The Java Concurrency API and Deadlock Prevention in a RETE Rules Engine to Implement a Pricing Service

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Goal of the Talk

What You Will Learn

How the Java platform can be used to write a Concurrent RETE Forward Production System:

The Zilonis Rules Engine

Agenda

Pricing Service in Retail

Rules Engine (RETE)

Concurrency in the Rules Engine

Deadlock Prevention

Other Optimizations

Demo!

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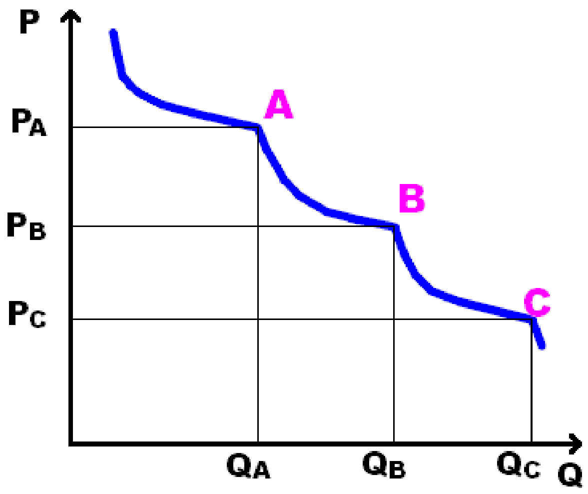
Pricing Service in Retail

It is more complicated than what it seems at first

- Cost Plus vs. List Minus
- Marketing Campaigns
- Bulk Pricing
- Different Providers/Vendors
- Zone, Geo Location
- Price Discrimination/Contracts
- Competition



Agenda

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Demo!

Rules Engine

The value in a system like a pricing engine

- Understandability:
  - Declarative, well defined rules
  - Easy to read and understand
  - Business engagement early on the process (KPLM)
- We can get a clear explanation of why a result was given
- Agile Maintainability
- Time to market

Rules Engine

The Structure

- Working Memory
  - A set of Facts: Working Memory Elements (WME)
- Production Memory
  - A set of Rules: Productions

Rules Engine

Working Memory

- Internal Representation is in 3-Tuples: Triples
- Complex Structures can be mapped to Triples

```
(Order (sku 3155123) (quantity 2) (channel web))
           W1:(1 clazz Order)
           W2:(1 sku 3155123)
           W3:(1 quantity 2)
           W4:(1 channel web)
```

- RDF uses the same approach (SPO) in the Semantic Web

Rules Engine

Production Memory

```
(Name-of-Production
   LeftHandSide     /* one or more conditions */
=>
   RightHandSide    /* one or more actions */
```

Rules Engine

Production Memory

```
(defrule retailPricingRule
  (order (channel web)
         (sku ?skuId))
  (item (sku ?skuId)
        (retailPrice ?price))
=>
  (assert (methodResult (price ?price)
                        (method retailPrice))))
```

Rules Engine

Complexity of the Match Phase

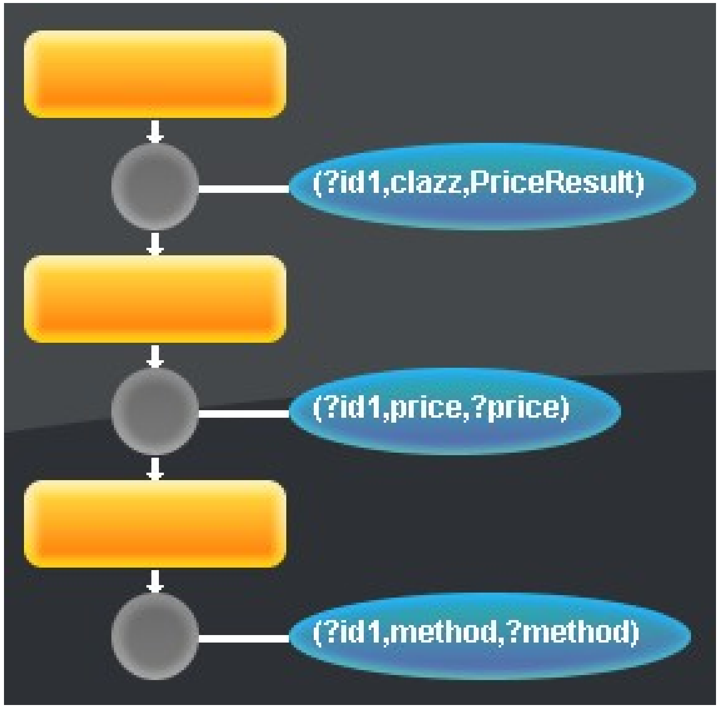
- Consider a production system of:
  - 1,000 rules with 3 conditions each
  - 1,000 Working Memory Elements (WME)
- Naive implementation:
  - Each production is matched against all tuples of size 3 from working memory (WM)
  - Over a trillion ($1{,}000 \times 1{,}000^3$) match operations per cycle
- Even specialized algorithms take 90% of time in this phase

RETE Algorithm

Version used in Zilonis and Soar

- Dataflow network to represent the conditions

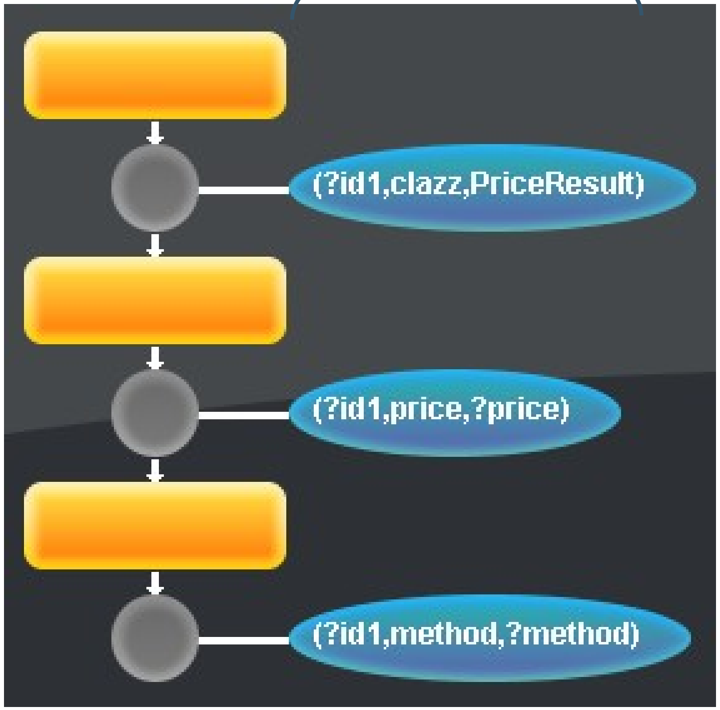
- The network has 2 parts:
  - Alpha Network
  - Beta Network



RETE Algorithm

The Alpha Network

Alpha Memory




```
(defrule PriceResultRule
    (?id clazz PriceResult)
    (?id price ?price)
    (?id method ?method)
=>
    (print “result: ?1 method ?2”
                        ?price ?method))
```

Results of C1

Results of C2

Results of C3

RETE Algorithm

The Beta Network

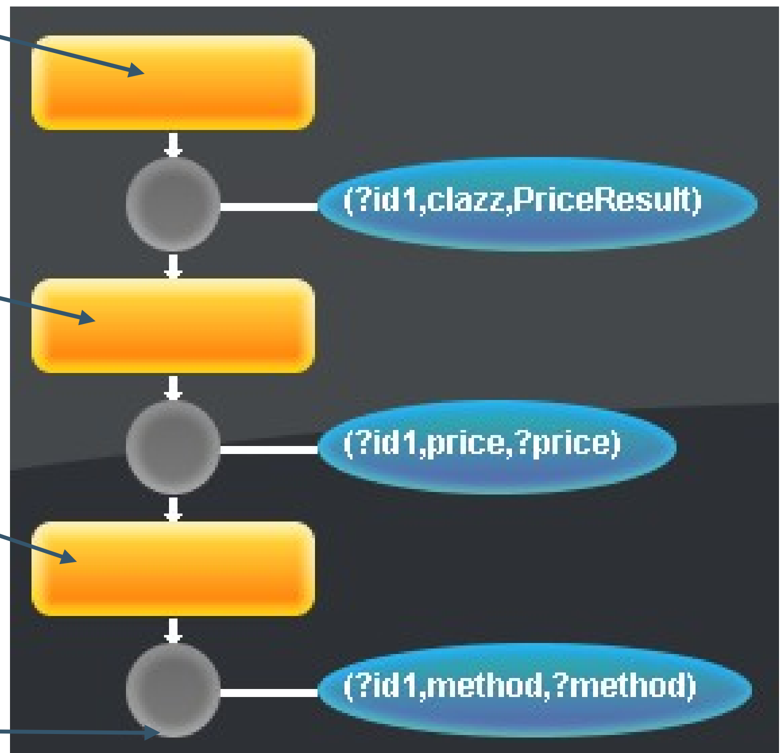
```
(PriceResultRule
    (?id clazz PriceResult)
    (?id price ?price)
    (?id method ?method)
=>
    RHS
```

Dummy Beta Memory

Results of C1

Results of C1 and C2

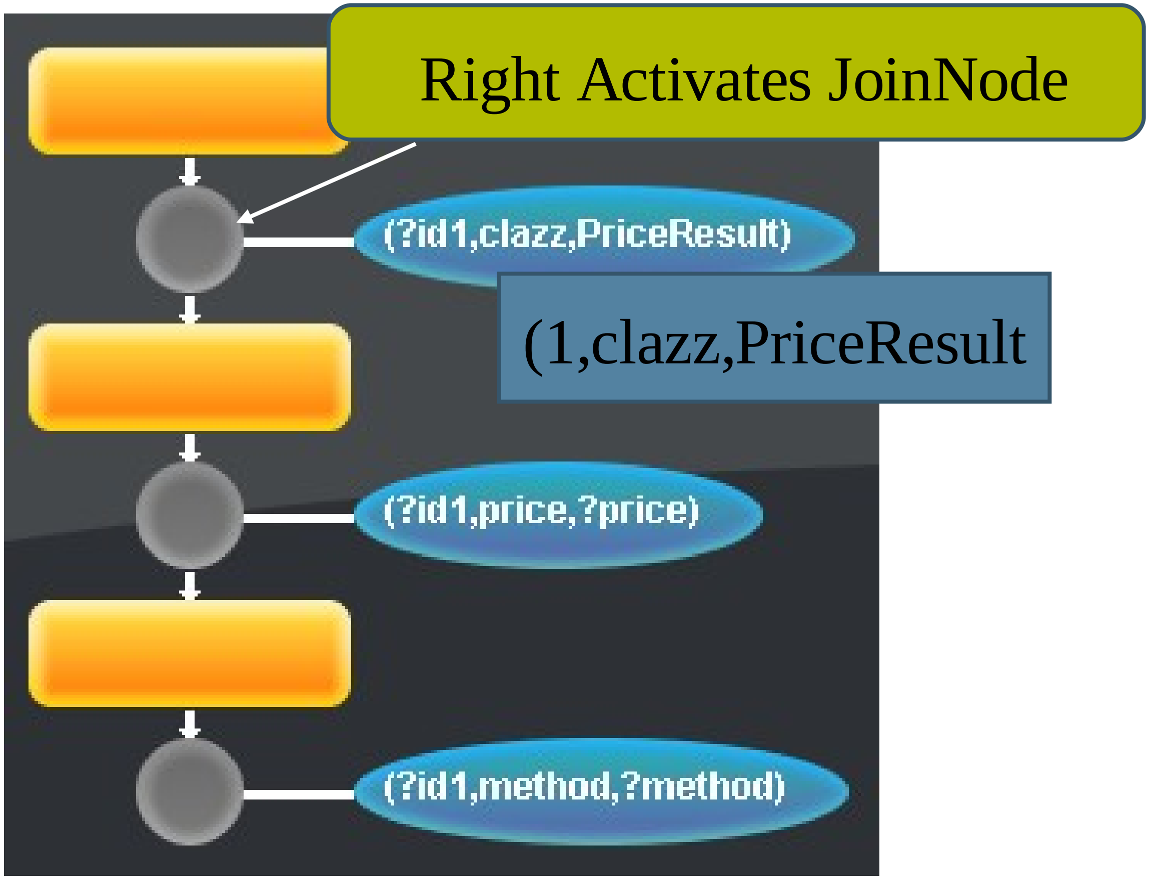
Results of C1 and C2 and C3



RETE Algorithm

Putting it all together

Assert: (1,clazz,PriceResult)



RETE Algorithm

Putting it all together

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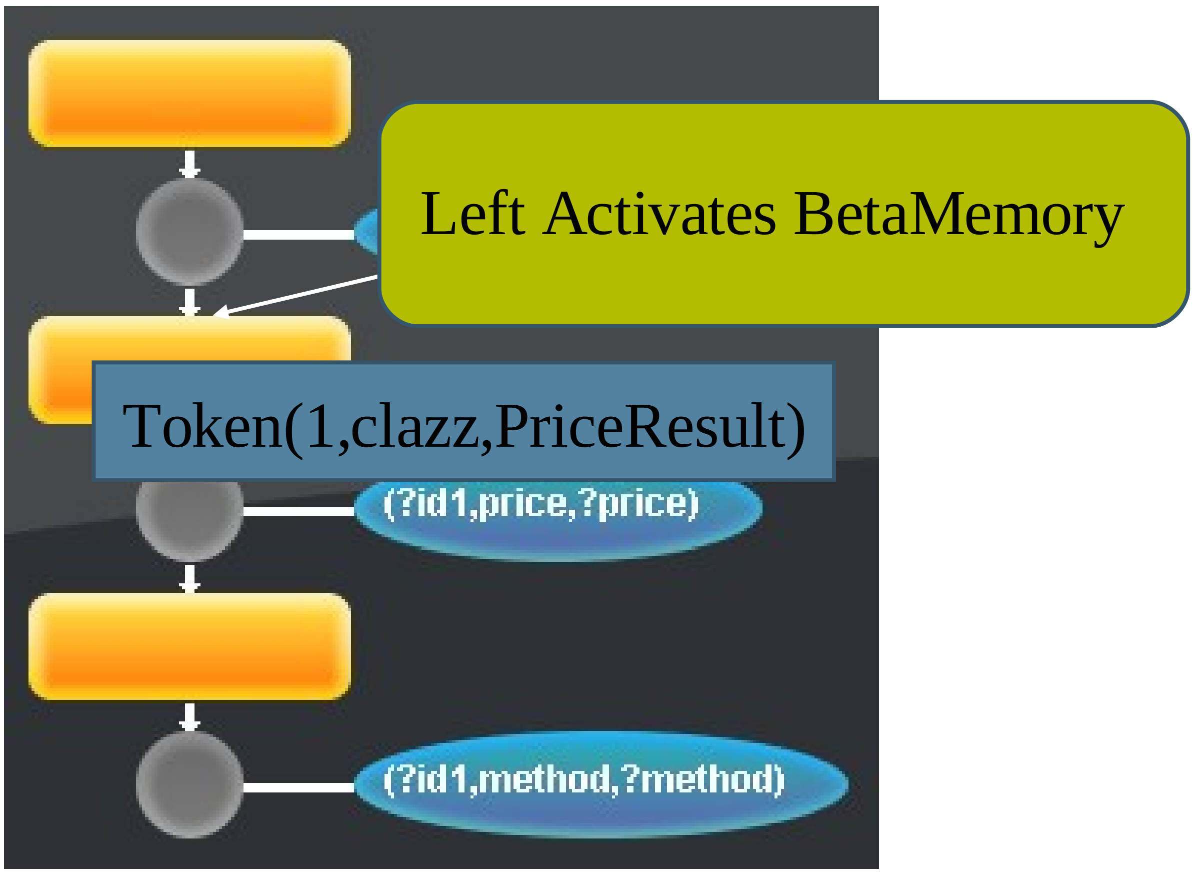
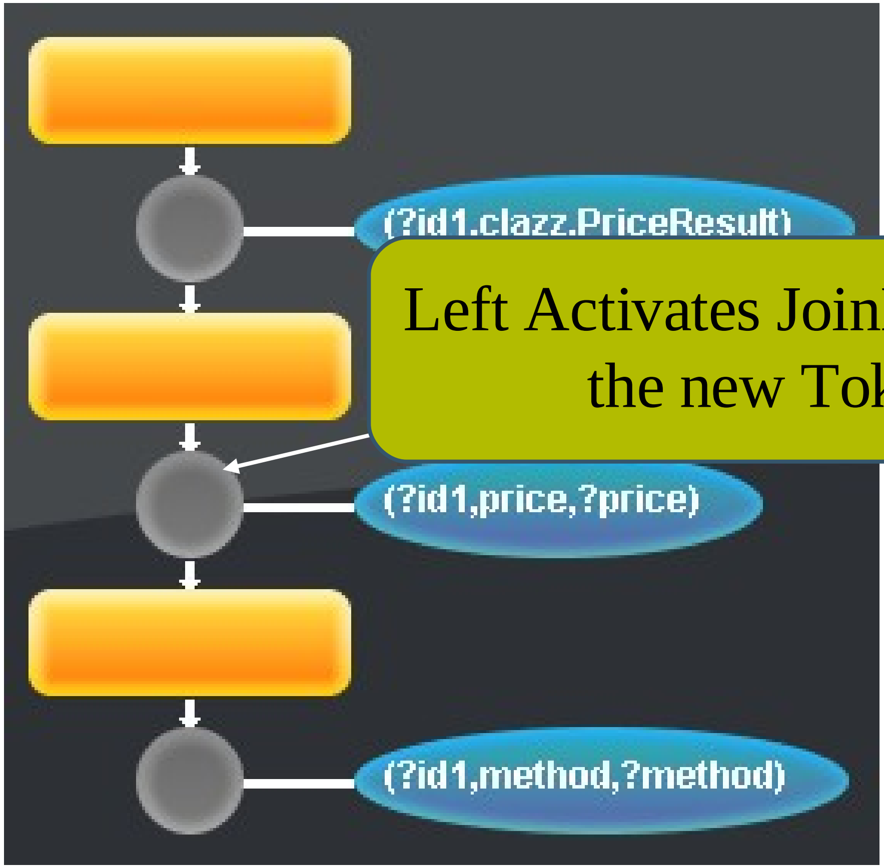


RETE Algorithm

Putting it all together

Assert: (1,clazz,PriceResult)

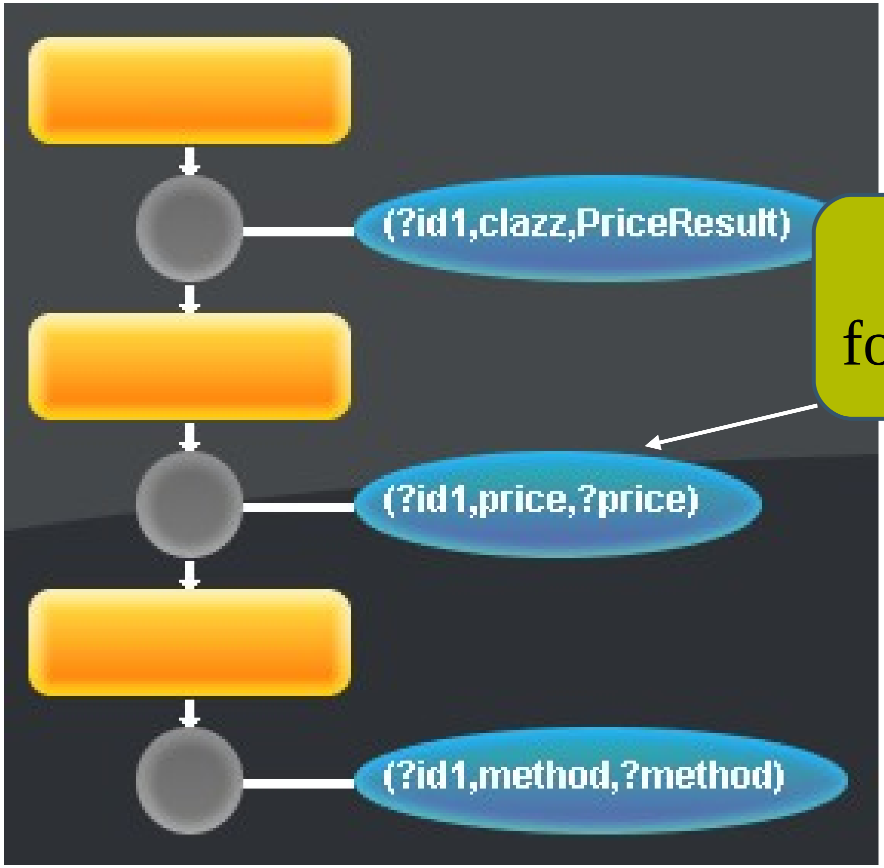


Left Activates JoinNode with the new Token

RETE Algorithm

Putting it all together

Assert: (1,clazz,PriceResult)



Queries AlphaMemory for WMEs and Tries to Match

Demo: Let’s see it in the Analysis Tool

RETE Algorithm

Main advantages over the naive algorithm

- State-saving reduces calculation time
  - Changes in WM: Are saved in Alpha and Beta Memories
  - No need to recalculate all the different possibilities

- Sharing of nodes
  - Alpha Memory
    - when two or more productions have similar conditions
  - Beta Memory
    - when the first few conditions of two or more productions are similar

RETE Algorithm

Why it is not widely used in E-Commerce?

- The traditional algorithm is not Thread-Safe
- Some of the available implementations are aware of the multithreaded challenges
  - They lock the entire engine, similar to what java.util.Hashtable does

RETE Rules Engine

Why it is not widely used in E-Commerce?

- Option #1: Create a RETE instance per Thread
  - When tried to load 20,000 products (close to 250k WMEs) the engine died.
  - Can not even dream creating an instance of the engine per Thread, just one does not work
- Option #2: One single instance, serial access to it
  - Doesn't take advantage of the multiprocessor/multi-core architectures
  - Does not scale to the throughput needs

Agenda

Pricing Service in Retail

Rules Engine (RETE)

Concurrency in the Rules Engine

Deadlock Prevention

Other Optimizations

Demo!

Thread Safety

- Managing Access to Shared Mutable State

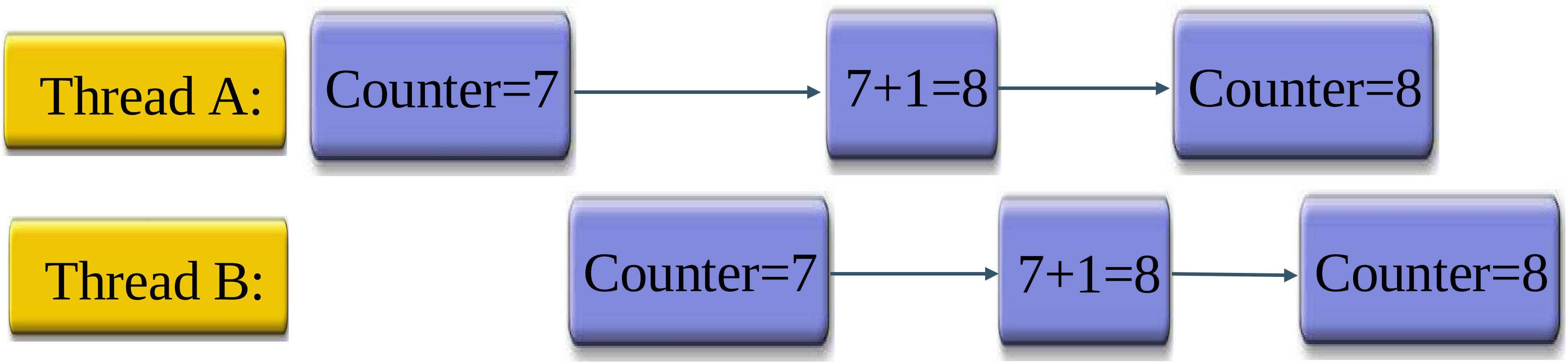
- Whenever more than one thread accesses a given state variable, and one of them might write to it, they all must coordinate their access using Synchronization
  - synchronized
  - volatile variables
  - explicit locks
  - atomic variables

Concurrency Challenges

Atomicity

```
// Susceptible to lost updates
private long counter=0;

public void execute() {
        counter++;
        System.out.println(counter);
}
```



Concurrency Challenges

Atomicity: the java.util.concurrent.atomic API

```
public class SafeCounter {

    private final AtomicLong counter = new
AtomicLong(0);
    public long getCounter() { return count.get(); }

    public void execute() {
        counter.incrementAndGet();
    }
}
```

Concurrency Challenges

Race Conditions: The need for Locks

```
public class NotSafeTransfer {

    private final AtomicLong checkingBalance =
                                 new AtomicLong(0);
    private final AtomicLong savingsBalance =
                                 new AtomicLong(0);

    public void transfer100() {
        checkingBalance.addAndGet(100);
        savingsBalance.addAndGet(-100);
    }

}
```

Concurrency Challenges

Intrinsic Locks: enforcing atomicity

```
public class SafeTransfer {

    private long checkingBalance = 0;
    private long savingsBalance = 0;

    public synchronized void transfer100() {
        checkingBalance+=100;
        savingsBalance-=100;
    }
}
```

Concurrency Challenges

- Modern Compiler and Processor:
  - Speculative Execution
  - Instruction Scheduling
  - Register Allocation
  - Common Sub-expression Elimination
  - Redundant Read Elimination
- Multiprocessor Systems
  - Each processor has its own cache

} Visibility

Understanding Visibility and the JMM

Without the proper synchronization

```
public class Unpredictable {
    private static boolean ready;
    private static int number;
    private static class CheckReady extends Thread {
        public void run() {
                while (!ready)
                        Thread.yield();
                System.out.println(number);
        }
    }
    public static void main(String[] arg) {
        new CheckReady().start();
        number = 42;
        ready = true;
    }
}
```

RETE Rules Engine

Principles to Implement a Concurrent Version

#1: Keep it simple, Keep it simple

Risks of Threads

Using Volatile

```
public class Predictable {

   private static volatile boolean ready;

   private static class CheckReady extends Thread {
      public void run() {
            while (!ready)
                  Thread.yield();
      }
   }
   public static void main(String[] arg) {
      new CheckReady().start();
      ready = true;
   }
}
```

RETE Rules Engine

Principles to Implement a Concurrent Version

#2: Don't reinvent the wheel:

- Create a RETE with the optimizations of one of the best algorithms available in the open source community (SOAR).

#3: Analyze alternatives to make it multithreaded:

- Reusing the RETE Dataflow Network across multiple Threads
- The Rules Developer should not worry about Session Ids

RETE Rules Engine

Principles to Implement a Concurrent Version

#4: **Use of Locks:**

- **Partitioning the way threads access our Alpha and Beta Memories**
- **With the right level of granularity**
- **Allowing multiple threads to operate in a thread-safe way**

RETE Rules Engine

Feasible Solution: Implement a Concurrent Version

Principles:

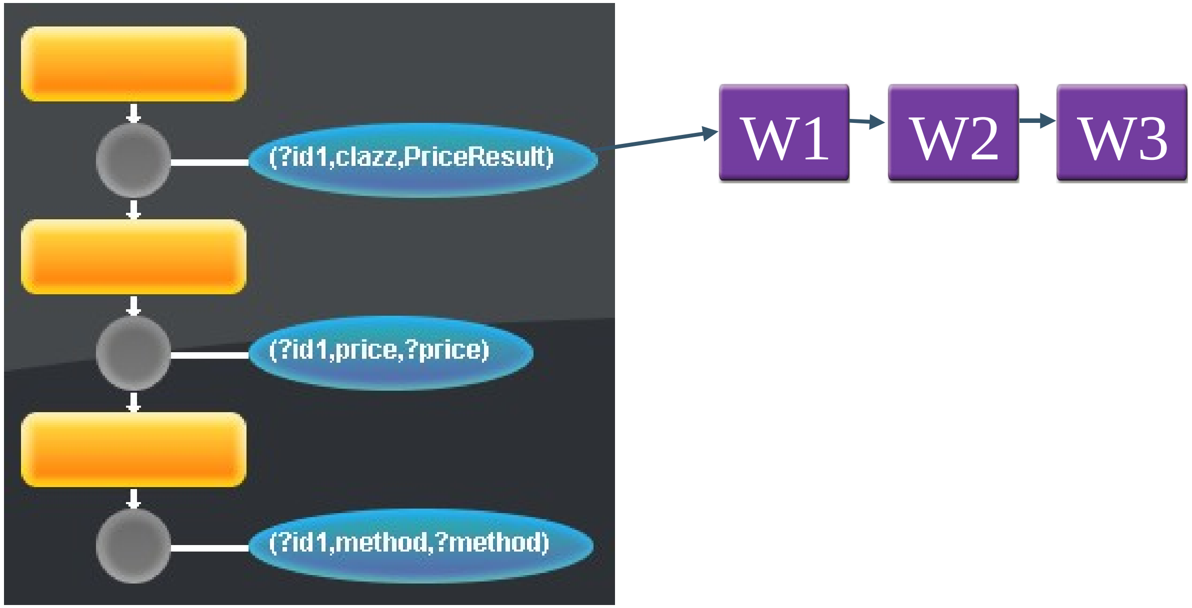
#5: **Follow a strict set of rules to obtain the Locks as a way to Preventing Deadlocks**

Zilonis RULES ENGINE

Multithreaded Rules Engine

Observation:

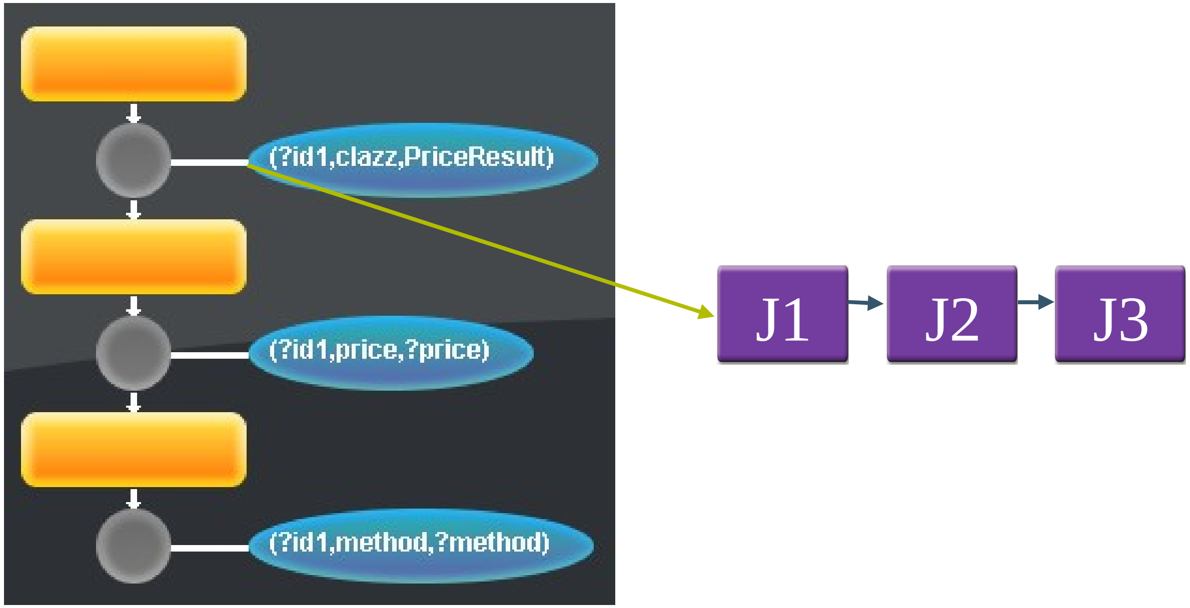
#1: Linked Lists are used to represent the set of WME in Alpha Nodes



Multithreaded Rules Engine

Observation:

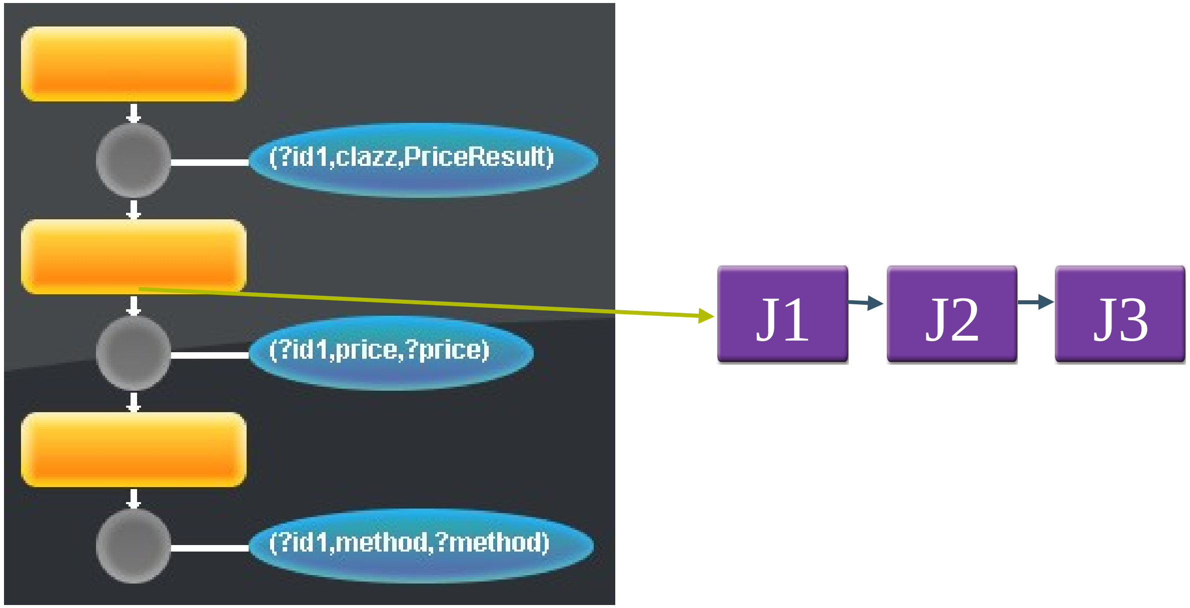
#2: Linked Lists are used to represent the set of Join Nodes in Alpha Nodes



Multithreaded Rules Engine

Observation:

#3: Linked List are used to represent the set of Join Nodes in Beta Memories

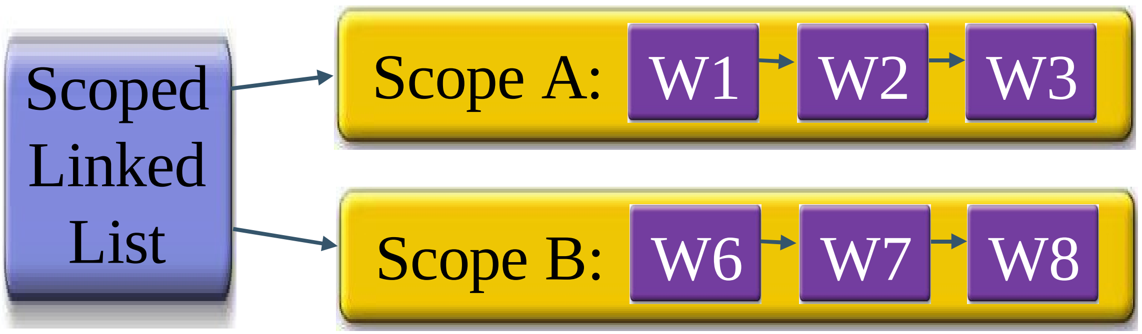


How the Concurrent Users would be using those Linked Lists?

- There is a part of them that is common, and does not change
  - That part can be safely shared
  - In out Pricing Engine example: 20,000 SKUs, and Pricing Rules
- Each User can have its own scope where only one user modifies the state at a time
  - Facts specific to that user
  - In our example: the information about the user, and the SKUs that wants to buy

Multithreaded Rules Engine

Building Block: The ScopedLinkedList

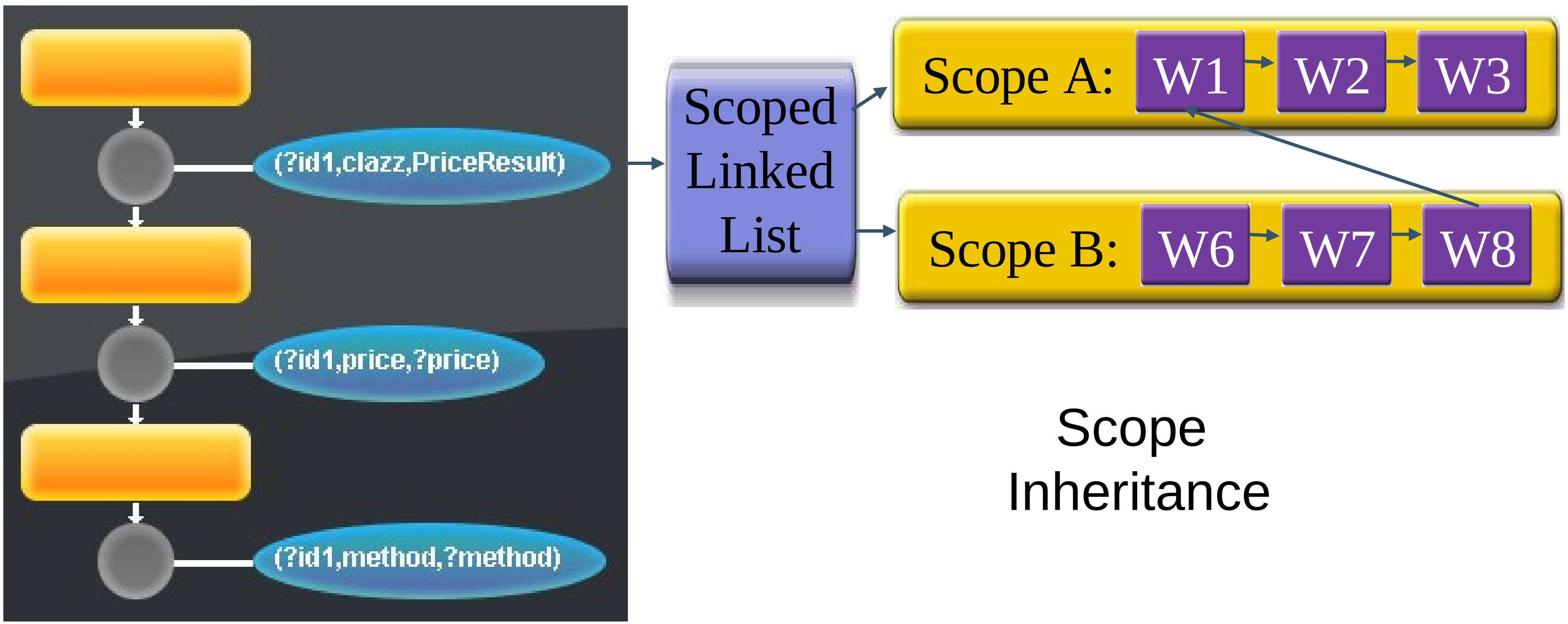


Lock on the Scope

A Thread can only hold the lock of a Scope at a time

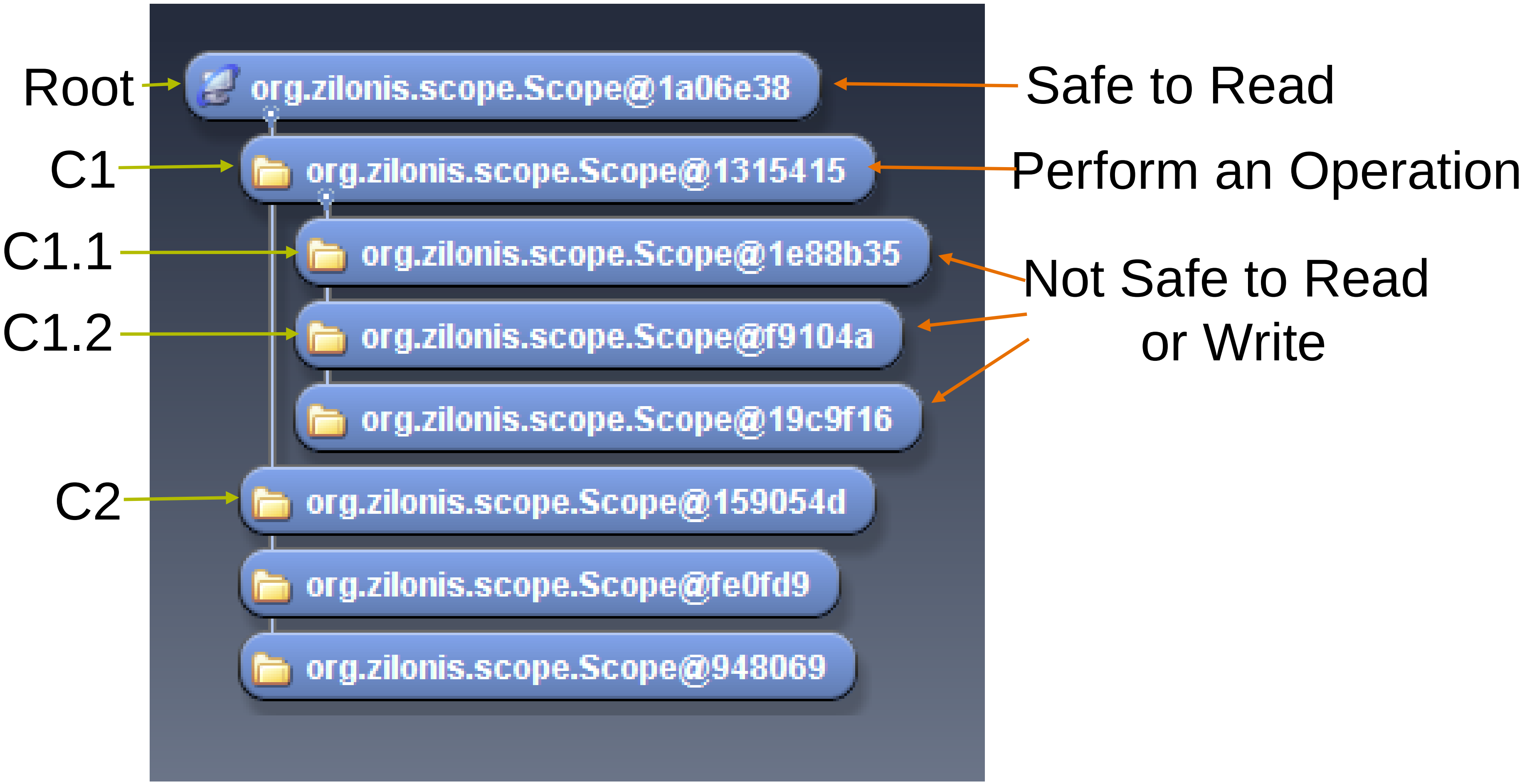
Multithreaded Rules Engine

Using the ScopedLinkedList



Scope Inheritance

Scopes and Concurrency



Scope class

```
public class Scope {
    private ReentrantReadWriteLock lock;
    private Scope parent;
    private LinkedList<Scope> children;

// The rest of the class implementation

}
```

Agenda

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Demo!

Deadlock

Necessary and Sufficient Conditions

- Mutual Exclusion Condition
- Hold and Wait Condition
- No-Preemptive Condition
- Circular Wait Condition

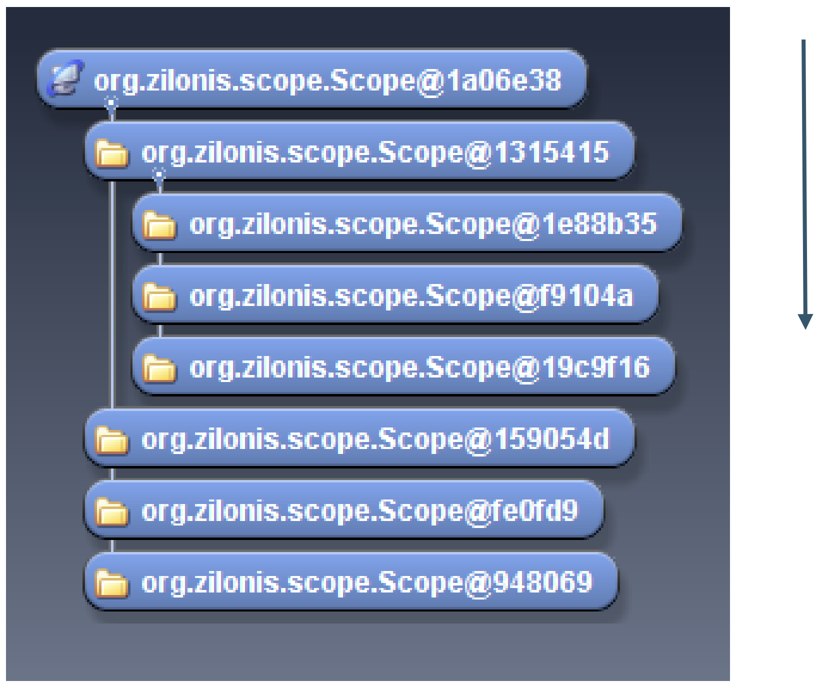
Deadlock Prevention

How can we safely Lock without the Deadlock fears

- Our Scopes are defined in a Tree structure (Graph without Cycles)
- Make sure we only get locks in one direction (Avoiding Circular Wait)

Deadlock Prevention

- Rule: To get the lock of a Scope, we need to get the Lock of the Parent Scope First



Zilonis RULES ENGINE

Scope class

```
public class Scope {
    . . .

    public void lock() {
        if (parent != null)
                parent.getReadLock();
        getWriteLock();
    }

    private void getWriteLock() {
        lock.writeLock().lock();
        for (Scope child : children)
                child.getWriteLock();
        }
}
```

Scope class

```
public class Scope {
    . . .

    private void getReadLock() {
        if (parent != null)
                parent.getReadLock();
        lock.readLock().lock();
}
```

ScopedLinkedList

```
public class ScopeLinkedList<Element> {
    private ConcurrentHashMap<Scope, SubList> map;

    public void add(Scope scope, Element element) {
        SubList subList = map.get(scope);
        if (subList == null) {
                sublist = new SubList(scope);
                map.put(scope, subList);
        }
        subList.add(element);
    }

    public Iterator<Element> iterator(Scope scope) {
        return new ScopedIterator(scope);
    }

}
```

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Other optimizations

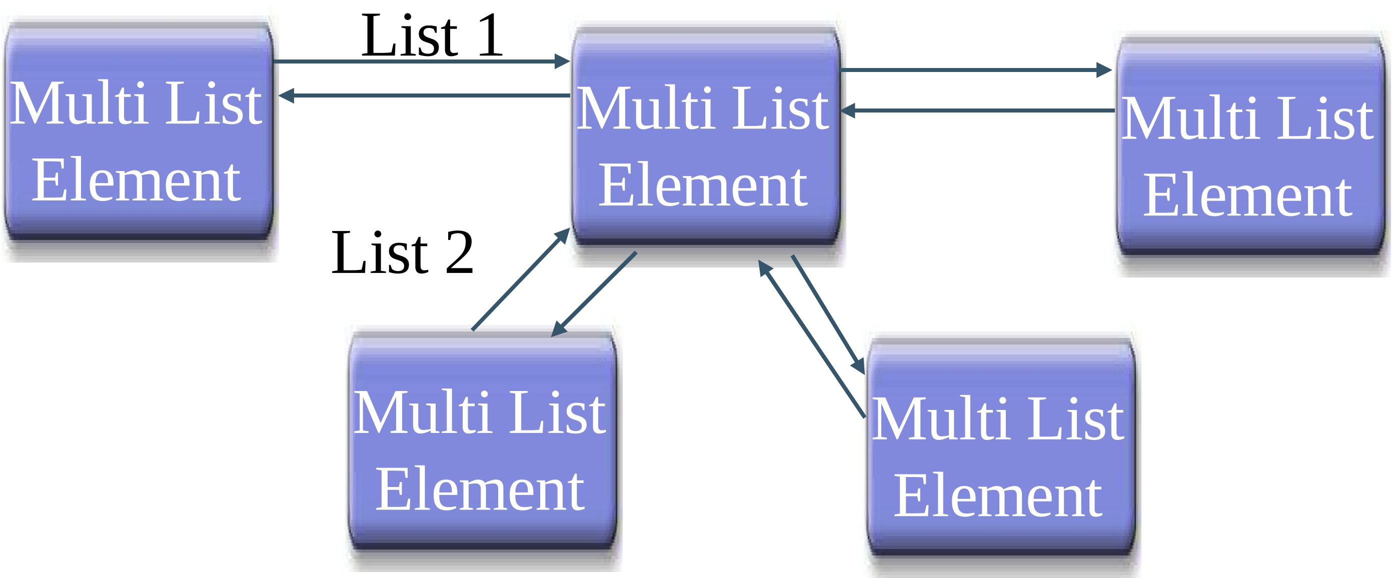
Demo!

Other Optimizations

- Implementation of the Entry in the linked list for fast removals
- Use of two global indexes:
  - Nodes in alpha memories
  - Nodes in beta memories

Implementation of Dobly Linked List

- The WME are in 2 lists
- The Tokens are in several lists also



MultiListElement

```
public class MultiListElement implements NextHolder,
                                  IMultiListElement {

    private IMultiListElement next[];

    private NextHolder prev[];

    . . .
    public void remove(int list) {
        // check for null references
        next[list].setPrev(prev[list]);
        prev[list].setNext(next[list]);
    }

}
```

WME and Token

```
public class Token extends MultiListElement {

    public Token(Token parent, WME wme) {
        super(NUMBER_OF_LISTS);
        . . .
    }
}
```

Searching for WMEs and Tokens

In Alpha and Beta Networks

```
public abstract class Index<Type extends IMultiListElement>
                                 implements NextHolder {

    private static final int LOG2_INDEX_SIZE = 13;
    private static final int INDEX_SIZE = (((int) 1) <<
                                 LOG2_INDEX_SIZE);
    private static final int INDEX_MASK = (INDEX_SIZE - 1);

    final IMultiListElement index[];

    . . .
}
```

One global index for all scopes

We need to lock here

Synchronization in the Index

In Alpha and Beta Networks

```
public abstract class Index<Type extends IMultiListElement>
                                  implements NextHolder {
   . . .
   private static final int SEGMENT_SIZE =
                     (((int) 1) << LOG2_SEGMENT_SIZE);
   private static final int SEGMENT_MASK =
                     (SEGMENT_SIZE - 1);

   final ReentrantLock segment[];
   final IMultiListElement index[];

   . . .
}
```

Follow the same pattern that **ConcurrentHashMap** uses

Some results

- Tested 20,000 Products, with a significant amount of pricing rules
- We achieved response times of 5 to 10 msec per request
- Up to 600 Req/Sec on just a Core 2 Duo Machine, with 1.5GB of RAM in the Heap of the VM

Roadmap

- Production Version 1.0
  - Full Multithreaded Support
  - CLIPS like language
  - Full JSR 094 Support
  - Embedded and WAR Deployable Service
  - Zilonis Analysis Tool
  - Good Documentation
- Next Version
  - Rules Management Tool with JSR 208: Java Business Integration (JBI) Support
  - Natural Language Generation (GATE, KPLM)
  - XML-Rules Language
  - Support for SBVR

For More Information

- http://www.zilonis.org
- http://weblogs.java.net/blog/elevy
- Production Matching for Large Learning Systems
  - Robert B. Doorenbos
- SOAR Project:
  - http://sitemaker.umich.edu/soar/home
- JSR 094: Java Rule Engine API
  - http://jcp.org/aboutJava/communityprocess/review/jsr094/

Let’s see a Complete Demo!

Q&A