Unified Rule Engine

Inference Control Meta-Learning

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SingularityNET Foundation

Unified Rule Engine: reminder

The URE evolves Inference Trees

```
A  A->B
-------(MP)
   B


    A->B  B->C
    ----------(DED)
A      A->C
-----------(MP)
     C


ForAll X P(X)  U(P(X), A)        A->B  B->C
-------------------------(INS)   ----------(DED)
            A                       A->C
            ----------------------------(MP)
                          C
```

- Leaves are premises
- Roots are conclusions

URE: Unified Rule Engine

Inference Trees are constructed by composing Rules

- forward: expand conclusion

```
A  A->B
-------(MP)
   B
```

$\Rightarrow$

```
A   A->B
--------(MP)
   B        B->C
   -------------(MP)
         C
```

URE: Unified Rule Engine

Inference Trees are constructed by composing Rules

- forward: expand conclusion

```
                                    A    A->B
A   A->B                            --------(MP)
-------(MP)            ⇒               B        B->C
   B                                   -------------(MP)
                                              C
```

- backward: expand premises

```
                                    ForAll X P(X)  U(P(X), A)
 A   A->B                           -------------------------(INS)
-------(MP)            ⇒                       A                        A->B
   B                                           ----------------------------(MP)
                                                              B
```

```
                                            A->C   C->B
A    A->B                                   -----------(DED)
-------(MP)            ⇒            A          A->B
   B                                ---------------(MP)
                                           B
```

URE: Unified Rule Engine

Inference Trees are Atomese Programs

```
A  A->B
-------(MP)
   B
```

```
(BindLink
  (VariableList                                             \
    (TypedVariableLink                                      |
      (VariableNode "$A")                                   |
      (TypeChoice                                           |
        (TypeNode "LambdaLink")                             |
        (TypeNode "PredicateNode")                          |
      )                                                     |
    )                                                       | Variables
    (TypedVariableLink                                      |
      (VariableNode "$B")                                   |
      (TypeChoice                                           |
        (TypeNode "LambdaLink")                             |
        (TypeNode "PredicateNode")                          |
      )                                                     |
    )                                                       |
  )                                                         /
  (AndLink                                                  \
    (ImplicationLink                                        |
      (VariableNode "$A")                                   | Pattern
      (VariableNode "$B")                                   |
    )                                                       /
    (EvaluationLink                                         \
      (GroundedPredicateNode "scm: true-enough")            |
      (ImplicationLink                                      |
        (VariableNode "$A")                                 |
        (VariableNode "$B")                                 |
      )                                                     |
    )                                                       | Preconditions
    (EvaluationLink                                         |
      (GroundedPredicateNode "scm: true-enough")            |
      (VariableNode "$A")                                   |
    )                                                       |
  )                                                         /
  (ExecutionOutputLink                                      \
    (GroundedSchemaNode "scm: modus-ponens-formula")        |
    (ListLink                                               |
      (VariableNode "$B")                                   |
      (VariableNode "$A")                                   |
      (ImplicationLink                                      | Production
        (VariableNode "$A")                                 |
        (VariableNode "$B")                                 |
      )                                                     |
    )                                                       |
  )                                                         /
```

URE: Unified Rule Engine

Inference Trees are Atomese Programs

```
A  A->B
-------(MP)
   B
```

```
(ExecutionOutputLink
  (GroundedSchemaNode "scm: modus-ponens-formula")
  (ListLink
    (VariableNode "$B")
    (VariableNode "$A")
    (ImplicationLink
      (VariableNode "$A")
      (VariableNode "$B")
    )
  )
)
```

URE: Unified Rule Engine

Inference Trees are Atomese Programs

```
     A->C   C->B
     -----------(DED)
A       A->B
------------(MP)
     B
```

```
(ExecutionOutputLink
  (GroundedSchemaNode "scm: modus-ponens-formula")
  (ListLink
    (VariableNode "$B")
    (VariableNode "$A")
    (ExecutionOutputLink
      (GroundedSchemaNode "scm: deduction-formula")
      (ListLink
        (ImplicationLink
          (VariableNode "$A")
          (VariableNode "$B")
        )
        (ImplicationLink
          (VariableNode "$A")
          (VariableNode "$C")
        )
        (ImplicationLink
          (VariableNode "$C")
          (VariableNode "$B")
        )
      )
    )
  )
)
```

URE: Unified Rule Engine

Algorithm

1. Select an inference tree to expand
2. Select a node from that tree to expand
3. Select a rule to expand with
4. Expand the inference tree and place it back to the pool of inference trees. Repeat till termination.

Combinatorial Explosion

Inference Control

Delegate the hard decisions to a cognitive process

Cognitive Schematics:

$$\text{Context} \,\&\, \text{Action} \Rightarrow \text{Goal}$$

Atomese:

```
Implication <TV>
  And
    <Context>
    <Action>
  <Goal>
```

Inference Control

```
A  A->B
-------(MP)
   B
```

Which rule to choose?

1. Modus Ponens
2. Universal Instantiation

Look for:

```
Implication <TV>
  And
    <inference-tree-pattern>
    <node-pattern>
    <rule-pattern>
  <produce-good-inference>
```

Inference Control

Examples of actual URE Cognitive Schematics

```
(ImplicationScopeLink (stv 0.45945946 0.04625)
   (VariableList
      (VariableNode "$T")
      (TypedVariableLink
         (VariableNode "$A")
         (TypeNode "DontExecLink")
      )
      (VariableNode "$L")
      (TypedVariableLink
         (VariableNode "$B")
         (TypeNode "DontExecLink")
      )
   )
   (AndLink
      (EvaluationLink
         (PredicateNode "URE:BC:preproof-of")
         (ListLink
            (VariableNode "$A")
            (VariableNode "$T")
         )
      )
      (ExecutionLink
         (SchemaNode "URE:BC:expand-and-BIT")
         (ListLink
            (VariableNode "$A")
            (VariableNode "$L")
            (DontExecLink
               (DefinedSchemaNode "deduction-inheritance-rule")
            )
         )
         (VariableNode "$B")
      )
   )
   (EvaluationLink
      (PredicateNode "URE:BC:preproof-of")
      (ListLink
         (VariableNode "$B")
         (VariableNode "$T")
      )
   )
)
```

```
(ImplicationScopeLink (stv 1 0.00625)
   (VariableList
      (VariableNode "$T")
      (TypedVariableLink
         (VariableNode "$A")
         (TypeNode "DontExecLink")
      )
      (VariableNode "$X")
      (TypedVariableLink
         (VariableNode "$B")
         (TypeNode "DontExecLink")
      )
   )
   (AndLink
      (EvaluationLink
         (PredicateNode "URE:BC:preproof-of")
         (ListLink
            (VariableNode "$A")
            (VariableNode "$T")
         )
      )
      (ExecutionLink
         (SchemaNode "URE:BC:expand-and-BIT")
         (ListLink
            (VariableNode "$A")
            (InheritanceLink
               (ConceptNode "a")
               (VariableNode "$X")
            )
            (DontExecLink
               (DefinedSchemaNode "conditional-full-instantiation-implication-scope-meta-rule"
            )
         )
         (VariableNode "$B")
      )
   )
   (EvaluationLink
      (PredicateNode "URE:BC:preproof-of")
      (ListLink
         (VariableNode "$B")
         (VariableNode "$T")
      )
   )
)
```

Inference Control Algorithm

Given:

- inference rules: R_1, ..., R_n
- control rules:
  - $R_1 \rightarrow \{\ C_{1,1}$, ..., $C_{1,m_1}\ \}$
  - ...
  - $R_n \rightarrow \{\ C_{n,1}$, ..., $C_{n,m_n}\ \}$

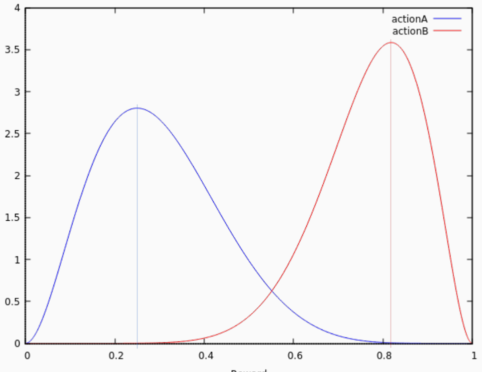
Combine $C_{i,j}$ to select best R_i

?

Inference Control Algorithm

Selecting inference rule R_i:

1. Mixture model: $M_i = C_{i,1} \oplus \cdots \oplus C_{i,m_i}$ (Bayesian Model Averaging, Solomonoff Operator Induction).
2. Thomspon Sampling: $R_i = TS(M_1, \ldots, M_n)$



Inference Control Meta-Learning

How to get Control Rules?

Answer: Learning

Record all decisions
the URE takes and learn from it

Currently: Pattern Mining

Inference Control Learning: URE Trace

```
A    A->B
-------(MP)
   B
```

Expand

$\longrightarrow$

```
            A->C    C->B
            -----------(DED)
A                A->B
---------------(MP)
          B
```

Atomese:

```
(ExecutionLink (stv 1 1)
   (SchemaNode "URE:BC:expand-and-BIT")
   (ListLink
      (DontExecLink
         (BindLink
            (VariableNode "$A-591b9032")
            (AndLink
               (VariableNode "$A-591b9032")
               (InheritanceLink
                  (VariableNode "$A-591b9032")
                  (InheritanceLink (stv 1 1)
                     (ConceptNode "v" (stv 0.84615385 1))
                     (ConceptNode "w")
                  )
               )
               (EvaluationLink
                  (GroundedPredicateNode "scm: gt-zero-confidence")
                  (VariableNode "$A-591b9032")
               )
               (EvaluationLink
                  (GroundedPredicateNode "scm: gt-zero-confidence")
                  (InheritanceLink
                     (VariableNode "$A-591b9032")
                     (InheritanceLink (stv 1 1)
                        (ConceptNode "v" (stv 0.84615385 1))
                        (ConceptNode "w")
                     )
                  )
               )
            )
            (ExecutionOutputLink
               (GroundedSchemaNode "scm: modus-ponens-formula")
               (ListLink
                  (InheritanceLink (stv 1 1)
                     (ConceptNode "v" (stv 0.84615385 1))
                     (ConceptNode "w")
                  )
                  (InheritanceLink
                     (VariableNode "$A-591b9032")
                     (InheritanceLink (stv 1 1)
                        (ConceptNode "v" (stv 0.84615385 1))
                        (ConceptNode "w")
                     )
                  )
                  (VariableNode "$A-591b9032")
               )
            )
         )
      )
      (VariableNode "$A-1860e3b6")
      (DontExecLink
         (DefinedSchemaNode "deduction-inheritance-rule")
      )
   )
```

```
(DontExecLink
   (BindLink
      (VariableList
         (TypedVariableLink
            (VariableNode "$A-2fbf17d5")
            (TypeChoice
               (TypeNode "ConceptNode")
               (TypeNode "AndLink")
               (TypeNode "OrLink")
               (TypeNode "NotLink")
            )
         )
         (TypedVariableLink
            (VariableNode "$C-2bdc1299")
            (TypeChoice
               (TypeNode "ConceptNode")
               (TypeNode "AndLink")
               (TypeNode "OrLink")
               (TypeNode "NotLink")
            )
         )
         (TypedVariableLink
            (VariableNode "$B-4a714efb")
            (TypeChoice
               (TypeNode "ConceptNode")
               (TypeNode "AndLink")
               (TypeNode "OrLink")
               (TypeNode "NotLink")
            )
         )
      )
      (AndLink
         (EvaluationLink
            (GroundedPredicateNode "scm: gt-zero-confidence")
            (InheritanceLink
               (InheritanceLink
                  (VariableNode "$A-2fbf17d5")
                  (VariableNode "$C-2bdc1299")
               )
               (InheritanceLink (stv 1 1)
                  (ConceptNode "v" (stv 0.84615385 1))
                  (ConceptNode "w")
               )
            )
         )
         (InheritanceLink
            (VariableNode "$B-4a714efb")
            (VariableNode "$C-2bdc1299")
         )
         (InheritanceLink
            (InheritanceLink
               (VariableNode "$A-2fbf17d5")
               (VariableNode "$C-2bdc1299")
            )
            (InheritanceLink (stv 1 1)
               (ConceptNode "v" (stv 0.84615385 1))
               (ConceptNode "w")
            )
         )
         (NotLink
            (IdenticalLink
               (VariableNode "$C-2bdc1299")
               (VariableNode "$A-2fbf17d5")
            )
         )
         (InheritanceLink
            (VariableNode "$A-2fbf17d5")
            (VariableNode "$B-4a714efb")
         )
      )
```

```
         (ExecutionOutputLink
            (GroundedSchemaNode "scm: modus-ponens-formula")
            (ListLink
               (InheritanceLink (stv 1 1)
                  (ConceptNode "v" (stv 0.84615385 1))
                  (ConceptNode "w")
               )
               (InheritanceLink
                  (InheritanceLink
                     (VariableNode "$A-2fbf17d5")
                     (VariableNode "$C-2bdc1299")
                  )
                  (InheritanceLink (stv 1 1)
                     (ConceptNode "v" (stv 0.84615385 1))
                     (ConceptNode "w")
                  )
               )
               (ExecutionOutputLink
                  (GroundedSchemaNode "scm: deduction-formula")
                  (ListLink
                     (InheritanceLink
                        (VariableNode "$A-2fbf17d5")
                        (VariableNode "$C-2bdc1299")
                     )
                     (InheritanceLink
                        (VariableNode "$A-2fbf17d5")
                        (VariableNode "$B-4a714efb")
                     )
                     (InheritanceLink
                        (VariableNode "$B-4a714efb")
                        (VariableNode "$C-2bdc1299")
                     )
                  )
               )
            )
         )
      )
   )
)
```

Inference Control Learning: URE Trace

```
           A->C    C->B
           -----------(DED)
A              A->B
---------------(MP)
       B
```

Quality $\longrightarrow$ (stv 0.0001, 0.00075)

Atomese:

```
(EvaluationLink (stv 0.0001 0.00075)
   (PredicateNode "URE:BC:preproof-of")
   (ListLink
      (DontExecLink
         (BindLink
            (VariableList
               (TypedVariableLink
                  (VariableNode "$A-2fbf17d5")
                  (TypeChoice
                     (TypeNode "ConceptNode")
                     (TypeNode "AndLink")
                     (TypeNode "OrLink")
                     (TypeNode "NotLink")
                  )
               )
               (TypedVariableLink
                  (VariableNode "$C-2bdc1299")
                  (TypeChoice
                     (TypeNode "ConceptNode")
                     (TypeNode "AndLink")
                     (TypeNode "OrLink")
                     (TypeNode "NotLink")
                  )
               )
               (TypedVariableLink
                  (VariableNode "$B-4a714efb")
                  (TypeChoice
                     (TypeNode "ConceptNode")
                     (TypeNode "AndLink")
                     (TypeNode "OrLink")
                     (TypeNode "NotLink")
                  )
               )
            )
            (AndLink
               (EvaluationLink
                  (GroundedPredicateNode "scm: gt-zero-confidence")
                  (InheritanceLink
                     (InheritanceLink
                        (VariableNode "$A-2fbf17d5")
                        (VariableNode "$C-2bdc1299")
                     )
                     (InheritanceLink (stv 1 1)
                        (ConceptNode "v" (stv 0.84615385 1))
                        (ConceptNode "w")
                     )
                  )
               )
               (InheritanceLink
                  (VariableNode "$B-4a714efb")
                  (VariableNode "$C-2bdc1299")
               )
               (InheritanceLink
                  (InheritanceLink
                     (VariableNode "$A-2fbf17d5")
                     (VariableNode "$C-2bdc1299")
                  )
                  (InheritanceLink (stv 1 1)
                     (ConceptNode "v" (stv 0.84615385 1))
                     (ConceptNode "w")
                  )
               )
               (NotLink
                  (IdenticalLink
                     (VariableNode "$C-2bdc1299")
                     (VariableNode "$A-2fbf17d5")
                  )
               )
               (InheritanceLink
                  (VariableNode "$A-2fbf17d5")
                  (VariableNode "$B-4a714efb")
               )
            )
```

```
            (ExecutionOutputLink
               (GroundedSchemaNode "scm: modus-ponens-formula")
               (ListLink
                  (InheritanceLink (stv 1 1)
                     (ConceptNode "v" (stv 0.84615385 1))
                     (ConceptNode "w")
                  )
                  (InheritanceLink
                     (InheritanceLink
                        (VariableNode "$A-2fbf17d5")
                        (VariableNode "$C-2bdc1299")
                     )
                     (InheritanceLink (stv 1 1)
                        (ConceptNode "v" (stv 0.84615385 1))
                        (ConceptNode "w")
                     )
                  )
                  (ExecutionOutputLink
                     (GroundedSchemaNode "scm: deduction-formula")
                     (ListLink
                        (InheritanceLink
                           (VariableNode "$A-2fbf17d5")
                           (VariableNode "$C-2bdc1299")
                        )
                        (InheritanceLink
                           (VariableNode "$A-2fbf17d5")
                           (VariableNode "$B-4a714efb")
                        )
                        (InheritanceLink
                           (VariableNode "$B-4a714efb")
                           (VariableNode "$C-2bdc1299")
                        )
                     )
                  )
               )
            )
         )
      )
      (InheritanceLink (stv 1 1)
         (ConceptNode "v" (stv 0.84615385 1))
         (ConceptNode "w")
      )
   )
)
```

Inference Control Learning: URE

Call the URE with a Control Rule Template as target

```
(cog-bc icr-rb (QuoteLink
                 (ImplicationScopeLink
                    (UnquoteLink
                       (VariableNode "$impl-vardecl")
                    )
                    (AndLink
                       (EvaluationLink
                          (PredicateNode "URE:BC:preproof-of")
                          (UnquoteLink
                             (VariableNode "$preproof-A-args")
                          )
                       )
                       (ExecutionLink
                          (SchemaNode "URE:BC:expand-and-BIT")
                          (UnquoteLink
                             (VariableNode "$expand-inputs")
                          )
                          (UnquoteLink
                             (VariableNode "$expand-output")
                          )
                       )
                    )
                    (EvaluationLink
                       (PredicateNode "URE:BC:preproof-of")
                       (UnquoteLink
                          (VariableNode "$preproof-B-args")
                       )
                    )
                 )
              )
           )
```

Inference Control Learning: URE

Call the URE with a Control Rule Template as target

```
(cog-bc icr-rb (QuoteLink
                 (ImplicationScopeLink
                    (UnquoteLink
                       (VariableNode "$impl-vardecl")
                    )
                    (AndLink
                       (EvaluationLink
                          (PredicateNode "URE:BC:preproof-of")
                          (UnquoteLink
                             (VariableNode "$preproof-A-args")
                          )
                       )
                       (ExecutionLink
                          (SchemaNode "URE:BC:expand-and-BIT")
                          (UnquoteLink
                             (VariableNode "$expand-inputs")
                          )
                          (UnquoteLink
                             (VariableNode "$expand-output")
                          )
                       )
                    )
                    (EvaluationLink
                       (PredicateNode "URE:BC:preproof-of")
                       (UnquoteLink
                          (VariableNode "$preproof-B-args")
                       )
                    )
                 )
              )
           )
```

```
(ImplicationScopeLink (stv 0.45945946 0.04625)
   (VariableList
      (VariableNode "$T")
      (TypedVariableLink
         (VariableNode "$A")
         (TypeNode "DontExecLink")
      )
      (VariableNode "$L")
      (TypedVariableLink
         (VariableNode "$B")
         (TypeNode "DontExecLink")
      )
   )
   (AndLink
      (EvaluationLink
         (PredicateNode "URE:BC:preproof-of")
         (ListLink
            (VariableNode "$A")
            (VariableNode "$T")
         )
      )
      (ExecutionLink
         (SchemaNode "URE:BC:expand-and-BIT")
         (ListLink
            (VariableNode "$A")
            (VariableNode "$L")
            (DontExecLink
               (DefinedSchemaNode "deduction-inheritance-rule")
            )
         )
         (VariableNode "$B")
      )
   )
   (EvaluationLink
      (PredicateNode "URE:BC:preproof-of")
      (ListLink
         (VariableNode "$B")
         (VariableNode "$T")
      )
   )
)
```

Inference Control Learning: URE + Pattern Miner

Call the URE with a Control Rule Template as target + Pattern Miner

```
(cog-bc icr-rb (QuoteLink
                  (ImplicationScopeLink
                     (UnquoteLink
                        (VariableNode "$impl-vardecl")
                     )
                     (AndLink
                        (EvaluationLink
                           (PredicateNode "URE:BC:preproof-of")
                           (UnquoteLink
                              (VariableNode "$preproof-A-args")
                           )
                        )
                        (ExecutionLink
                           (SchemaNode "URE:BC:expand-and-BIT")
                           (UnquoteLink
                              (VariableNode "$expand-inputs")
                           )
                           (UnquoteLink
                              (VariableNode "$expand-output")
                           )
                        )
                     )
                     (EvaluationLink
                        (PredicateNode "URE:BC:preproof-of")
                        (UnquoteLink
                           (VariableNode "$preproof-B-args")
                        )
                     )
                  )
               )
            )
```

```
(ImplicationScopeLink (stv 1 0.00625)
    (VariableList
        (VariableNode "$T")
        (TypedVariableLink
            (VariableNode "$A")
            (TypeNode "DontExecLink")
        )
        (VariableNode "$X")
        (TypedVariableLink
            (VariableNode "$B")
            (TypeNode "DontExecLink")
        )
    )
    (AndLink
        (EvaluationLink
            (PredicateNode "URE:BC:preproof-of")
            (ListLink
                (VariableNode "$A")
                (VariableNode "$T")
            )
        )
        (ExecutionLink
            (SchemaNode "URE:BC:expand-and-BIT")
            (ListLink
                (VariableNode "$A")
                (InheritanceLink
                    (ConceptNode "a")
                    (VariableNode "$X")
                )
                (DontExecLink
                    (DefinedSchemaNode "conditional-full-instantiation-implication-scope-meta-rule")
                )
            )
            (VariableNode "$B")
        )
    )
    (EvaluationLink
        (PredicateNode "URE:BC:preproof-of")
        (ListLink
            (VariableNode "$B")
            (VariableNode "$T")
        )
    )
)
```

Issues, forthcoming work

- Issues:
  - Pattern Miner (WIP), looking for challenges!
  - Too many control rules?
- Forthcoming:
  - Experimentations, looking for challenges!
  - Other learning methods, MOSES, etc
  - Integrate ECAN

Issues, forthcoming work

- Issues:
  - Pattern Miner (WIP), looking for challenges!
  - Too many control rules?
- Forthcoming:
  - Experimentations, looking for challenges!
  - Other learning methods, MOSES, etc
  - Integrate ECAN

Demo time...