will revisit this concept when we study "condition variables" later in the course

Monitors – a Diagrammatic summary

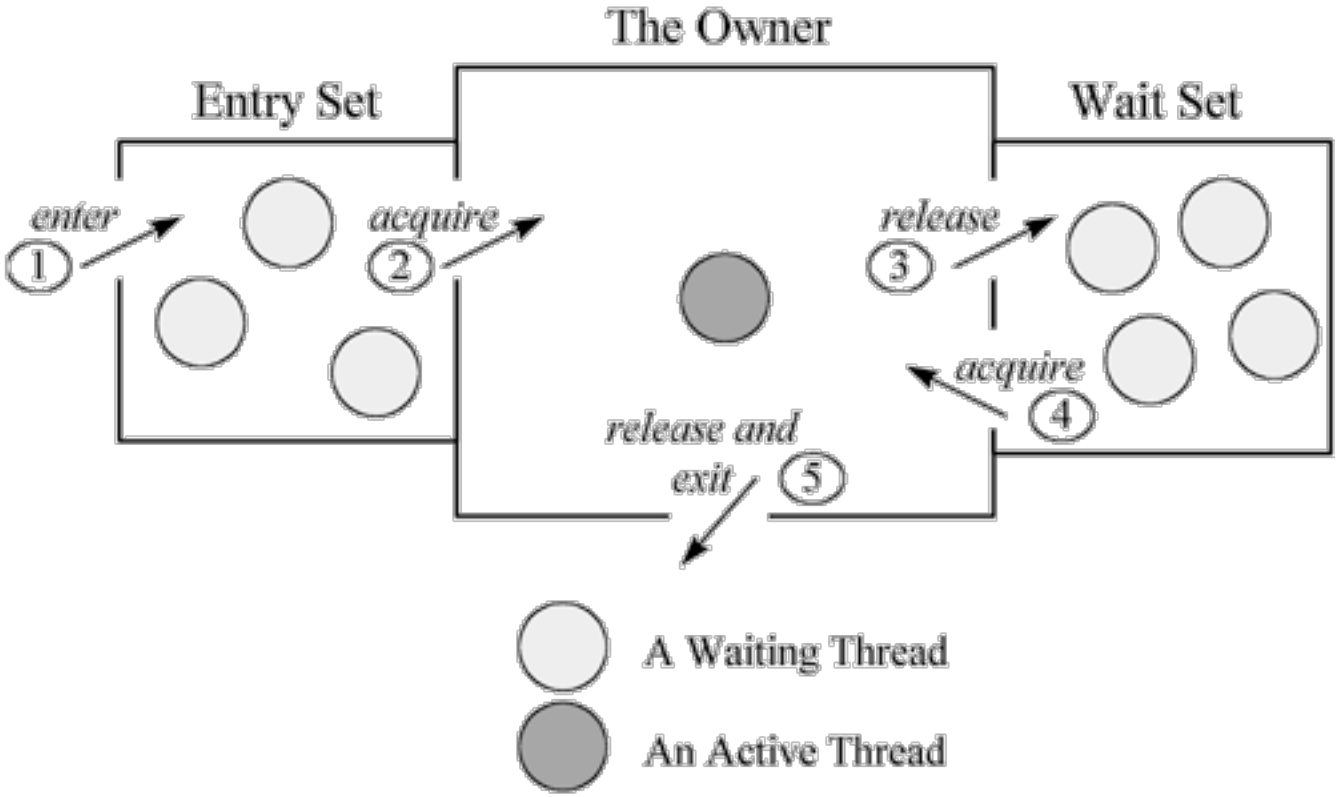


Figure 20-1. A Java monitor.

Figure source: http://www.artima.com/insidejvm/ed2/images/fig20-1.gif

Converting Standard Java Libraries to Monitors

Different approaches:

1. Restrict access to a single task ➔ no modification needed
2. Ensure that each call to a public method is isolated ➔ excessive serialization
3. Use specialized implementations that minimize serialization across public methods ➔ Java Concurrent Collections

- We will focus on three java.util.concurrent classes that can be used freely in HJ programs, analogous to Java Atomic Variables
  - ConcurrentHashMap, ConcurrentLinkedQueue, CopyOnWriteArraySet
- Other j.u.c. classes can be used in standard Java, but not in HJ because they may perform blocking operations
  - ArrayBlockingQueue, CountDownLatch, CyclicBarrier, DelayQueue, Exchanger, FutureTask, LinkedBlockingQueue, Phaser PriorityBlockingQueue, Semaphore, SynchronousQueue

The Java Map Interface

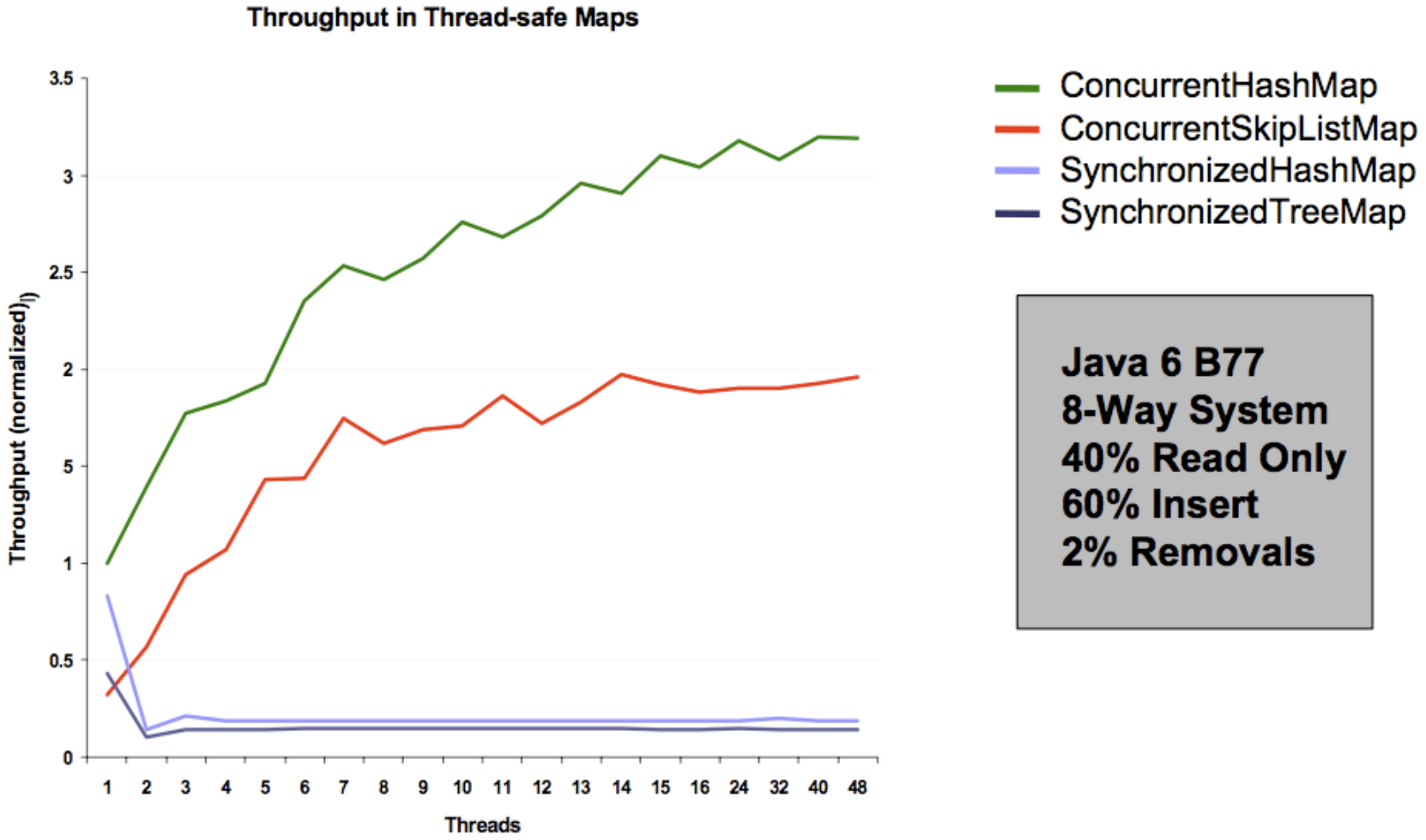
- Map describes a type that stores a collection of key-value pairs
- A Map associates a key with a value
- The keys must be unique
  - the values need not be unique
- Useful for implementing software caches (where a program stores key-value maps obtained from an external source such as a database), dictionaries, sparse arrays, …

- A Map is often implemented with a hash table (HashMap)
- Hash tables attempt to provide constant-time access to objects based on a key (String or Integer)
  - key could be your Student ID, your telephone number, social security number, account number, …
- The direct access is made possible by converting the key to an array index using a hash function that returns values in the range 0 … ARRAY_SIZE-1, typically by using a (mod ARRAY_SIZE) operation

java.util.concurrent.concurrentHashMap

- Implements ConcurrentMap sub-interface of Map
- Allows read (traversal) and write (update) operations to overlap with each other
- Some operations are atomic with respect to each other e.g.,
  - get(), put(), putIfAbsent(), remove()
- Aggregate operations may not be viewed atomically by other operations e.g.,
  - putAll(), clear()
- Expected degree of parallelism can be specified in ConcurrentHashMap constructor
  - ConcurrentHashMap(initialCapacity, loadFactor, concurrencyLevel)
  - A larger value of concurrencyLevel results in less serialization, but a larger space overhead for storing the ConcurrentHashMap

Concurrent Collection Performance



Example usage of ConcurrentHashMap in org.mirrorfinder.model.BaseDirectory

```
1  public abstract class BaseDirectory extends BaseItem implements Directory {
2    Map files = new ConcurrentHashMap();
3    . . .
4    public Map getFiles() {
5      return files;
6    }
7    public boolean has(File item) {
8      return getFiles().containsValue(item);
9    }
10   public Directory add(File file) {
11     String key = file.getName();
12     if (key == null) throw new Error(. . .);
13     getFiles().put(key, file);
14     . . .
15     return this;
16   }
17   public Directory remove(File item) throws NotFoundException {
18     if (has(item)) {
19       getFiles().remove(item.getName());
20       . . .
21     } else throw new NotFoundException("can't remove unrelated item");
22   }
23 }
```

Listing 1: Example usage of ConcurrentHashMap in org.mirrorfinder.model.BaseDirectory [1]

java.util.concurrent.ConcurrentLinkedQueue

- `Queue` interface added to `java.util`
  - interface Queue extends Collection and includes

```
boolean offer(E x); // same as add() in Collection
E poll(); // remove head of queue if non-empty
E remove(o) throws NoSuchElementException;
E peek(); // examine head of queue without removing it
```

- Non-blocking operations
  - Return `false` when full
  - Return `null` when empty
- Fast thread-safe non-blocking implementation of Queue interface: `ConcurrentLinkedQueue`

Example usage of ConcurrentLinkedQueue in org.apache.catalina.tribes.io.BufferPool15Impl

```
1  class BufferPool15Impl implements BufferPool.BufferPoolAPI {
2    protected int maxSize;
3    protected AtomicInteger size = new AtomicInteger(0);
4    protected ConcurrentLinkedQueue queue = new ConcurrentLinkedQueue();
5    . . .
6    public XByteBuffer getBuffer(int minSize, boolean discard) {
7      XByteBuffer buffer = (XByteBuffer) queue.poll();
8      if ( buffer != null ) size.addAndGet(-buffer.getCapacity());
9      if ( buffer == null ) buffer = new XByteBuffer(minSize,discard);
10     else if ( buffer.getCapacity() <= minSize ) buffer.expand(minSize);
11     . . .
12     return buffer;
13   }
14   public void returnBuffer(XByteBuffer buffer) {
15     if ( (size.get() + buffer.getCapacity()) <= maxSize ) {
16       size.addAndGet(buffer.getCapacity());
17       queue.offer(buffer);
18     }
19   }
20 }
```

Listing 2: Example usage of ConcurrentLinkedQueue in org.apache.catalina.tribes.io.BufferPool15Impl

java.util.concurrent.CopyOnWriteArraySet

- Set implementation optimized for case when sets are not large, and read operations dominate update operations in frequency
- This is because update operations such as add() and remove() involve making copies of the array
  - Functional approach to mutation
- Iterators can traverse array "snapshots" efficiently without worrying about changes during the traversal.

Example usage of CopyOnWriteArraySet in org.norther.tammi.spray.freemarker.DefaultTemplateLoader

```
1  public class DefaultTemplateLoader implements TemplateLoader, Serializable
2  {
3    private Set resolvers = new CopyOnWriteArraySet();
4    public void addResolver(ResourceResolver res)
5    {
6      resolvers.add(res);
7    }
8    public boolean templateExists(String name)
9    {
10       for (Iterator i = resolvers.iterator(); i.hasNext();) {
11         if (((ResourceResolver) i.next()).resourceExists(name)) return true;
12       }
13       return false;
14   }
15   public Object findTemplateSource(String name) throws IOException
16   {
17     for (Iterator i = resolvers.iterator(); i.hasNext();) {
18       CachedResource res = ((ResourceResolver) i.next()).getResource(name);
19       if (res != null) return res;
20     }
21     return null;
22   }
23  }
```

Listing 3: Example usage of CopyOnWriteArraySet in org.norther.tammi.spray.freemarker.DefaultTemplateLoader

Outline

- Spanning Tree Example
- Monitors
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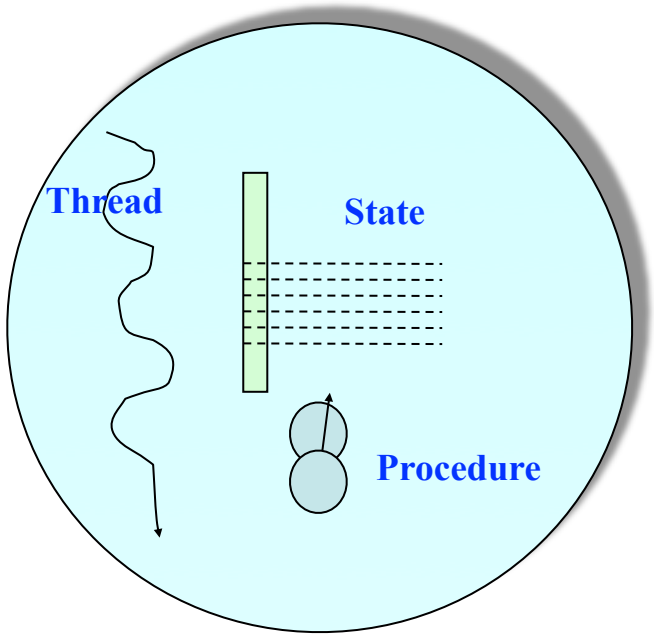
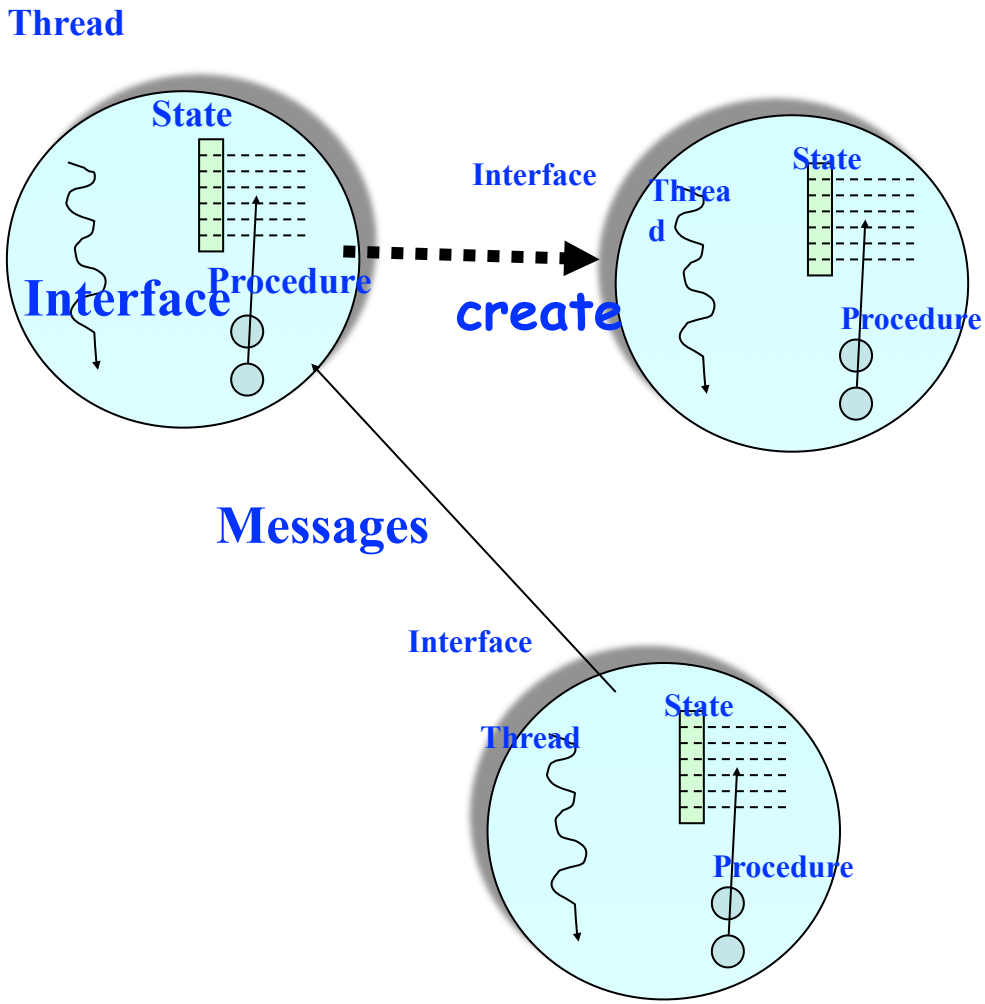
Actors as concurrent objects

- An actor is an autonomous, interacting component of a parallel system.
- An actor has:
  - —an immutable identity (name, virtual address)
  - —a mutable local state (encapsulated)
  - —procedures to manipulate local state (provide an interface)
  - —a thread of control

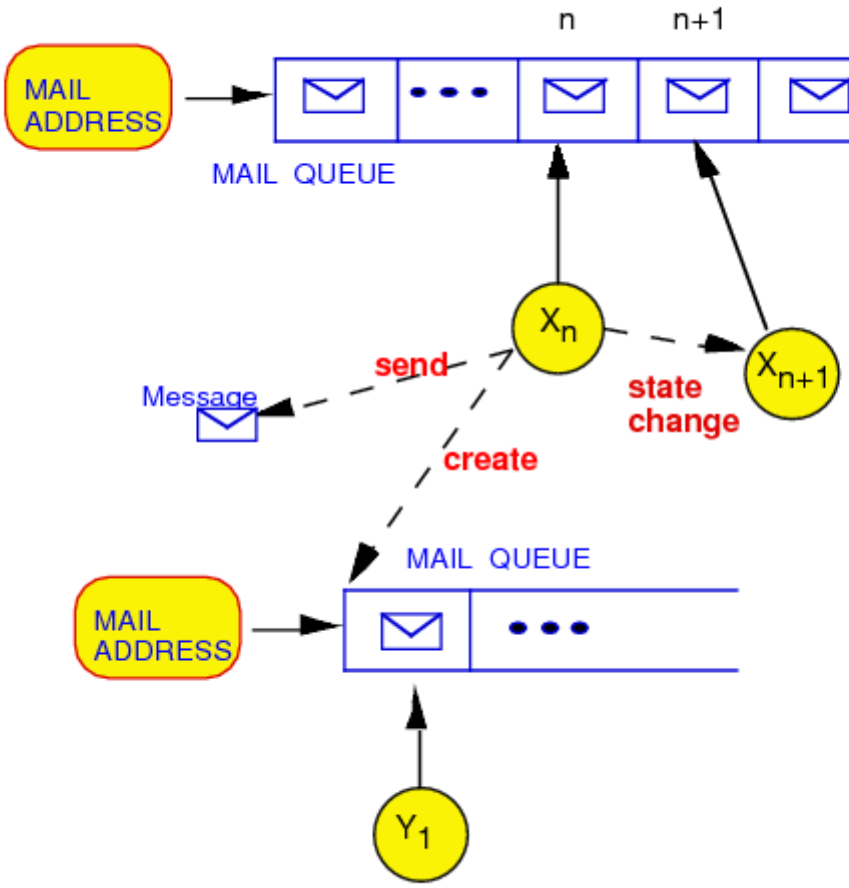


The Actor Model: Fundamentals

- An actor may:
  - process messages
  - send messages
  - change local state
  - create new actors



Arrival Order Nondeterminism



Communication is asynchronous: no assumption can be made about order of message delivery

Actor anatomy

Actors = encapsulated state + behavior (methods) +

thread of control + mailbox