#### Leo de Penning

#### **Neural Symbolic Cognitive Agents**

11 11 Ē

Training and Assessment in Simulators

**TNO | Knowledge for business** 

#### **TNO Virtual Instruction Platform (VIP)**

Integrating Users, Environments and Organizations for Training, Assessment and Research



#### Automated Assessment! The ingredients

- 1. Start with an agent with access to the simulator, task and user
- 2. Add a Recurrent Temporal Restricted Boltzmann Machine (RTRBM)
- 3. Use a Continuous Stochastic input layer to handle continuous data
- 4. Encode and extract knowledge to/from RTRBM using its energy function







## Multi-Agent Virtual Instruction Platform

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#### Virtual Instruction Platform Configuration

- <SOAP-ENV:Envelope xmlns:SOAP-ENV="http://schemas.xmlsoap.org/soap/envelope/">

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- <SOAP-ENV:Header>
```

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<interval type="long" value="5" />
```

```
<loglevel type="string" value="INFO" />
```

- <children>

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```

```
<agent class="org.tno.simscorm.instruction.Instructor" file="instruction.xml" online="false" type="string" value="VInstructor" /> </SOAP-ENV:Header>
```

```
- <SOAP-ENV:Body>
```

```
- <cmi>
```

```
<scaled_passing_score />
```

```
<success_status type="string" value="unknown" />
```

```
<exit type="string" value="suspend" />
```

```
- <objectives>
```

```
- <drive id="1">
```

```
<id type="urn" value="urn:tno:drive" />
```

```
<description type="string" value="Drive for a while" />
```

```
- <score>
```

```
<raw ref="world.student_car.RelativeSpatial.RPM" type="double" value="789.969630783632" /> <scaled type="double" value="-0.7742943912046766" />
```

```
<min type="double" value="0.0" />
```

```
<max type="double" value="7000.0" />
```

```
</score>
<success_status type="string" />
```

```
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```



#### Virtual Instruction Platform Presentation



#### Neural Symbolic Cognitive Agent Architecture

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T

#### Neural Symbolic Cognitive Agent Recurrent Temporal Restricted Boltzmann Machine (RTRBM)



Automated Assessment







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Automated Assessment





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#### Neural Symbolic Cognitive Agent Automated Assessment

![](_page_12_Figure_1.jpeg)

![](_page_12_Figure_2.jpeg)

#### Neural Symbolic Cognitive Agent Automated Assessment

![](_page_13_Figure_1.jpeg)

![](_page_13_Figure_2.jpeg)

Adaptive Training with Cognitive-based Feedback

![](_page_14_Figure_2.jpeg)

![](_page_14_Picture_3.jpeg)

![](_page_14_Picture_4.jpeg)

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![](_page_14_Figure_5.jpeg)

Adaptive Training with Cognitive-based Feedback

![](_page_15_Figure_2.jpeg)

![](_page_15_Figure_3.jpeg)

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#### Neural Symbolic Cognitive Agent Adaptive Training with Cognitive-based Feedback

**Measurement Data Initial Conditions Dynamic Behaviour** Learner Profile Context Data Script/Constraints Measurements Learner data **Beliefs** Intersection Vehicle right ∆TTI < 3s Novice Level... Rules (t-1) Rules (t) Train Giving Priority **Desires/Intentions** Short term evaluation Feedback Long term evaluation Mid term evaluation Instructions Feedback **Assessment Data** Assessment Instructions

![](_page_16_Picture_3.jpeg)

#### Neural Symbolic Cognitive Agent Adaptive Training with Cognitive-based Feedback

**Measurement Data Initial Conditions Dynamic Behaviour** Learner Profile Context Data Script/Constraints Measurements Learner data **Beliefs** Intersection Vehicle right ∆TTI < 3s Novice Level... -Should Check Mirror\_ Rules (t-1) Should Brake Rules (t) Train Giving Priority **Desires/Intentions** Short term evaluation Feedback Long term evaluation Mid term evaluation Instructions Feedback **Assessment Data** Assessment Instructions

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Continuous Stochastic Input

![](_page_18_Figure_2.jpeg)

Hsin Chen and Alan F. Murray. Continuous restricted Boltzmann machine with an implementable training algorithm. In Vision, Image and Signal Processing, IEE Proceedings, pages 153-158, 2003.

![](_page_18_Picture_5.jpeg)

Symbolic Extraction and Encoding with Penalty Logic

#### Penalty Logic Well Formed Formula (PLOFF):

1000	$N \to R$	Nixon is a Republican
1000	$N \to Q$	Nixon is also a Quaker
10	$R \rightarrow \neg P$	Republicans tend not to be Pacifist
10	$Q \rightarrow P$	Quakers tend to be Pacifist
3000	Ν	the person we reason about is Nixon

![](_page_19_Figure_4.jpeg)

*Gadi Pinkas*. Reasoning, nonmonotonicity and learning in connectionist networks that capture propositional knowledge. In Artificial Intelligence v.77 n.2, pages 203-247, September 1995.

![](_page_19_Picture_7.jpeg)

Symbolic Extraction and Encoding with a RTRBM

![](_page_20_Figure_2.jpeg)

![](_page_20_Picture_4.jpeg)

From Penalty Logic to Temporal Logic

#### Conditions:

(Area = urban)

#### Scenario:

ApproachingIntersection  $\land \Diamond$ (ApproachingTraffic = right)

 $((Speed > 0) \land (HeadingIntersection)) \ (DistanceIntersection < x)$  $\rightarrow ApproachingIntersection$ 

#### Assessment:

ApproachingIntersection  $\land$  (DistanceIntersection = 0) (ApproachingTraffic = right)  $\land \square$ (Speed = 0)  $\rightarrow$  (Evaluation

# Trainee

#### Fuzzy Evidential Logic:

 $B = true \leftrightarrow w > 0, \neg B = true \leftrightarrow w < 0$ 

- $\Box B = true \leftrightarrow w \approx 1, \ \Box \neg B = true \leftrightarrow w \approx -1$
- $\Diamond B = \text{true} \leftrightarrow w \approx 0, \ \Diamond \neg B = \text{true} \leftrightarrow w \approx 0$

*Ron Sun*. A neural network model of causality. In IEEE Transactions on Neural Networks, Vol. 5, No. 4. pages 604-611. July, 1994. Temporal Logic:  $\alpha \mathbb{S}\beta: \ \beta \to \alpha \mathbb{S}\beta$  $\alpha \land \bullet (\alpha \mathbb{S}\beta) \to \alpha \mathbb{S}\beta$ 

*Luís C. Lamb, Rafael V. Borges, Artur S. d'Avila Garcez. A Connectionist Cognitive Model for Temporal Synchronisation and Learning. In Proceedings of the Conference on Association for the Advancement of Artificial Intelligence (AAAI), pages 827-832, 2007.* 

![](_page_21_Picture_18.jpeg)

#### Results

- <environment comment="Agent environment" type="org.tno.trinity.models.Model">

```
- <assessor interval="100" type="org.tno.trinity.agents.NSCAgent">
```

- <memory comment="Agent memory" type="org.tno.trinity.views.View">
- <environment comment="Agent environment" type="org.tno.trinity.models.Model">
- <br/>
   <
- <rules comment="Rules for reasoning with beliefs" size="10">
- <rule\_0 bias="4.2430946070335676" id="0" type="double" value="0.9555749">
- <prev\_rules comment="Previous applied rules">

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<speed bias="-54.9487688940324" id="1" max="7000.0" min="0.0" op="fessorequal" type="double" value="7000.0000000" weight="-9.057454322907315" />
</rule\_0>

- <rule\_1 bias="4.60062020202672413" id="1" type="double" value="0.0545924">
- <prev\_rules comment="Previous applied rules">

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<rule_1 bias="4.6000&lt;/th&gt;&lt;th&gt;/2029267243.3" id="&lt;b">'' c</rule_1>	or "areaber or equal" to be	"double <u>" volue "0.94228</u>	4" weight="0.6490951 <b>9658</b>	25427" />		
<rule_2 bias="4.5000&lt;/th&gt;&lt;th&gt;.31823627538" id="X&lt;/th&gt;&lt;th&gt;/ / / / / requal //&lt;/th&gt;&lt;th&gt;oubi va e 10.9: 5273&lt;/th&gt;&lt;th&gt;9" weight="0.8447893&lt;b&gt;9773&lt;/b&gt;&lt;/th&gt;&lt;th&gt;66996"></rule_2>						
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<rule_4 bias="4.5133&lt;/th&gt;&lt;th&gt;0254135314855" id="" th="" 🏴<="" 🚄=""><th>🗣 🗖 glaska 🗖 🖓 quai 🛛 type</th><th></th><th>62" weight="0.547001<b>4235</b></th><th>958757" /&gt;</th><th></th></rule_4>	🗣 🗖 glaska 🗖 🖓 quai 🛛 type		62" weight="0.547001 <b>4235</b>	958757" />		
<rule_5 5°="" bias="4.2940&lt;/th&gt;&lt;th&gt;(2544),283322° id∞" c<="" th=""><th>p="greaterorequal" type=</th><th>"double" value="0.894549</th><th>12" weight="0.91.2440449574</th><th>84513" /&gt;</th><th></th></rule_5>	p="greaterorequal" type=	"double" value="0.894549	12" weight="0.91.2440449574	84513" />		
<rule_6 6"="" bias="4.4064&lt;/th&gt;&lt;th&gt;469094358198° id=" c<="" th=""><th>p="greatencequal" type=</th><th>"double" value="0.8933.22</th><th>2" weight="0.5666814<b>1258</b></th><th>80919" /&gt;</th><th></th></rule_6>	p="greatencequal" type=	"double" value="0.8933.22	2" weight="0.5666814 <b>1258</b>	80919" />		
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<prev_rules <="" comment="" th=""><th><b>Previous applied rules</b></th><th>"&gt;</th><th></th><th></th><th></th><th></th></prev_rules>	<b>Previous applied rules</b>	">				
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crule\_1 bias="4.600620292672413" id="1" op="greaterorequal" type="double" value="0.9949409" weight="0.6808701223704264" />
crule\_2 bias="4.600620292672413" id="1" op="greaterorequal" type="double" value="0.9949609" weight="0.7423709633123091" />
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crule\_6 bias="4.406469094358198" id="6" op="greaterorequal" type="double" value="0.9940962" weight="0.7197623194788468" />
crule\_7 id= 7" op="greaterorequal" type="double" value="0.9940962" weight="0

![](_page_22_Picture_16.jpeg)

![](_page_22_Picture_17.jpeg)

#### Results

![](_page_23_Picture_1.jpeg)

![](_page_23_Picture_3.jpeg)

#### **Future Work**

- <environment comment="Agent environment" type="ora.tno.trinity.models.Model">

- <assessor interval="100" type="org.tno.trinity.agents.NSCAgent">

- <memory comment="Agent memory" type="org.tno.trinity.views.View">
- <environment comment="Agent environment" type="org.tno.trinity.models.Model">
- <br/>- <br/>
   <br/>
- <beliefs comment="Beliefs on the environment" type="double" value="0.1447801"> <score bias="0.36152741802402305" id="0" max="100.0" min="0.0" type="double" value="90.0000000" /> <speed bias="-54,9487688940324" id="1" max="7000.0" min="0.0" type="double" value="3014,6008232" />
- cules comment="Rules for reasoning with beliefs" size="10">
- crule\_0\_blas="4.2430946070335676" kl="0" type="double" value="0.9555749";
- Readable represenation of XML PLOFF in temporal logic and

natural "pins"4.450228944295311" id="3" op="greaterorequal" type="double" value="0.9944382" weight="0.7260354586900216" ang 1.260354586900216" ang 1.26035 "greaterorequal" type="double" value="0.9953213" weight="0.8468246601093128" biss="4,495469094353198" id="6" op="createrpresual" type="double" yslue="0.9946012" weight="0.9096922278415648 gule 7 bias="4.59081292363694" id="7" op="createroregual" type="double" value="0.9950574" weight="0.7141003732263917" crule 8 bias="4.335197564346316" id="0" op="createrpresual" type="double" value="0.9936395" weinbt="0.6566676756033129"

#### Validation of Neural Symbolic Cognitive Agent through validation

#### of extracted rules by Subject Matter Experts (SMEs)

.2430946020335576° id="0" op="meateroregual" type="double" value="0.9940046" weight="0.85766 -mile 1 hiss="4.6686502092672413" id="1" on="createronegual" type="double" vslue="0.9947284" weight="0.5498951965825437" /> <rule 2 bias="4,505131823627538" id="2" op="createroregual" bype="double" value="0.9952739" weight="0.8447893977366996" /> .460228944295311° id="3" op-"createrpregual" type="double" value="0.9940826" weight="0.5536945454954049"

Unsupervised learning of higher-order rules using Deep Boltzmann<sup>3</sup> Machines<sup>1</sup> p="greaterorequal" type="double" value="0.9945599" weight="0.6176915796165499" / 300 Boltzmann<sup>3</sup> Machines<sup>1</sup> p="greaterorequal" type="double" value="0.9945024" weight="0.8027390668239669"

<score blas="0.36152741802402303" id="0" max="100.0" min="0.0" op="greaterorequal" type="double" value="56.9445477" weight="0.6595079032264264" /:</pre> <soged bias="-54,9487688940324" id="1" max="7000.0" min="0.0" op="lessoneggal" type="double" value="7000.00000000" weight="-9.553719225414566" /> </rule 1>

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- <rule\_2 bias="4.505131823627538" id="2" type="double" value="0.9542151">
- <prev rules comment="Previous applied rules">

<rule\_0 bias="4.2430946070335676" id="0" op="greaterorequal" type="double" value="0.9929133" weight="0.699327604961496" /> <rule\_1 bias="4.600620292672413" id="1" op="greateroregual" type="double" value="0.9949409" weight="0.6808701223704264" /> <rule\_2 bias="4.505131823627538" id="2" op="greaterorequal" type="double" value="0.9947669" weight="0.7423709633123091" /> <rule\_3 bias="4.460228944295311" id="3" op="greaterorequal" type="double" value="0.9951821" weight="0.8703549774488882" /> <rule\_4 bias="4.5133254135314855" id="4" op="greateroregual" type="double" value="0.9946559" weight="0.7130773368356851" /> <rule\_5 bias="4.294075441783322" id="5" op="greaterorequal" type="double" value="0.9943501" weight="0.8763712983825316" /> <rule\_6 bias="4.406469094358198" id="6" op="greaterorequal" type="double" value="0.9940962" weight="0.7197623194788468" /> 

#### Neural Symbolic Cognitive Agent Higher-order rules with Deep Boltzmann Machines

![](_page_25_Figure_1.jpeg)

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#### **Neural Symbolic Cognitive Agent** Higher-order rules with Deep Boltzmann Machines

![](_page_26_Figure_1.jpeg)

#### Conclusions

- <environment comment="Agent environment" type="ora.tno.trinity.models.Model">

```
- <assessor interval="100" type="org.tno.trinity.agents.NSCAgent">
```

- <memory comment="Agent memory" type="org.tno.trinity.views.View">
- <environment comment="Agent environment" type="org.tno.trinity.models.Model">
- <br/>- <br/>
   <br/> - <beliefs comment="Beliefs on the environment" type="double" value="0.1447801">
  - <score bias="0.36152741802402305" id="0" max="100.0" min="0.0" type="double" value="90.0000000" /> <speed bias="-54.9487688940324" id="1" max="7000.0" min="0.0" type="double" value="3014.6008232" /> </beliefs>
- <rules comment="Rules for reasoning with beliefs" size="10">
- <rule 0 bias="4.2430946070335676" id="0" type="double" value="0.9555749">
- <prey rules comment="Previous applied rules">

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     <rule 3 bios="4.460.22894429531.1" id="3" op="greaterorequal" bype="double" value="0.9044382" weicht="0.9260354586000316" />
     <rule_4 bias="4.5133254135314355" id="4" op="greateroregual" type="double" volue="0.9953211" weight="0.8458246601093128" />
     <rule_5 bizs="4.294075441783322" id="5" op="greateroregual" type="double" value="0.9937757" weight="0.7789742125091277" />
     <rule_6 bias="4.406469094358198" id="6" op="greateroregual" type="double" value="0.9946612" weicht="0.8095922278415548" />
                 "4.5903(292) (3104" ) = 7" (p="greater requait type="double" value="0.9950574" velott="0.7141003732200917" />
"4.305 PATTA KERSULTS=12 (Compromission Completence) (>
"4.487 PATTA KERSULTS=12 (Compromission Completence) (>
   </rray miss
   <score bias="0.36152741802402305" id="0" max=1100.0" min="0.0" op="greateroregual" type="double" value="53.9040275" weight="0.418713272306781" />
   cspeed bias="-54,9487688940324" id="1" mat="7000.0" min="0.0" op="lessoreceal" type="double" value="7000.0000000" wecht="-9.057454322907315" />
  </r>
- <rul>- <rul>1 bias="4.600600292672413" id="1" type="double" value="0.9545924"
 - cpress
            Experiments and validation ongoing
     ender 3 bine
                                                                                                      94478890
                                                                                                                    alaidda6" />
     <rule_3 bias="4.460228944295311" id="3" ap="greateroragual" type="double" value="0.9940826" weight="0.66369454549646499" />
     <rule_4 b:s="4.5133254135314555" id="4" op="greateroregaal" type="double" value="0.9957662" weight="0.9470814235956757" />
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     <rule_6 plas="4.406469094358198" id="6" op="greaterorequal" type="double" value="0.9931222" weight="0.5660814125880919" />
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     <rule 8 bias="4.395197504340316" id="8" op="greateroregual" type="double" value="0.9945024" weight="0.8027390668209669" />
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   </prev rules>
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   <speed bias="-54.9487688940324" id="1" max="7000.0" min="0.0" op="lessoregual" type="double" value="7000.0000000" weight="-9.553719225414566" />
  </rule 1>
- <rule_2 bias="4.505131823627538" id="2" type="double" value="0.9542151">
 - <prev rules comment="Previous applied rules">
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![](_page_27_Picture_12.jpeg)

#### **Questions?**

- <environment comment="Agent environment" type="org.tno.trinity.models.Model">

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- <assessor interval="100" type="org.tno.trinity.agents.NSCAgent">
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- <memory comment="Agent memory" type="org.tno.trinity.views.View">
- <environment comment="Agent environment" type="org.tno.trinity.models.Model">
- <br/>drain comment="Assessment model" cost="2.0000000000002E-7" epochs="1" momentum="0.5" rate="0.01" type="org.tno.trinity.views.CRTRBMView"><br/>- <br/>deliefs comment="Beliefs on the environment" type="double" value="0.1447801">
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  <speed bias="-54.9487688940324" id="1" max="7000.0" min="0.0" type="double" value="3014.6008232" />
  </beliefs>
- <rules comment="Rules for reasoning with beliefs" size="10">
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- <prev\_rules comment="Previous applied rules">

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<rule\_9 bias="4. 219

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<rule 5 bias="4.29

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<rule 7 bias="4.

<rule 8 bias="4.

</prev rules>

<speed bias="-54.9487688</pre>

- <rule\_1 bias="4.60062029\_72 - <prev\_rules comment="Previou <rule 0 bias="4.2430946070.</p>

</rule 0>

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19.

**)4**" `

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1292

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![](_page_28_Picture_19.jpeg)