Modernizing Drools: From Production Rules to Blended AI

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Red Hat

OPS5 Onwards (Slowly)

- Drools Improvements
  - Property Reactive
  - OO Path
  - Prolog(ish) Backward Chaining
  - Game Loops
- Slow Progress
- Foundations
- Canonical Model
- Pluggable Knowledge
  - Bayesian Belief
- Pluggable Beliefs Systems
  - Simple Truth Maintenance
  - Defeasible Reasoning
  - Bayesian Network
- Units
- Papers
  - Recommended Reading

OPS5 Onwards (Slowly)

OPS

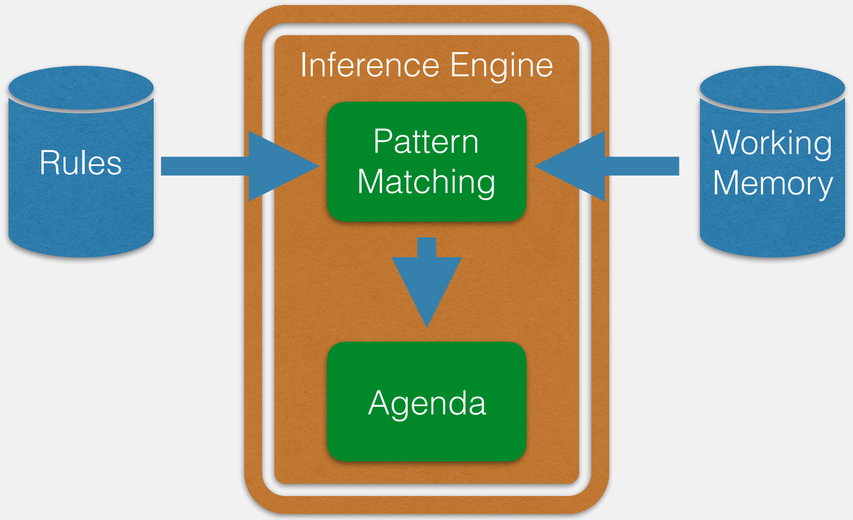
OPS

- Official Production System.
- pre OPS5 linear Search.
- Conflict Resolution
  McDermott, Charles L (Charles Lanny) Forgy. “Production System Conflict Resolution Strategies,” 1976, 23.

OPS5 1981

- Language
- Rete
- LEX/MEA

```
(p mb17
  (goal ^status active ^type on ^object <o>)
  (object ^name <o> ^at <p>)
  (monkey ^at <p> ^holds nil)
    -->
  (write (crlf) "climb onto" <o>)
  (modify 3 ^on <o>)
  (modify 1 ^status satisfied))
```



CLIPS

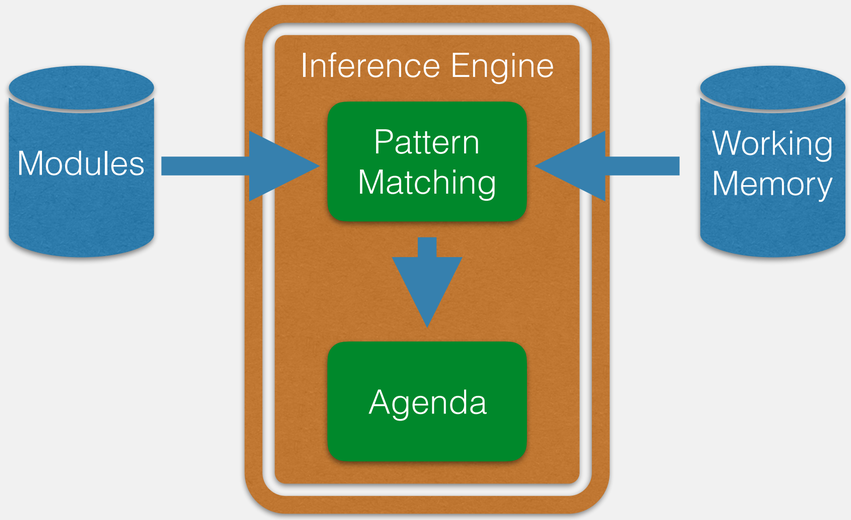
CLIPS

- Syntax based on ART (Haley Systems)
- Modules based on GoldWorks
- PIE Clips Modules

CLIPS 1993

- Lisp (ish)
- exists/forall
- Subnetworks
- Modules
- Simple TMS

```
(defrule climb-directly ""
  ?goal <- (goal-is-to (action on) (arguments ?obj))
  (thing (name ?obj) (location ?place) (on-top-of ?on))
  ?monkey <- (monkey (location ?place) (on-top-of ?on) (holding bla
  =>
  (printout t "Monkey climbs onto the " ?obj "." crlf)
  (modify ?monkey (on-top-of ?obj))
  (retract ?goal))
```



Jess

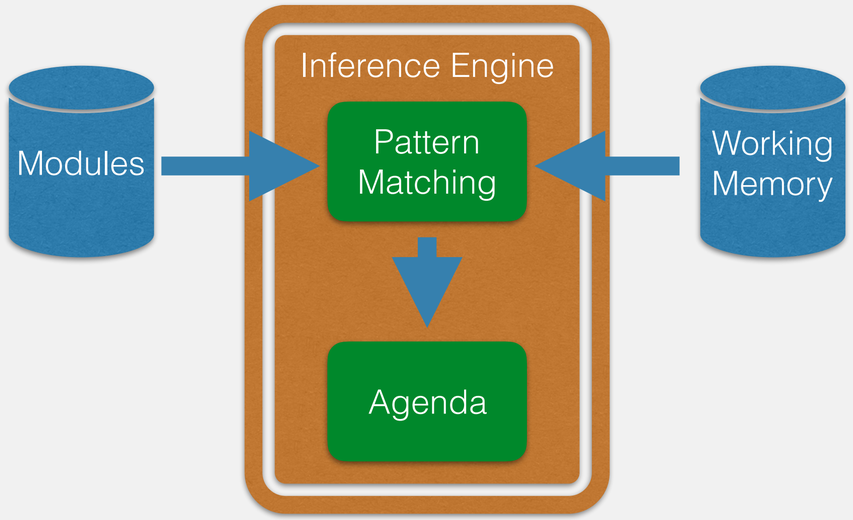
Jess

- Java implementation of Clips syntax

Jess7 2006

- Accumulate
- Slot Specific
- Backward Chaining (ish)

```
(deftemplate employee (slot salary) (slot name))
(defrule count-highly-paid-employees
  ?c <- (accumulate (bind ?count 0)                          ;; initializer
                    (bind ?count (+ ?count 1))               ;; action
                    ?count                                   ;; result
                    (employee (salary ?s&:(> ?s 100000))))   ;; CE
  =>
  (printout t ?c " employees make more than $100000/year." crlf))
```



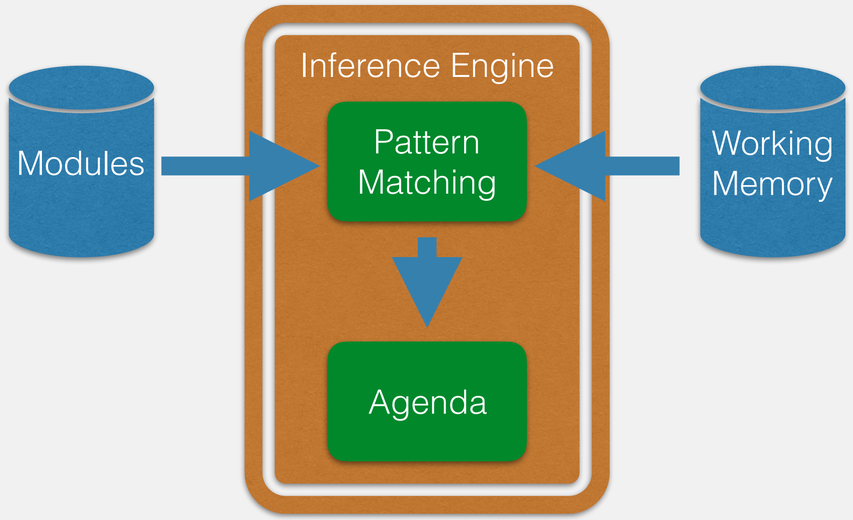
Drools

Drools

- Clips/Jess derivative with Java-like language

Drools 7.x

- Accumulate
- Temporal Operators
- Property Reactive
- Prolog(ish) Backward Chaining
- OOPath



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Slow Progress
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Drools Improvements

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Drools Improvements

Property Reactive

Property Reactive

“Advances in RETE Pattern Matching” (1986)

```
@PropertyReactive
public class Employee {
    int salary;
    int lengthOfService

    // getters and setters below
}
```

```
rule “Salary award for min 2 years service” when
    e : Employee( lengthOfService >= 2 )
then
    modify( e ) { setSalary( e.getSalary() * 1.05 ) };
end

rule “Salary award for min 8 years service” when
    e : Employee( lengthOfService >= 8 )
then
    modify( e ) { setSalary( e.getSalary() * 1.02 ) };
end
```

Property Reactive

```
rule “Salary award for min 2 years service” when
    e : Employee( lengthOfService > 2 )
then
    modify( e ) { setSalary( e.getSalary() * 1.05 ) };
end

rule “Salary award for min 8 years service” when
    e : Employee( lengthOfService > 8 )
then
    modify( e ) { setSalary( e.getSalary() * 1.02 ) };
end
```

```
rule “Salary award for min 2 years service” when
    e : Employee( lengthOfService >= 2 )
          @Watch( !salary )
then
    modify( e ) { setSalary( e.getSalary() * 1.05 ) };
end

rule “Salary award for min 8 years service” when
    e : Employee( lengthOfService >= 8 )
          @Watch( !salary )
then
    modify( e ) { setSalary( e.getSalary() * 1.02 ) };
end

rule “Record Salary Changes” when
    e : Employee( ) @Watch( salary )
then
    insert( new SalaryChange( e, e.getSalary() );
end
```

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Drools Improvements

OOPath

OOPath

```
rule R1 when
    $student : Student ()
    $plan : Plan ( owner == $student.name )
    $exam : Exam( plan == $plan.code, course == ”Big Data” )
    $grade : Grade( exam == $exam.code )
then
    // RHS
end

rule R3 when
    Student( $grade: /plan/exams{course == ”Big Data”}/grades )
then
    /* RHS */
end
```

	Batch (ms)	Incremental (ms)	Total (ms)
Relational	5596	1844	7440
From	2698	2912	5610
OOpath	3373	1368	4741

Table 3. Benchmark results with 400,000 items (ms.)

OOPath

Access by index

```
Student( $grade : /plan/exams[0]{ course == ”Big Data”}/grades )
```

Inline cast for type safety

```
Student( $grade : /plan/exams{ #PracticalExam, lab == ”hazard safe”,
                               course == ”Material Explosions”}/grades )
```

Indexed back reference

```
A( $var: /b/c/d{ f1 == ../../f2}/e ) // the ../../ back references to the ‘b’ field access
```

Variable back reference

```
A( $var: /$b : b/c/d{ f1 == $b.f2}/e ) // the $b is inline bound for later use
```

Back tracking

```
A( $var: /$b : b/c/d{ f1 == $b.f2}/$b/f2 ) // $var is bound to results of the f2 access
```

Out of Pattern use

```
$student : Student()
  $grade : /$student/plan/exams{course == ”Big Data”}/grades;
```

OPS5 Onwards (Slowly)

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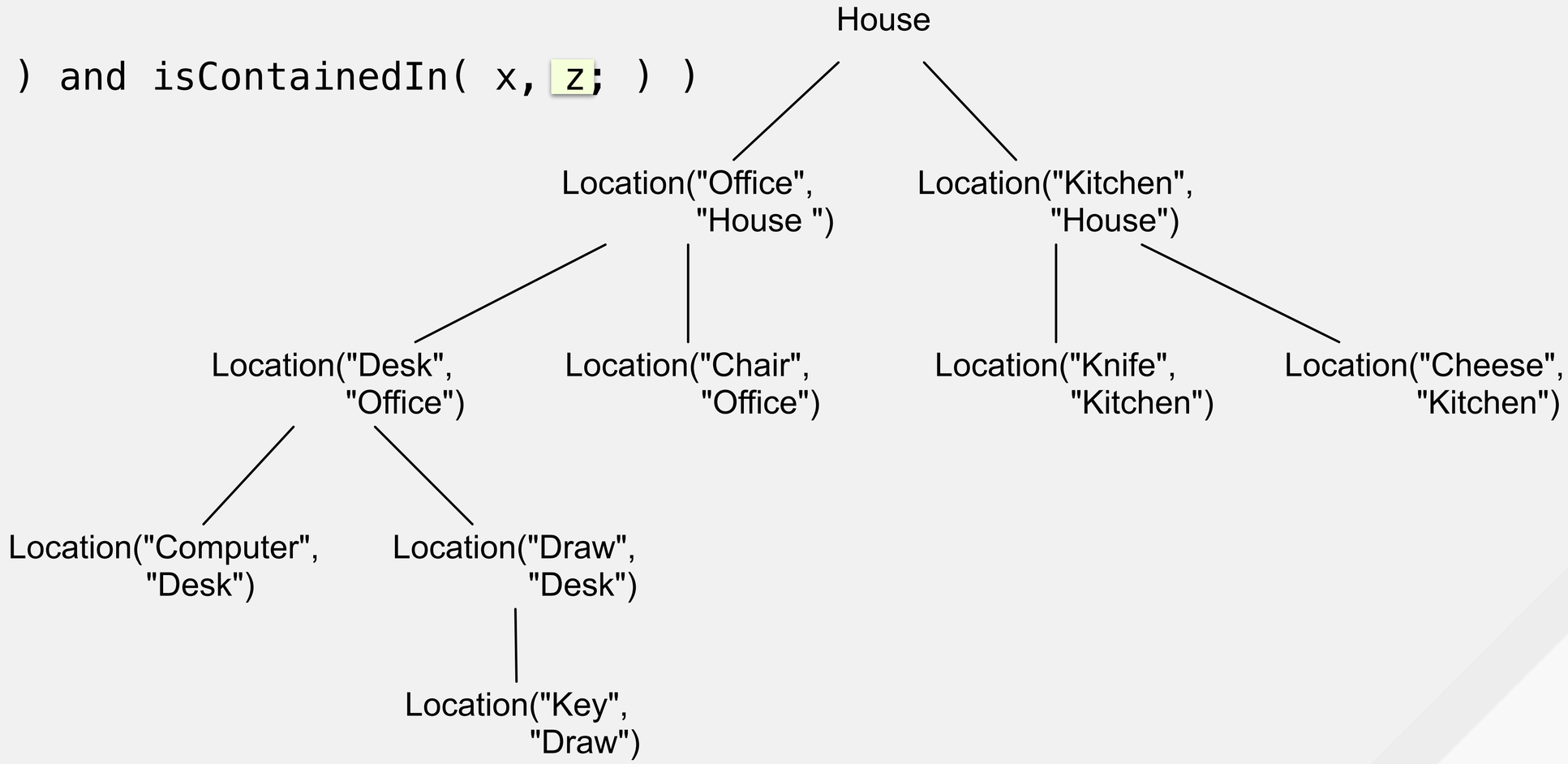
Drools Improvements

Prolog(ish) Backward Chaining

Prolog(ish) Backward Chaining

```
query isContainedIn( String x, String y )
  Location( x, y; )
  or
  ( Location( z, y; ) and isContainedIn( x, z; ) )
end
```

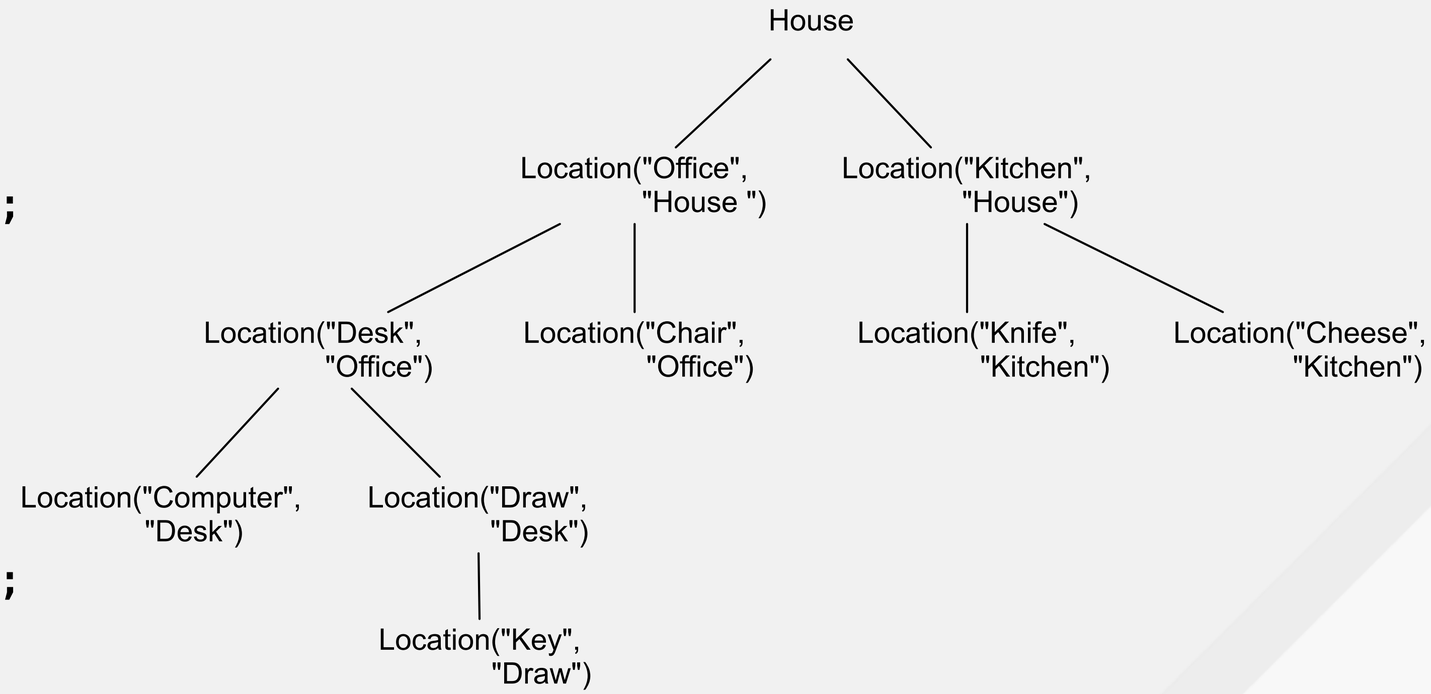


Prolog(ish) Backward Chaining

```
query isContainedIn( String x, String y )
  Location( x, y; )
  or
  ( Location( z, y; ) and isContainedIn( x, z; ) )
end
```

```
rule “Find Key Rule” when
    Goal( name ==  “Find Key” )
    isContainedIn(“Find”, “House”; )
then
    System.out.println( “Key in the House" );
end
```

```
rule “Find Key Rule” when
    Goal( name ==  “Find Key” )
    ?isContainedIn(“Find”, “House”; )
then
    System.out.println( “Key in the House" );
end
```



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Drools Improvements

Game Loops

Games Loops

```
rule GameLoop when
    r : Run()
then
    setFocus( "Draw" );
    setFocus( "Bullet" );
    setFocus( "Move" );
    setFocus( "Keys" );
end

rule Draw when
    r : Run()
then
    modify( r ) {} // force loop
    fpsTimer.incFrame();
end
```

```
rule Collision agenda-group "Bullet" when
    b : Bullet( ) @watch( y )
    i : Invader( x < b.x, x + width > b.x, y > b.y)
    Run()
then
    modify( i ) { alive = false }
end
```

Games Loops (TODO)

- Existence-Drive and Data-Drive
  - “Design of a Rule-Oriented System for Implementing Expertise,” ROSIE (1979)
- Incremental and NonIncremental

```
rule GameLoop when
    r : Run()
then
    setFocus( "Draw" );
    setFocus( "Bullet" );
    setFocus( "Move" );
    setFocus( "Keys" );
end

rule Draw when
    r : Run()
then
    modify( r ) {} // force loop
    fpsTimer.incFrame();
end
```

```
rule Collision existanceDriven nonIncremental
               agenda-group "Bullet" when
    b : Bullet( ) @watch( y )
    i : Invader( x < b.x, x + width > b.x, y > b.y)
then
    modify( i ) { alive = false }
end
```

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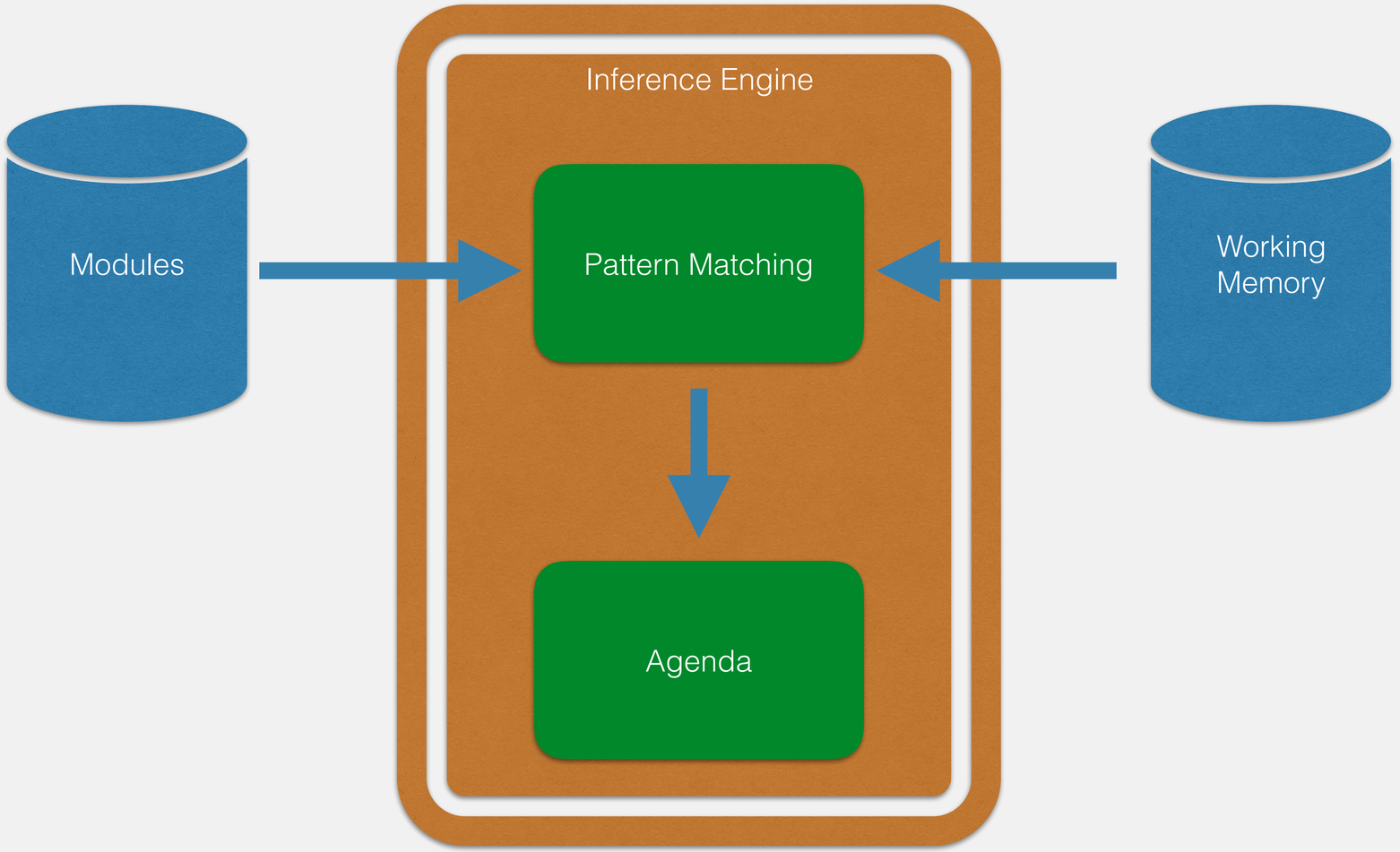
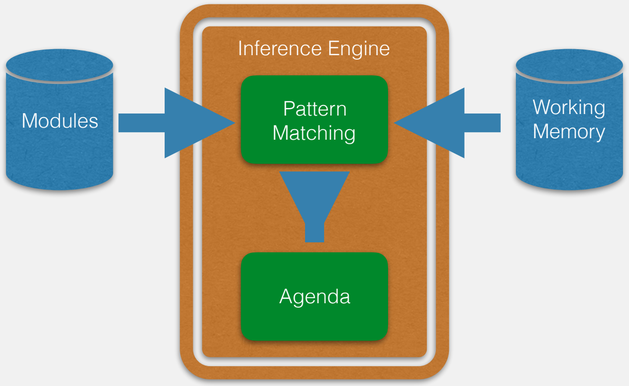
Slow Progress

Is Still Progress

Still Here


Inference Engine
Modules
Pattern Matching
Working Memory
Agenda

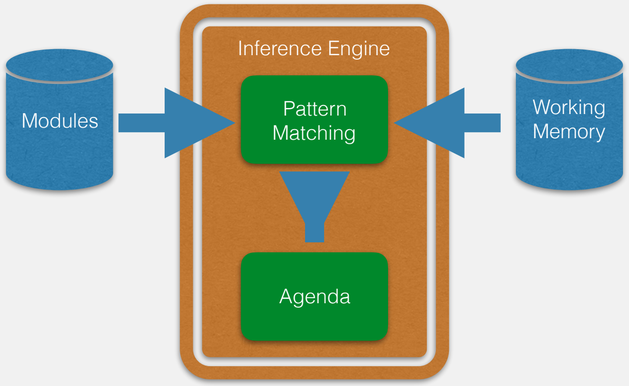
Still Here



“Today, I want to make clear that the future prospects for production rule technology are diminishing.….
production rule technology is inadequate ”
(Paul Haley 2013)

http://haleyai.com/wordpress/2013/06/22/confessions-of-a-production-rule-vendor-part-1/

Still Here



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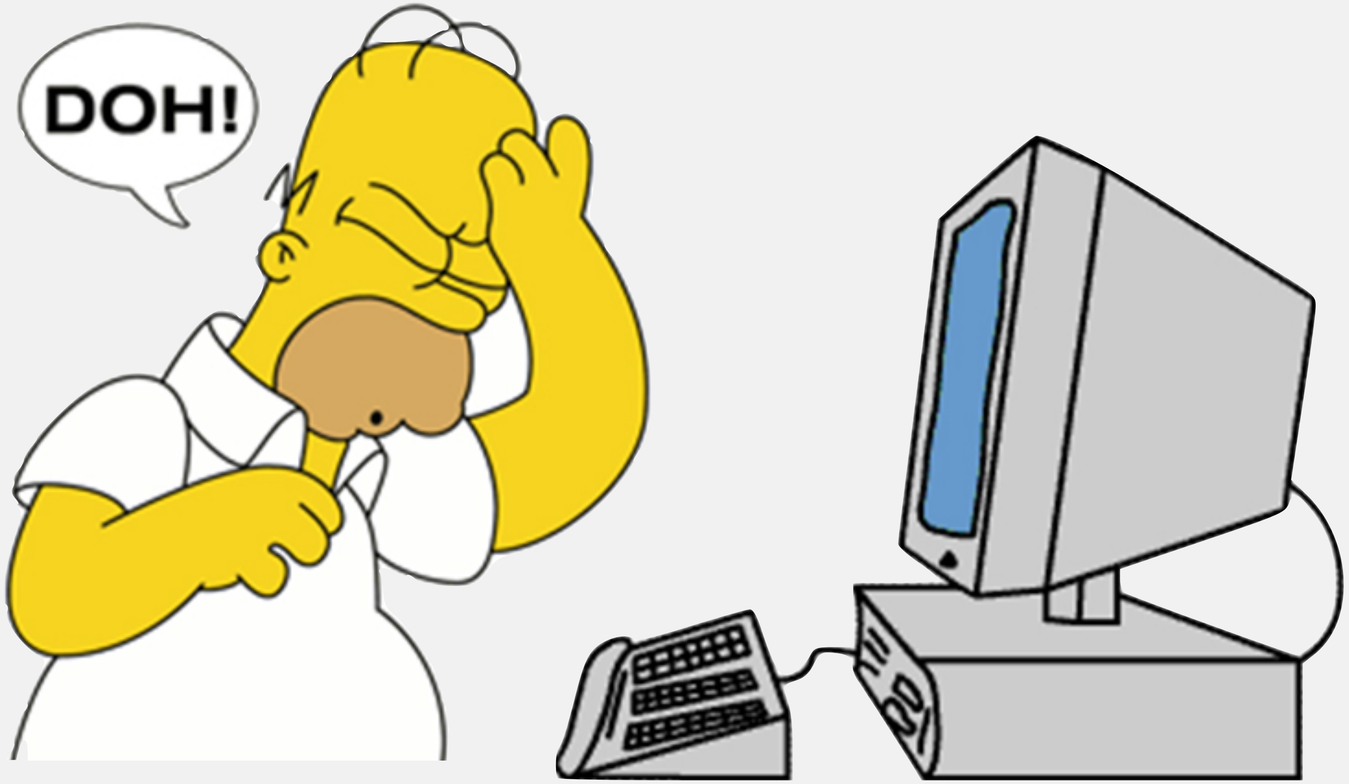


http://haleyai.com/wordpress/2013/06/22/confessions-of-a-production-rule-vendor-part-1/

Offshoots

Active DataBases

- Validation enforcement, triggers.
- Simpler semantics, no forward chaining.
- Without 2 phase. Does not allow mutation of selected tables.
- Scoped deterministic execution within the transaction

Decisioning

- DMN

CEP

- Power of production system LHS, with additional temporal reasoning
- No inference, rules are isolated

Reactive Programming with Pattern Matching

- Light Weight, simple facet of a production system
- No Reactive Joins, but can do passive joins
- Built into native language

Reactive Programming / Pattern Matching

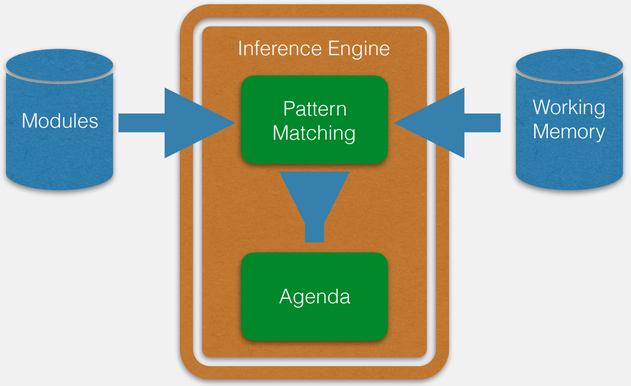
```
public static class Customer {
        int String name;
        int discount = 0;
    }
    public static class GoldCustomer extends Customer { }
    public static class SilverCustomer extends Customer { }
    public static class BronzeCustomer extends Customer { }

    public static void main( String[] args ) {
        observable.subscribe( customer -> {
            switch (customer) {
                case GoldCustomer g:   {
                    CriteriaQuery<Double> cr = cb.createQuery(Double.class);
                    Root<ShoppingCart> root = cr.from(ShoppingCart.class);
                    cr.select(cb.sum(root.get("items.value"))).where("customer = " + g.name);
                    Query<Double> query = session.createQuery(cr);
                    double total = query.getResultList().get(0);
                    g.discount = total > 100 ? 20 : 15;
                    break;
                }
                case SilverCustomer s: s.discount = 10; ..... break;
                case BronzeCustomer b: b.discount = 5; ..... break;
                default:               customer.discount = 0;
            }
        } );
    }
```

Blended Languages - LinQ / Reactive LinQ

```
var result=
    (
        from data in myData
        join inData in incomingData
            on data.ID equals inData.ID
        select new
        {
            data.ID,
            inData.LOCATION,
            data.COUNT
        }
    ).ToList();
```

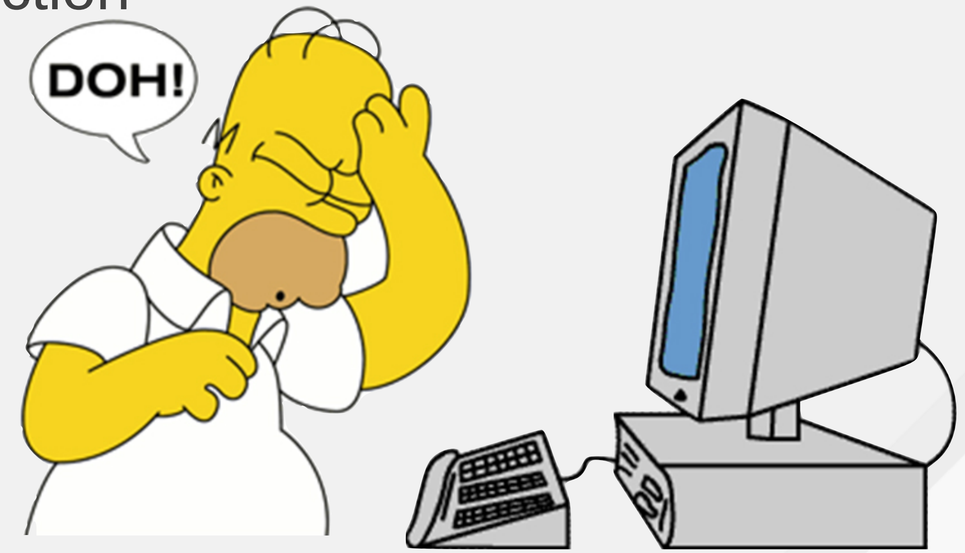
Still Here



“It’s time to trade rule technology dating back to the 80’s for state of the art AI…

Artificial intelligence (AI) and natural language processing (NLP) have improved dramatically.

Logical reasoning technology has advanced while production rule technology remains stagnant” (Paul Haley 2018)



- http://haleyai.com/wordpress/2018/04/02/confessions-of-a-production-rule-vendor-part-2/

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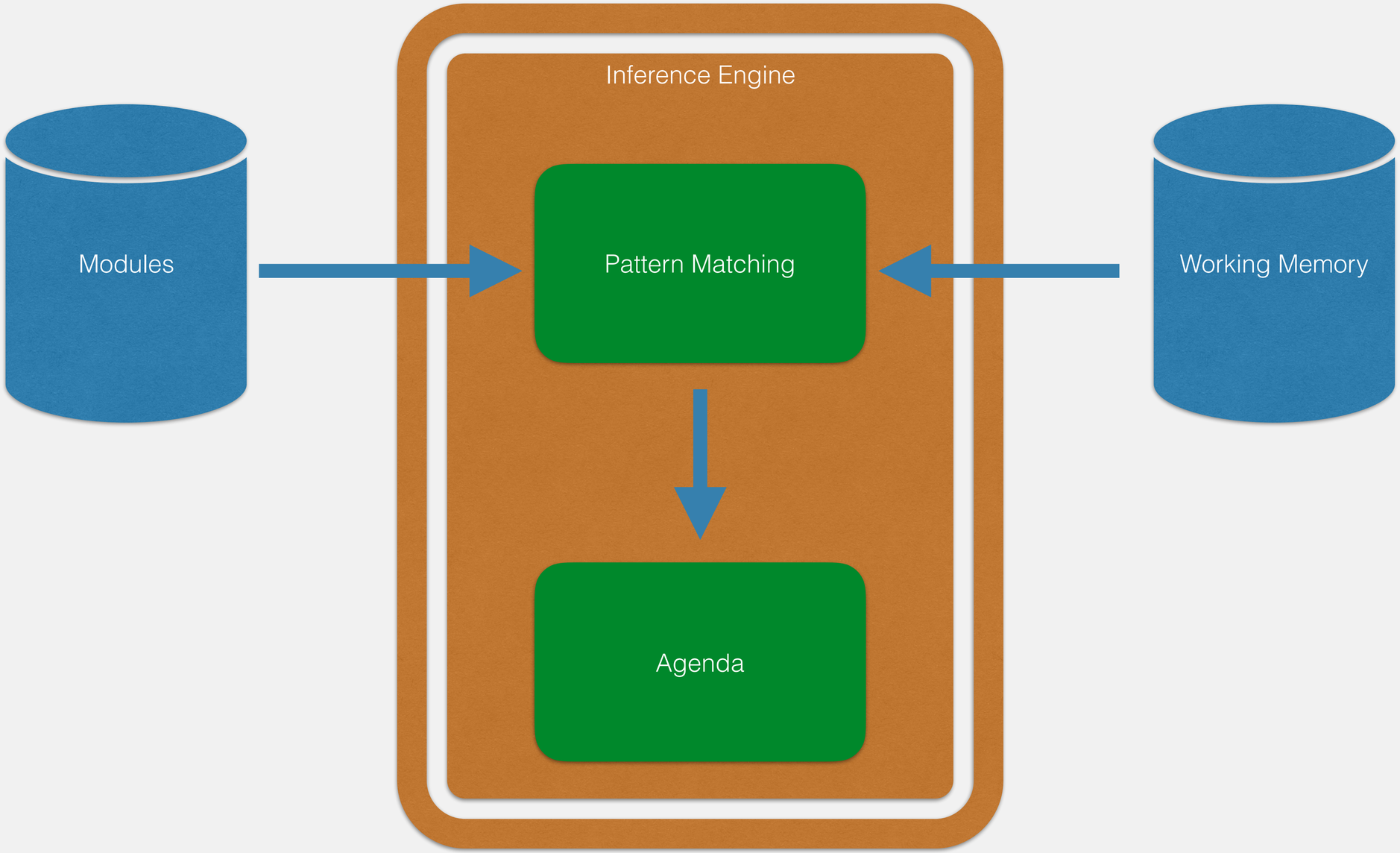
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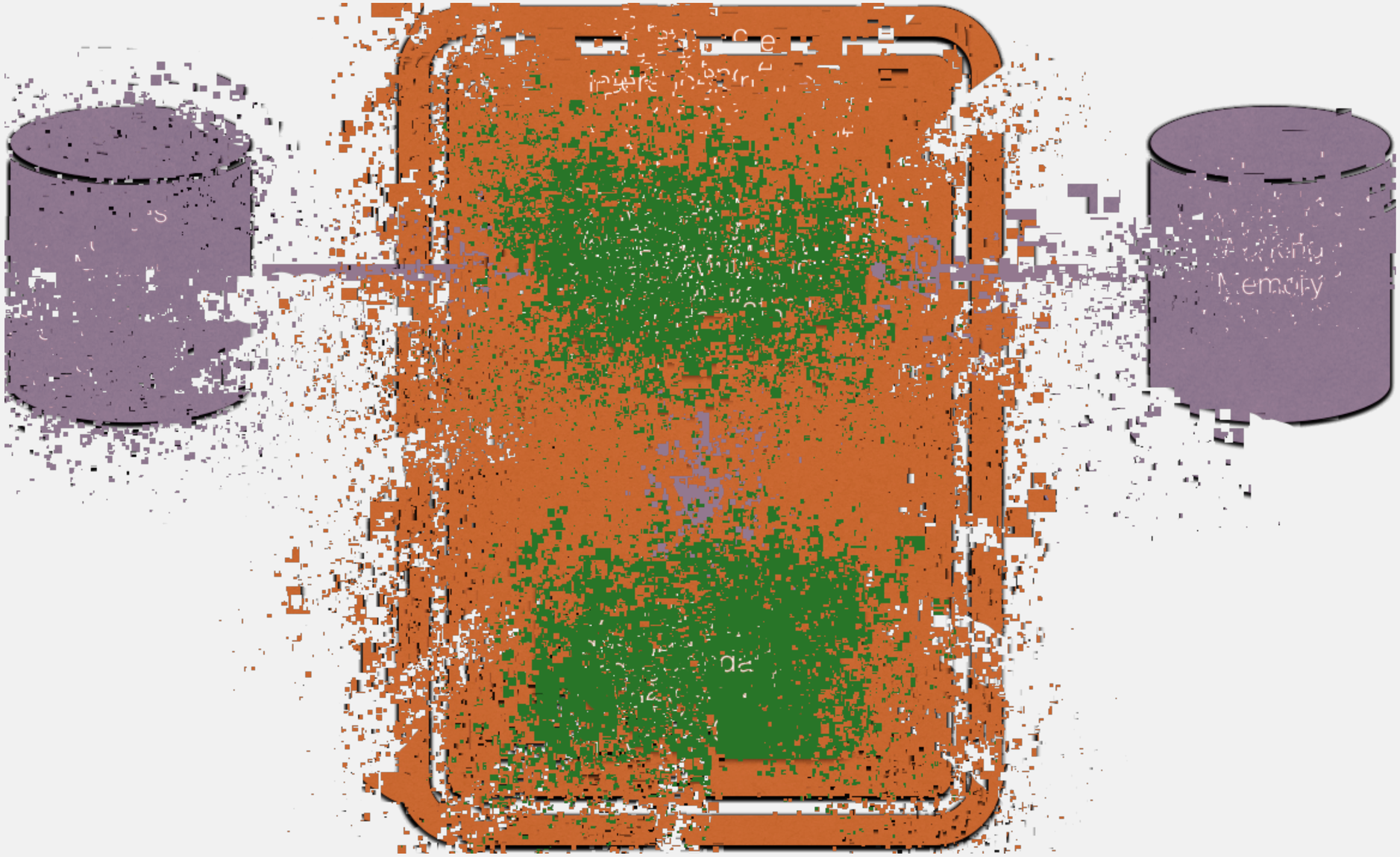

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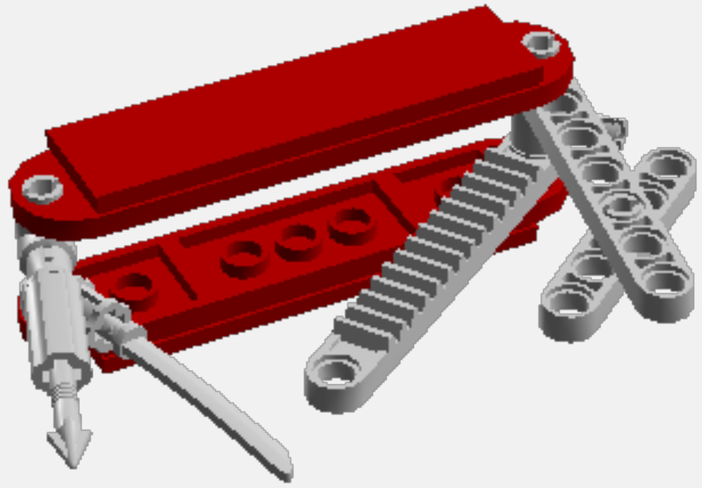
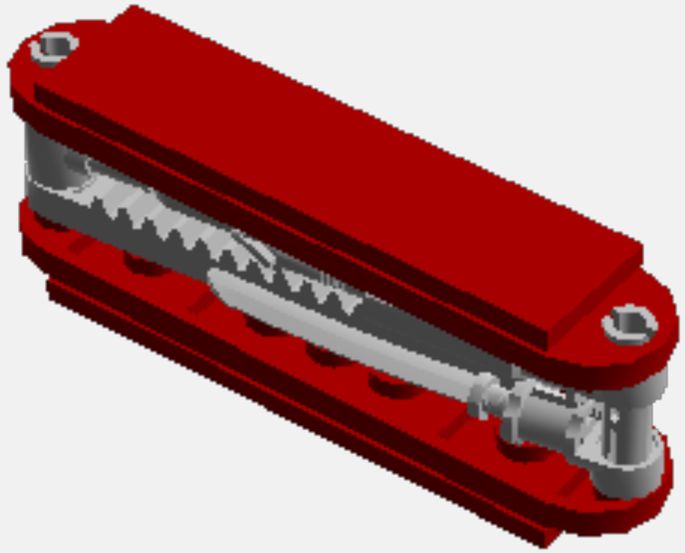
Foundations

Swiss Army Knife

The Building Blocks of a Swiss Army Knife





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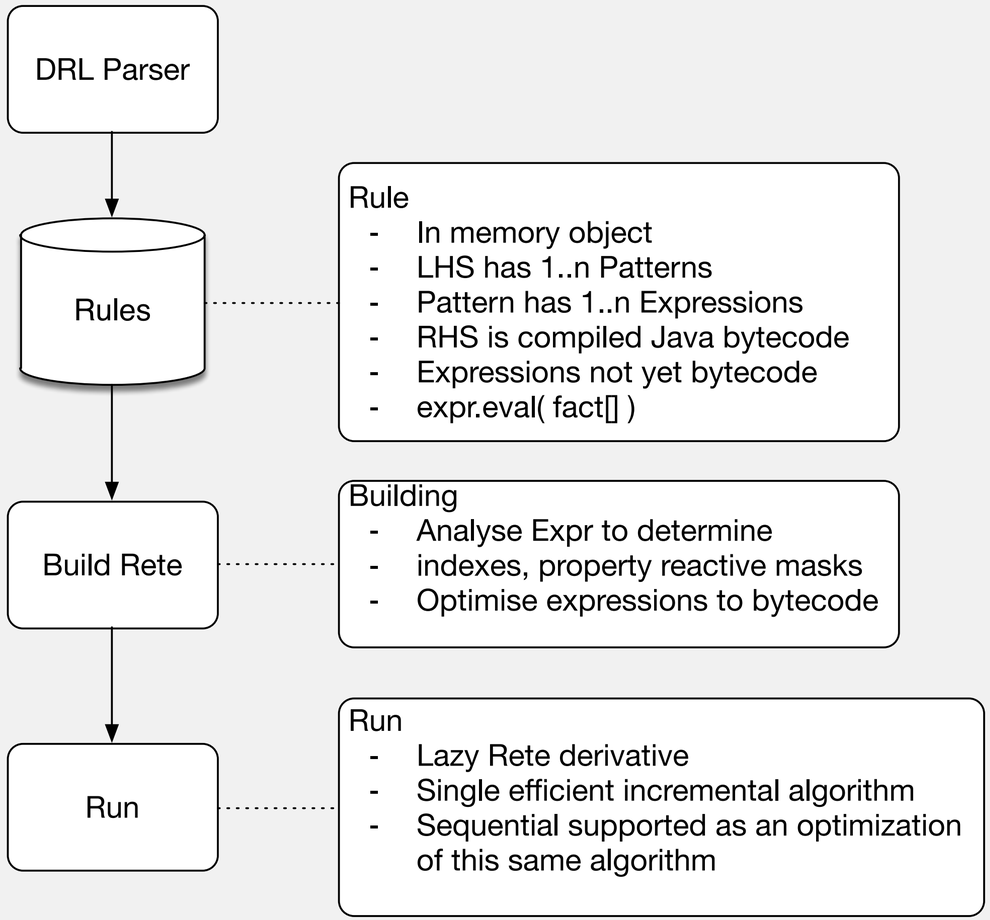
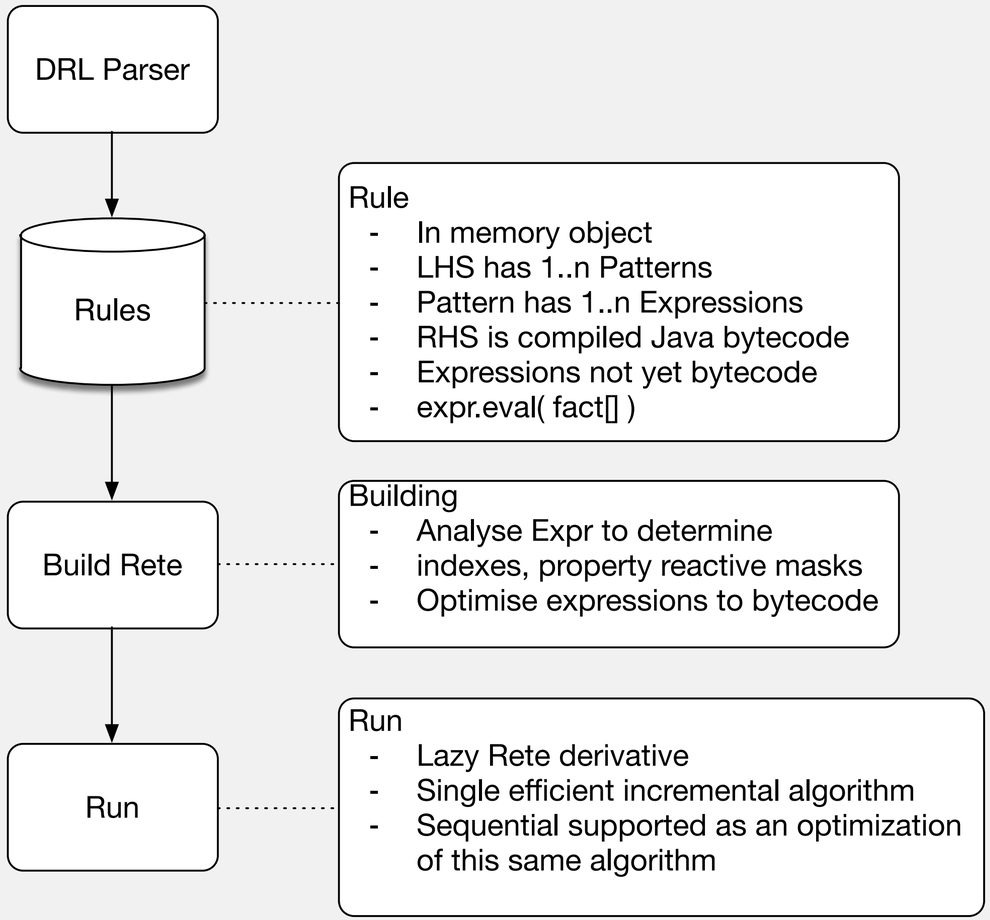
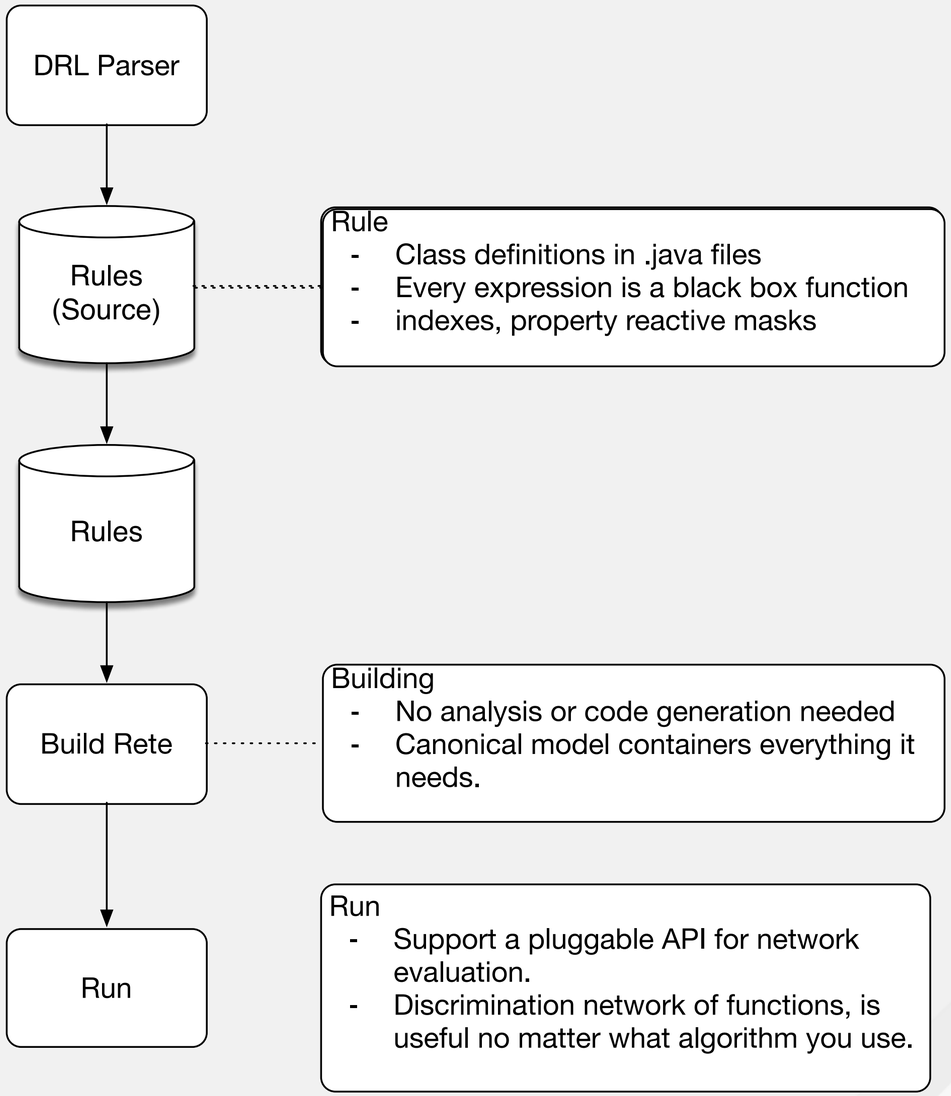
Canonical Model

Canonical Production Rules



Canonical Production Rules





Canonical Production Rules

```
Rule rule = rule(“beta")
    .build(expr("exprA", markV, p -> p.getName().equals(“Mark"))
        .indexedBy(String.class, ConstraintType.EQUAL, 1, Person::getName, “Mark")
        .reactOn("name"), // also react on age, see RuleDescr.lookAheadFieldsOfIdentifier
     bind(markAge).as(markV, Person::getAge).reactOn(“age”),
         expr("exprB", olderV, p -> !p.getName().equals(“Mark"))
         .indexedBy(String.class, ConstraintType.NOT_EQUAL, 1, Person::getName, “Mark")
         .reactOn(“name"),
     expr("exprC", olderV, markAge, (p1, age) -> p1.getAge() > age)
         .indexedBy(int.class, ConstraintType.GREATER_THAN, 0, Person::getAge, int.class::cast)
         .reactOn("age"),
     on(olderV, markV).execute((drools, p1, p2) -> drools.insert(p1.getName() +
                                                  “ is older than " + p2.getName())));
```

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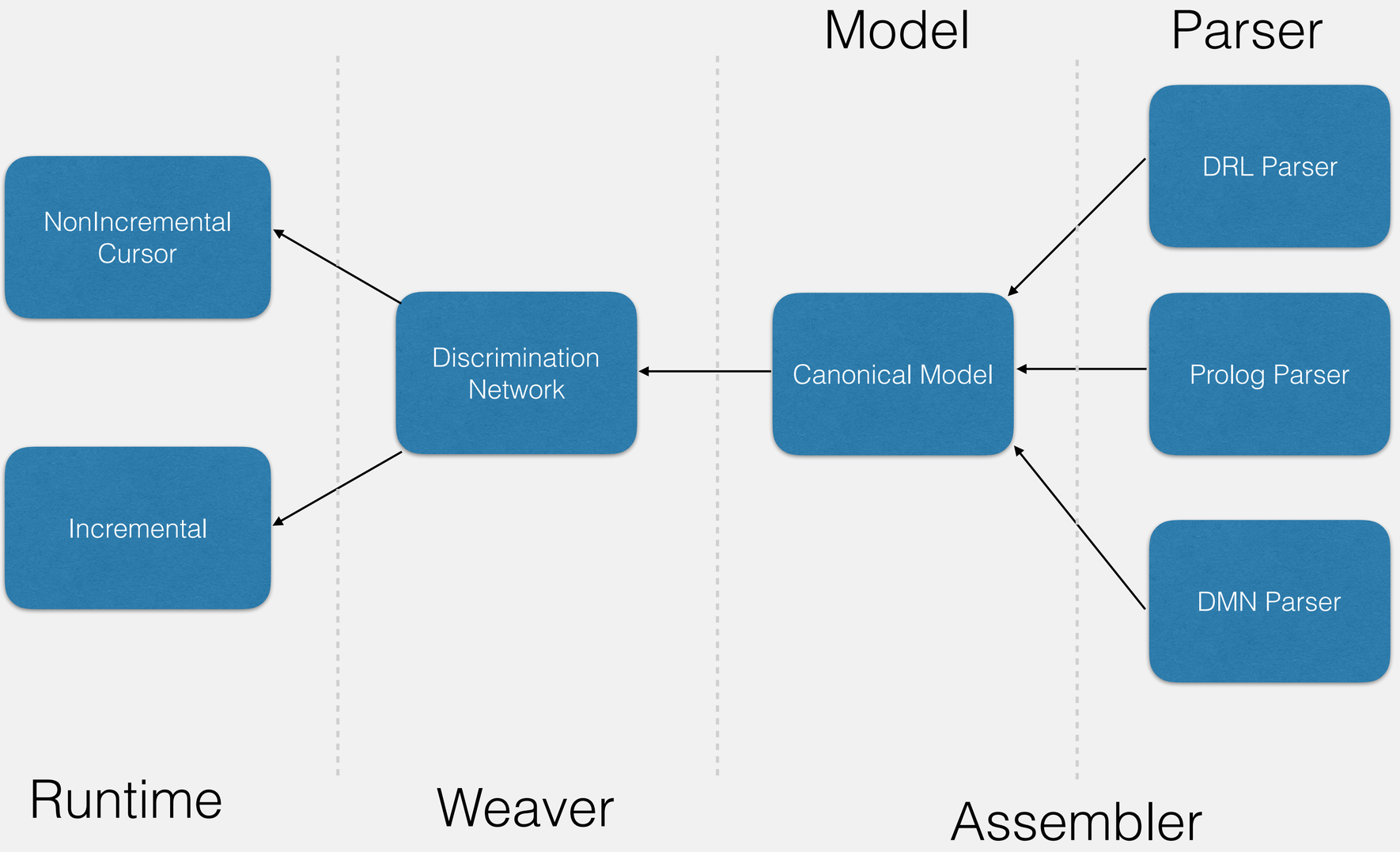
Pluggable Knowledge

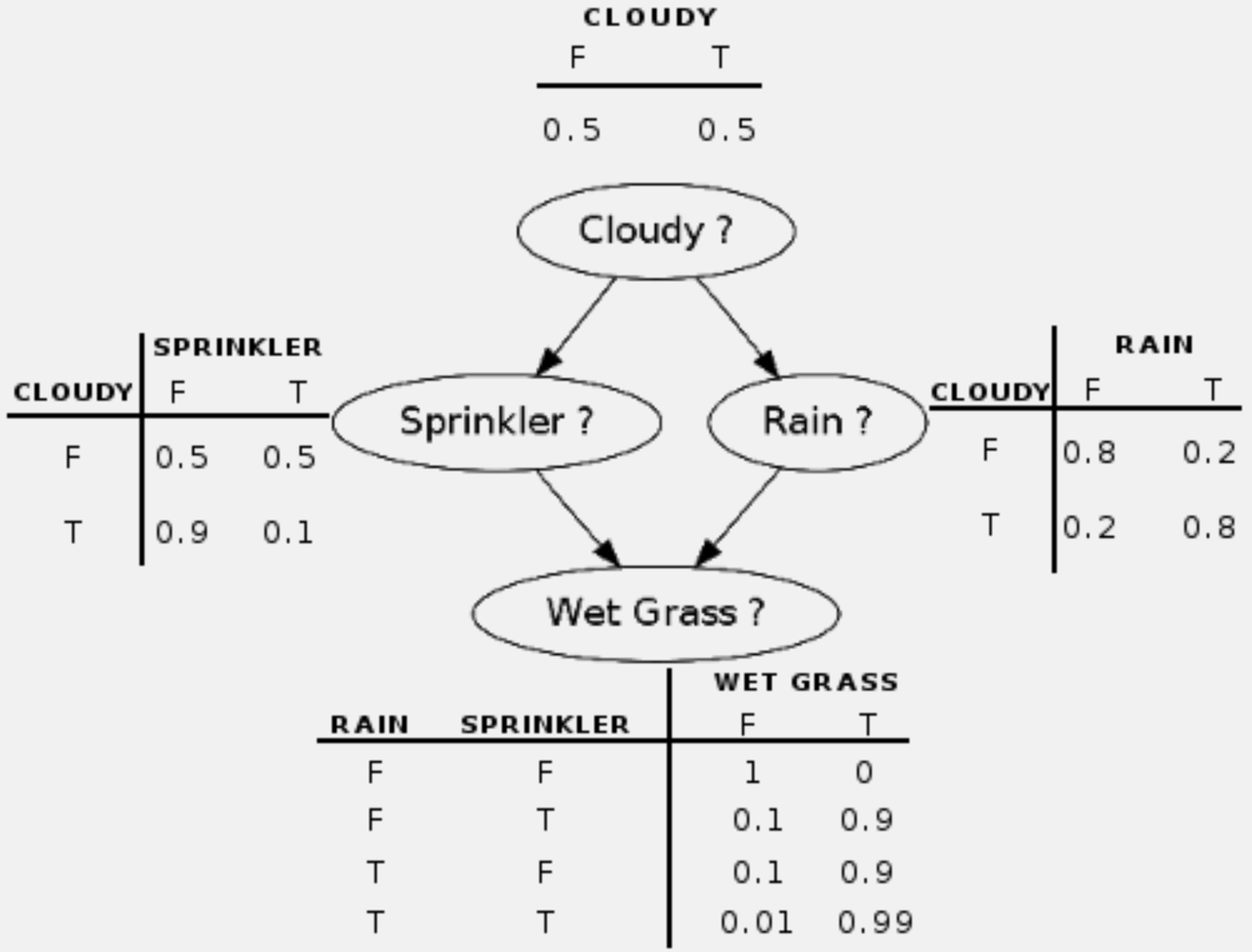
Bayesian Belief

Pluggable Knowledge



Pluggable Knowledge - Bayesian Networks

- Bayesian Networks



CLOUDY	F	T
	0.5	0.5

CLOUDY	SPRINKLER: F	SPRINKLER: T
F	0.5	0.5
T	0.9	0.1

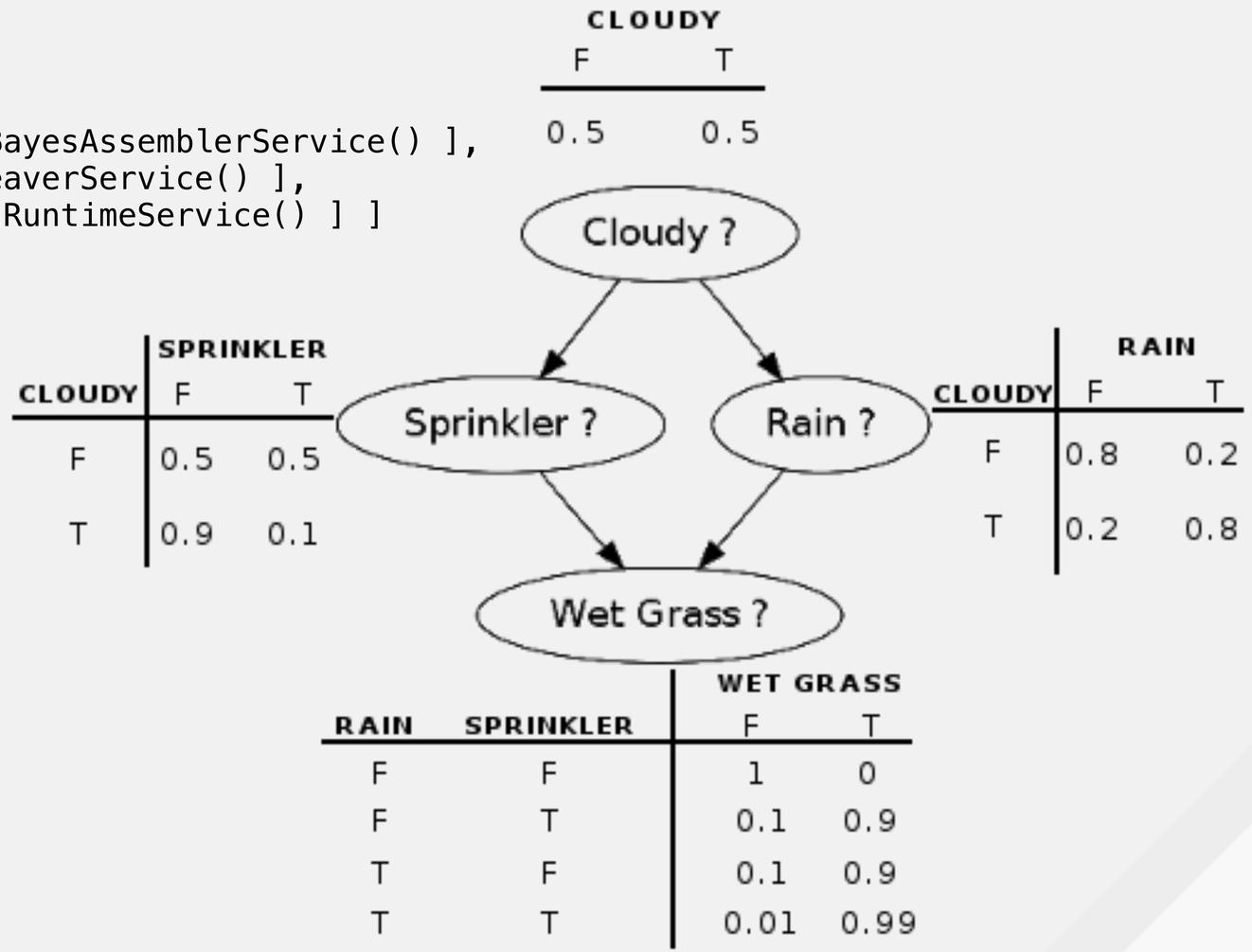
CLOUDY	RAIN: F	RAIN: T
F	0.8	0.2
T	0.2	0.8

RAIN	SPRINKLER	WET GRASS: F	WET GRASS: T
F	F	1	0
F	T	0.1	0.9
T	F	0.1	0.9
T	T	0.01	0.99

Pluggable Knowledge - Bayesian Networks

- Bayesian Networks
- XMLBIF

```
[ 'assemblers' : [ new org.drools.beliefs.bayes.assembler.BayesAssemblerService() ],
  'weavers' : [ new org.drools.beliefs.bayes.weaver.BayesWeaverService() ],
  'runtimes' : [ new org.drools.beliefs.bayes.runtime.BayesRuntimeService() ] ]
```



CLOUDY	F	T
	0.5	0.5

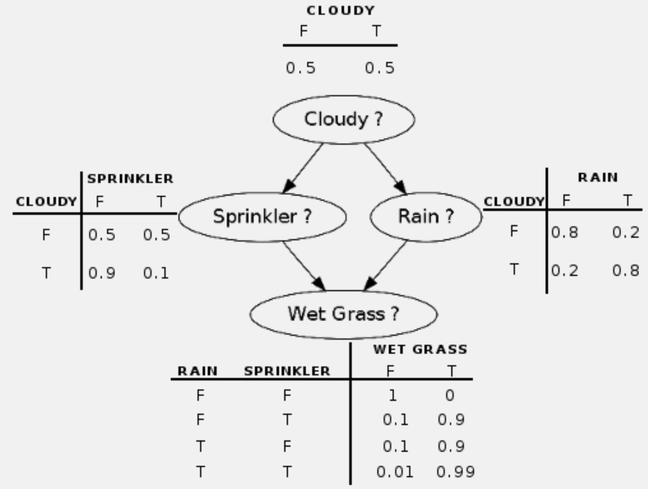
CLOUDY	SPRINKLER	F	T
F		0.5	0.5
T		0.9	0.1

CLOUDY	RAIN	F	T
F		0.8	0.2
T		0.2	0.8

RAIN	SPRINKLER	WET GRASS F	WET GRASS T
F	F	1	0
F	T	0.1	0.9
T	F	0.1	0.9
T	T	0.01	0.99

Pluggable Knowledge - Bayesian Networks

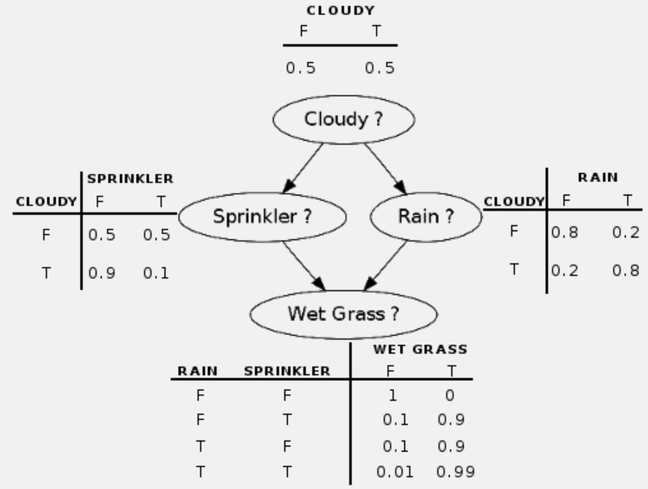
```
KnowledgeBuilder kBuilder = KnowledgeBuilderFactory.newKnowledgeBuilder();
kBuilder.add( ResourceFactory.newClassPathResource("Garden.xmlbif"),ResourceType.BAYES );

KnowledgeBase kBase = KnowledgeBaseFactory.newKnowledgeBase();
kBase.addKnowledgePackages( kBuilder.getKnowledgePackages() );

StatefulKnowledgeSession kSession = kBase.newStatefulKnowledgeSession();

BayesRuntime bayesRuntime = ksession.getKieRuntime(BayesRuntime.class);
BayesInstance<Garden> instance = bayesRuntime.createInstance(Garden.class);
```



Pluggable Knowledge - Bayesian Networks

```
KnowledgeBuilder kBuilder = KnowledgeBuilderFactory.newKnowledgeBuilder();
kBuilder.add( ResourceFactory.newClassPathResource("Garden.xmlbif"),ResourceType.BAYES );

KnowledgeBase kBase = KnowledgeBaseFactory.newKnowledgeBase();
kBase.addKnowledgePackages( kBuilder.getKnowledgePackages() );

StatefulKnowledgeSession kSession = kBase.newStatefulKnowledgeSession();

BayesRuntime bayesRuntime = ksession.getKieRuntime(BayesRuntime.class);
BayesInstance<Garden> instance = bayesRuntime.createInstance(Garden.class);
```

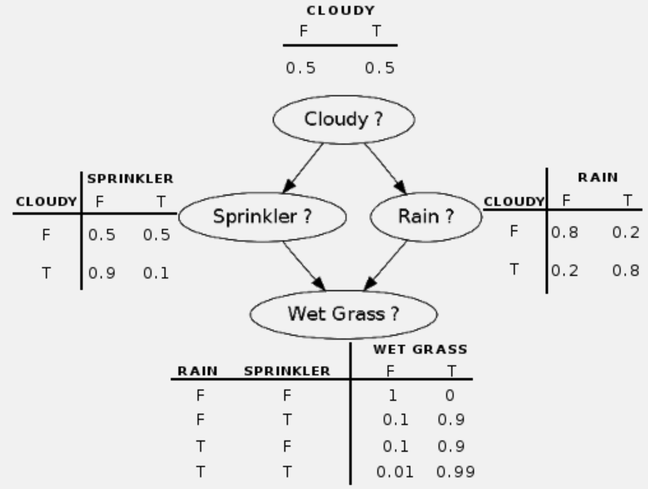
```
BayesVariable var = ( BayesVariable ) instance.getFieldNames().get( “WetGrass” );
bayesInstance.setDecided(var, true);
bayesInstance.setLikelyhood( var, [1.0,0.0] );

BayesVariable var = ( BayesVariable ) instance.getFieldNames().get( “Cloudy” );
bayesInstance.setDecided(var, true);
bayesInstance.setLikelyhood( var, [1.0,0.0] )
```



Pluggable Knowledge - Bayesian Networks

```
KnowledgeBuilder kBuilder = KnowledgeBuilderFactory.newKnowledgeBuilder();
kBuilder.add( ResourceFactory.newClassPathResource("Garden.xmlbif"),ResourceType.BAYES );

KnowledgeBase kBase = KnowledgeBaseFactory.newKnowledgeBase();
kBase.addKnowledgePackages( kBuilder.getKnowledgePackages() );

StatefulKnowledgeSession kSession = kBase.newStatefulKnowledgeSession();

BayesRuntime bayesRuntime = ksession.getKieRuntime(BayesRuntime.class);
BayesInstance<Garden> instance = bayesRuntime.createInstance(Garden.class);


BayesVariable var = ( BayesVariable ) instance.getFieldNames().get( “WetGrass” );
bayesInstance.setDecided(var, true);
bayesInstance.setLikelyhood( var, [1.0,0.0] );

BayesVariable var = ( BayesVariable ) instance.getFieldNames().get( “Cloudy” );
bayesInstance.setDecided(var, true);
bayesInstance.setLikelyhood( var, [1.0,0.0] )
```

```
Garden garden = instance.marginalize();
assertTrue(garden.isDecided());
assertTrue(garden.isRained());
```



OPS5 Onwards (Slowly)
Drools Improvements
    Property Reactive
    OO Path
    Prolog(ish) Backward Chaining
    Game Loops
Slow Progress
Foundations
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    Bayesian Belief
Pluggable Beliefs Systems
    Simple Truth Maintenance
    Defeasible Reasoning
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Papers
    Recommended Reading

Pluggable Belief Systems

Simple Truth Maintenance

Simple TMS

- A rule “logically” inserts an object
- When the rule is no longer true, the object is retracted.

```
rule "IsChild"
when
  $p : Person( age < 16 )
then
    logicalInsert( new IsChild( $p ) )
end

rule "IsAdult"
when
  $p : Person( age >= 16 )
then
    logicalInsert( new IsAdult( $p ) )
end
```

```
rule "Issue Child Bus Pass"
when
  $p : Person( )
       IsChild( person =$p )
then
  logicalInsert(new ChildBusPass( $p ) );
end

rule "Issue Adult Bus Pass"
when
  $p : Person()
       IsAdult( person =$p )
then
  logicalInsert(new AdultBusPass( $p ) );
end
```

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Pluggable Belief Systems

Defeasible Reasoning

Defeasible

```
rule "All Birds Fly" @Defeasible
when
    $b : Bird( )
then
    logicalInsert(new Fly( $b ) );
end
```

```
rule "Penguins Don't Fly"
        @Defeasible @Defeater
when
  $b : Bird( )
         Penguin($b;)
then
    logicalInsert(new Fly( $b ), “neg” );
end
```

```
rule "Penguins With Rockets Fly”
        @Defeasible @Defeats(“Penguins Don't Fly”)
when
    $b : Penguin( )
          Rocket($b;)
then
     logicalInsert(new Fly( $b ) );
end
```

Defeasible

- Defeasible for Legal
  - ‘claim’, ’objection,’ ‘rebuttal,’ ‘attack,’ ‘refutation,’ ‘rebutting defeater’ and ‘undercutting defeater’
  - http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.858.8225&rep=rep1&type=pdf
- Deontic logic and Temporal
  - Obligatory, Permitted, Forbidden
  - https://www.ics.forth.gr/_publications/Dimaresis_master.pdf

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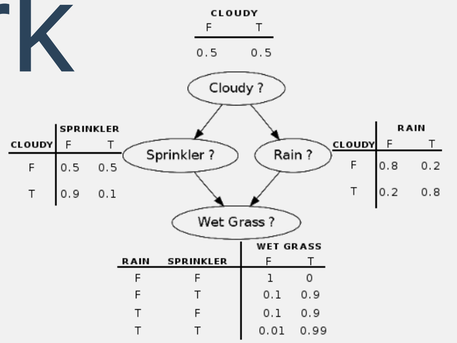
Pluggable Belief Systems

Bayesian Network

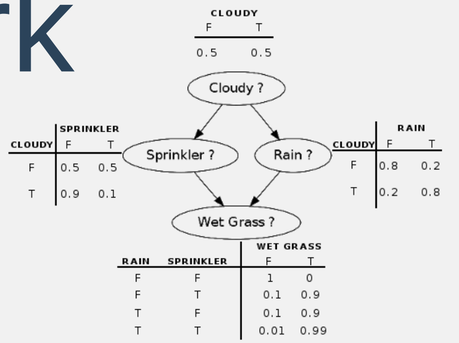
Pluggable Beliefs - Bayesian Network




```
KnowledgeBuilder kBuilder = KnowledgeBuilderFactory.newKnowledgeBuilder();
kBuilder.add( ResourceFactory.newClassPathResource(“rules.drl”), ResourceType.DRL );
kBuilder.add( ResourceFactory.newClassPathResource("Garden.xmlbif"),ResourceType.BAYES );

KnowledgeBase kBase = KnowledgeBaseFactory.newKnowledgeBase();
kBase.addKnowledgePackages( kBuilder.getKnowledgePackages() );
```

Pluggable Beliefs - Bayesian Network




```
BayesVariable var = ( BayesVariable ) instance.getFieldNames().get( “WetGrass” );
bayesInstance.setDecided(var, true);
bayesInstance.setLikelyhood( var, [1.0,0.0] );

Garden garden = instance.marginalize();;
FactHandle fh = ksession.insert( garden );
ksession.insert( new Cloud() );
ksession.fireAllRules();


rule "I see clouds" when
    g : Garden(decided == false)
    exists Cloud()
then
    insertLogical( bayesVar(g, 'Cloudy'),
                   evidenceFactory.create( new double[] {1.0,0.0} ) );
end

rule "It probably rained" when
    Garden(decided == true, rain == true)
then
    System.out.println( "Rain" );
end
```

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Units

Venus Rule Language

- Rules and data are decoupled
- Declarative Guards

```
module stipulate_relations(standby[],same[])

   rule same_is_symmetric;
   if (TRUE) {enforce_symmetry(same[]);}

   rule same_is_transitive;
   if (TRUE) {enforce_transitivity(same[]);}

   rule standby_is_symmetric;
   if (TRUE) {enforce_symmetry(standby[]);}
```

```
module  enforce_symmetry(Relation r[])
{
   rule enforce;
   from r[*] s;
   from r[?] t;
      if(!(s.domain_oid == t.range_oid &&
           s.range_oid == t.domain_oid)) {

            Relation *ins = new Relation;
            ins->domain_oid = s.range_oid;
            ins->range_oid = s.domain_oid;
            r.insert(ins);
   }
}
```

Units

```
package org.mypackage.myunit
public class AdultUnit implements RuleUnit {

    private int adultAge;

    private DataSource<Person> persons;

    public AdultUnit( ) { }
    public AdultUnit( DataSource<Person> persons, int age ) {
        this.persons = persons;
        this.age = age;
    }




}
```

Units

```
package org.mypackage.myunit
public class AdultUnit implements RuleUnit {

    private int adultAge;

    private DataSource<Person> persons;

    public AdultUnit( ) { }
    public AdultUnit( DataSource<Person> persons, int age ) {
        this.persons = persons;
        this.age = age;
    }




}
```

```
package org.mypackage.myunit
unit AdultUnit

rule Adult when
    $p : /persons{age >= adultAge}
then
    System.out.println($p.getName() +
    " is adult and greater than " + adultAge);
end
```

Units

```
package org.mypackage.myunit
public class AdultUnit implements RuleUnit {

    private int adultAge;

    private DataSource<Person> persons;

    public AdultUnit( ) { }
    public AdultUnit( DataSource<Person> persons, int age ) {
        this.persons = persons;
        this.age = age;
    }

    @Override
    public void onStart() { System.out.println(getName() + " started.");}

    @Override
    public void onEnd() { }
}
```

```
package org.mypackage.myunit
unit AdultUnit

rule Adult when
    $p : /persons{age >= adultAge}
then
    System.out.println($p.getName() +
    " is adult and greater than " + adultAge);
end
```

Guards

```
public class BoxOfficeUnit implements RuleUnit {
    private DataSource<BoxOffice> boxOffices;
}
```

```
package org.mypackage.myunit
unit BoxOfficeUnit

rule BoxOfficeIsOpen when
    $box: /boxOffices{ open }
then
    drools.guard( TicketIssuerUnit.class );
end
```

```
public class TicketIssuerUnit implements RuleUnit {
    private DataSource<Person> persons;
    private DataSource<AdultTicket> tickets;
    private List<String> results;
}
```

```
package org.mypackage.myunit
unit TicketIssuerUnit

rule IssueAdultTicket when
    $p: /persons{ age >= 18 }
then
    tickets.insert(new AdultTicket($p));
end

rule RegisterAdultTicket when
    $t: /tickets
then
    results.add( $t.getPerson().getName() );
end
```

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Units
Papers
- **Recommended Reading**

Papers

Recommended Reading

Papers - Recommended Reading

- Acharya, Anurag, and Milind Tambe. “Collection-Oriented Match: Scaling up the Data in Production Systems.” *… of the Second International Conference on …*, no. 7597 (1992). http://teamcore.usc.edu/papers/1993/cikm-final.pdf.
- Browne, James C., Allen Emerson, Mohamed G. Gouda, Daniel P. Miranker, Aloysius Mok, Lance Obermeyer, Furman Haddix, Rwo-hsi Wang, and Sarah Chodrow. “Modularity and Rule-Based Programming.” *International Journal on Artificial Intelligence Tools* 4, no. 01n02 (1995): 201–218.
- Doorenbos, RB. “Production Matching for Large Learning Systems,” 1995. http://reports-archive.adm.cs.cmu.edu/anon/anon/usr0/ftp/1995/CMU-CS-95-113.pdf.
- Forgy, CL. “Rete: A Fast Algorithm for the Many Pattern/Many Object Pattern Match Problem.” *Artificial Intelligence* 19, no. 3597 (1982): 17–37.
- “The OPS83 Report,” 1984. http://repository.cmu.edu/cgi/viewcontent.cgi?article=2478&context=compsci.
- Haley, Paul. “DATA-DRIVEN BACKWARD CHAINING,” no. September (1987): 1–4.
- Homeier, Peter V, and Thach C Le. “ECLIPS: An Extended CLIPS For Backward Chaining and Goal-Directed Reasoning.” In *NASA. Johnson Space Center, Second CLIPS Conference Proceedings*, 2:273--283, 1991.
- McDermott, Charles L (Charles Lanny) Forgy. “Production System Conflict Resolution Strategies,” 1976, 23.
- McDermott, J, Newell, A, Moore. “The Efficiency of Certain Production System Implementations.” In *Pattern-Directed Inference Systems*, 155--176. Elsevier, 1978.
- Nuutila, E. *Combining Rule Based and Procedural Programming in the XC and XE Programming Languages*, 1990. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.9.1106&rep=rep1&type=pdf.
- Scales, DJ. “Efficient Matching Algorithms for the SOAR/OPS5 Production System,” no. June (1986). ftp://reports.stanford.edu/pub/cstr.old/reports/cs/tr/86/1124/CS-TR-86-1124.pdf.
- Schor, MI, TP Daly, HS Lee, and BR Tibbitts. “Advances in RETE Pattern Matching.” *… of the Fifth National Conference on …*, 1986, 226–32.
- Sowizral, Henry A., and James R. Kipps. *ROSIE: A Programming Environment for Expert Systems*. Sanata Monica, CA: Rand, 1985.
- Waterman, D A, Robert Anderson, Frederick Hayes-Roth, Philip Klahr, Michael G Martinson, and Stanley J Rosenschein. “Design of a Rule-Oriented System for Implementing Expertise,” no. 1158 (1979): 67.
- Waterman, D. A., and Frederick Hayes-Roth, eds. *Pattern-Directed Inference Systems*. New York: Academic Press, 1978.

Papers - Recommended Reading

- Sklenar, Lukas. “Bayesian Belief Network Propagation Engine In Java.” University of Kent., Nd Web, (2012), 1–8.
- Bry, F, and Jakub Kotowski. “Reason Maintenance-State of the Art,” (2008). http://epub.ub.uni-muenchen.de/14900/.
- Bryant, Daniel, and Paul Krause. “A Review of Current Defeasible Reasoning Implementations.” Knowledge Engineering Review 00 (2008): 1–24. https://doi.org/10.1017/S000000000000000.