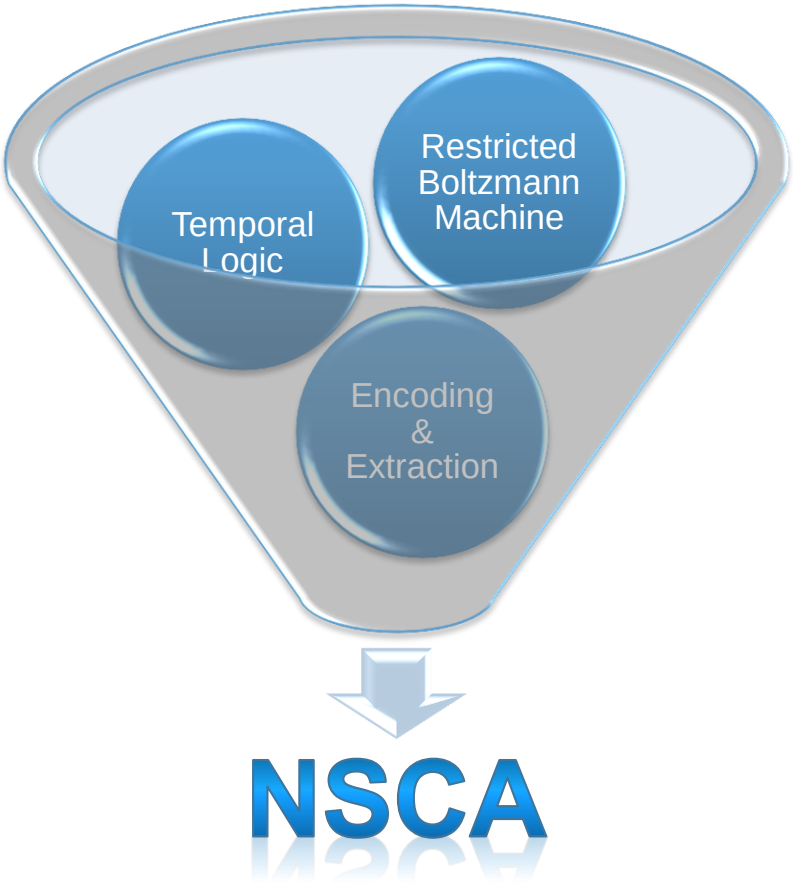
TNO innovation for life

Neural-Symbolic Cognitive Agents

Architecture and Theory



Leo de Penning
Artur d'Avila Garcez
Luis Lamb
John-Jules Meyer

COGNITIVE MODEL

COMPLEX BEHAVIOUR

ROBUST

REAL-TIME

EXPRESSIVE

WHITE BOX

NEURAL-SYMBOLIC LEARNING AND REASONING

ENCODING

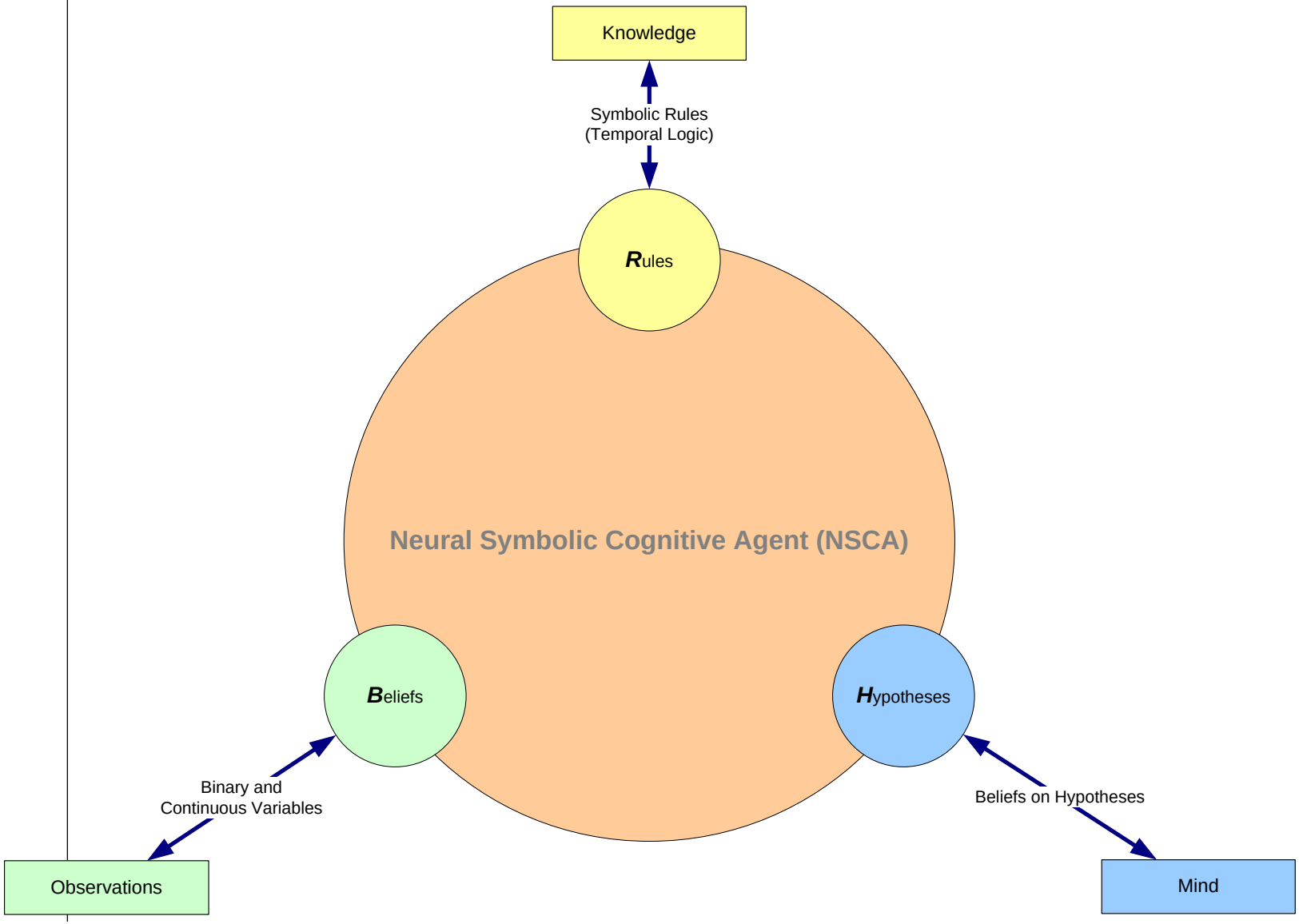
NEURAL NETWORK

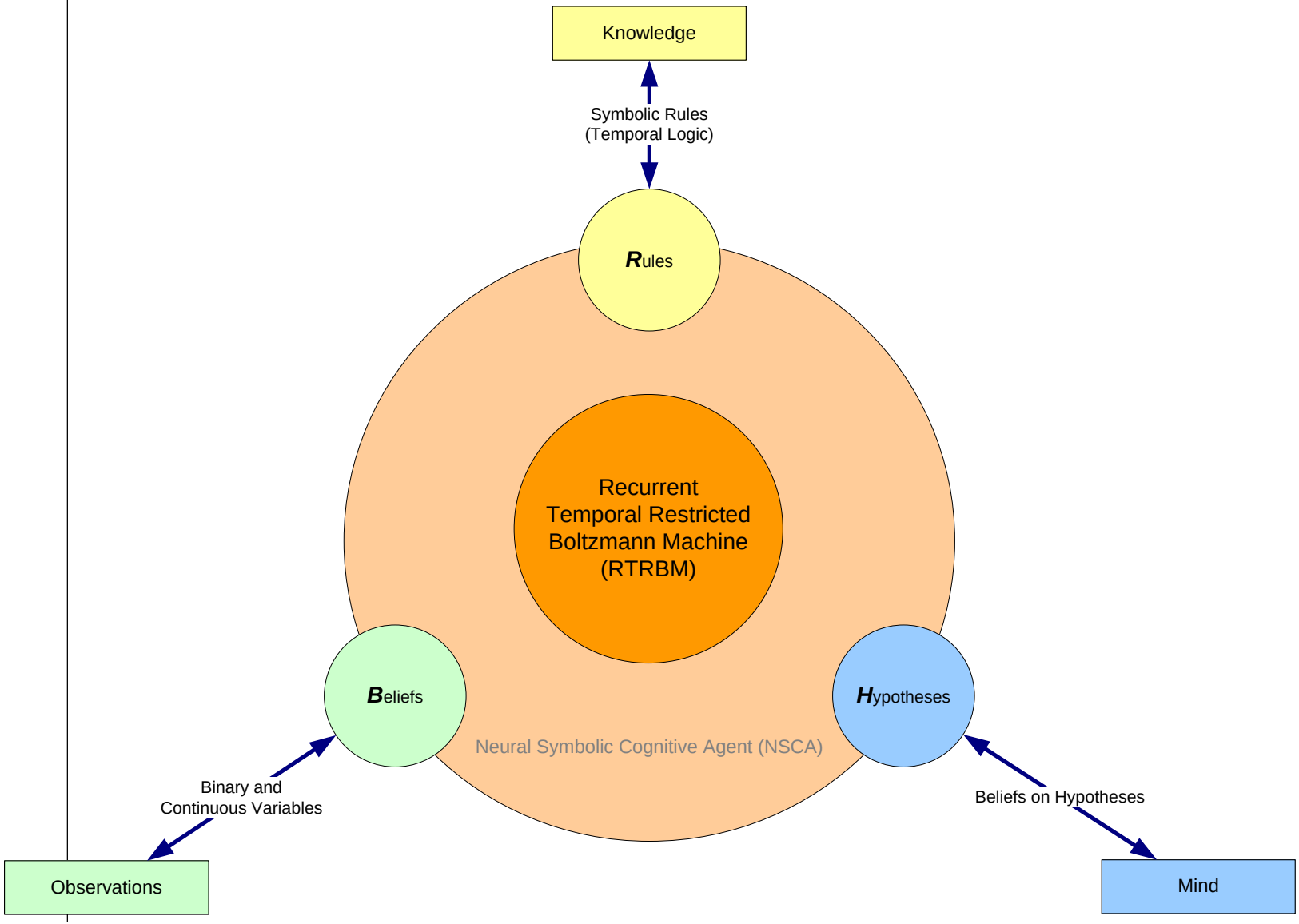
LEARNING FROM OBSERVATION

(SUB)SYMBOLIC REASONING

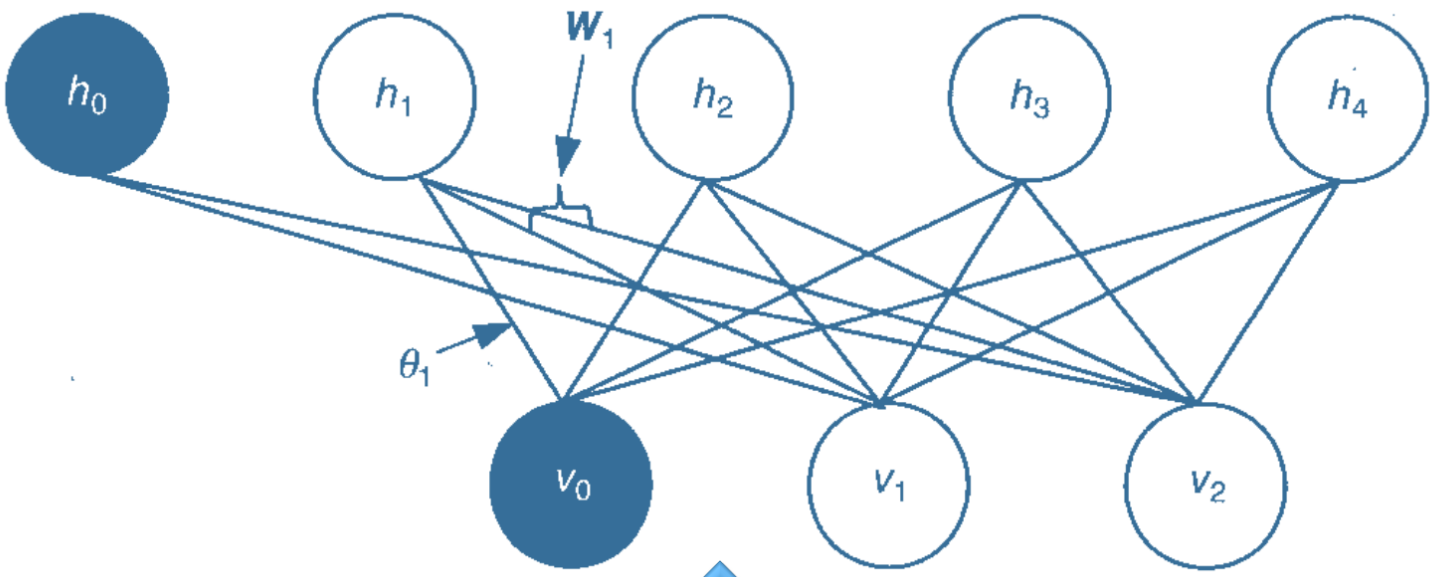
EXTRACTION

TEMPORAL LOGIC


Knowledge
Symbolic Rules
(Temporal Logic)
Rules
Neural Symbolic Cognitive Agent (NSCA)
Beliefs
Hypotheses
Binary and
Continuous Variables
Beliefs on Hypotheses
Observations
Mind

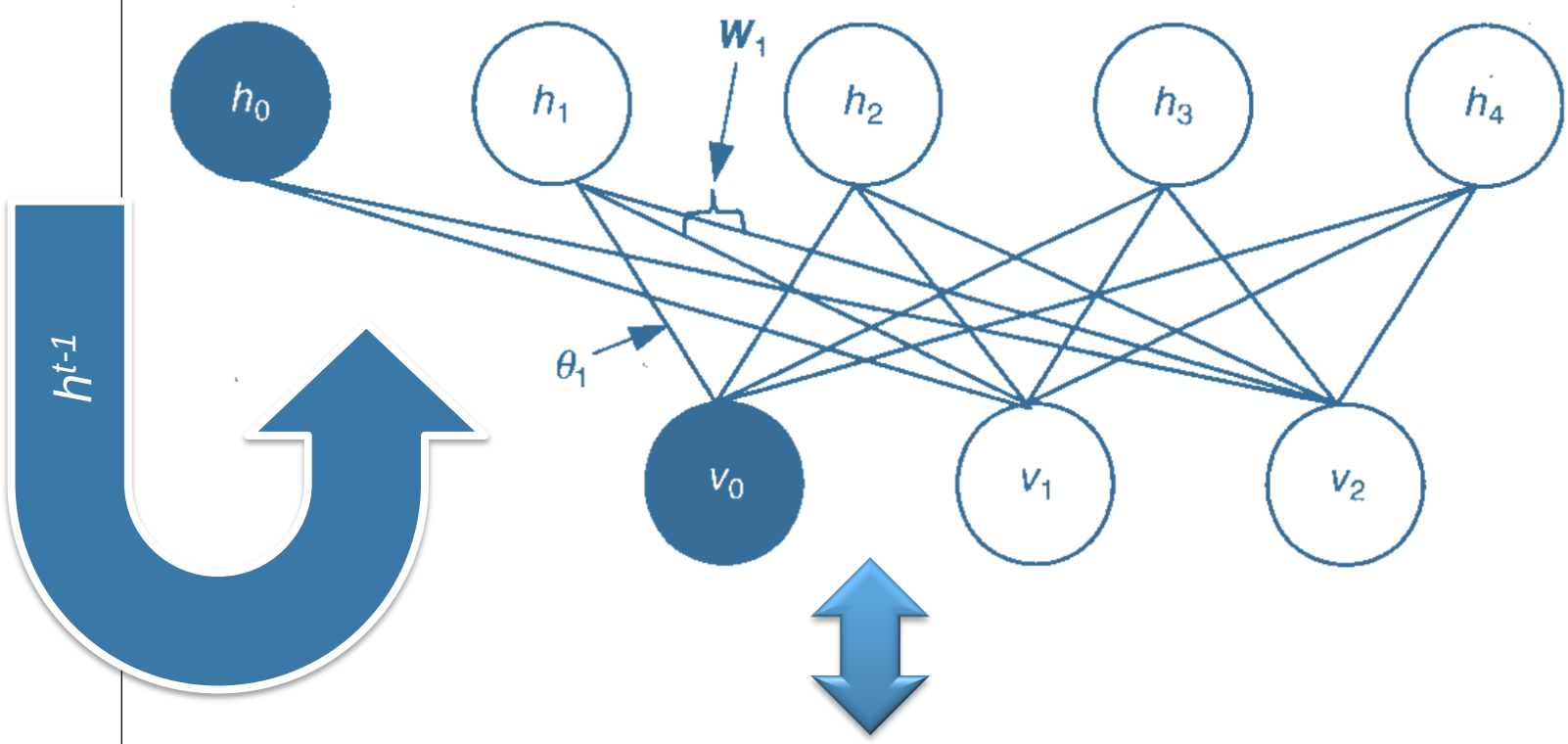

Knowledge
Symbolic Rules
(Temporal Logic)
Rules
Recurrent
Temporal Restricted
Boltzmann Machine
(RTRBM)
Beliefs
Hypotheses
Neural Symbolic Cognitive Agent (NSCA)
Binary and
Continuous Variables
Beliefs on Hypotheses
Observations
Mind

Restricted Boltzmann Machine (RBM)

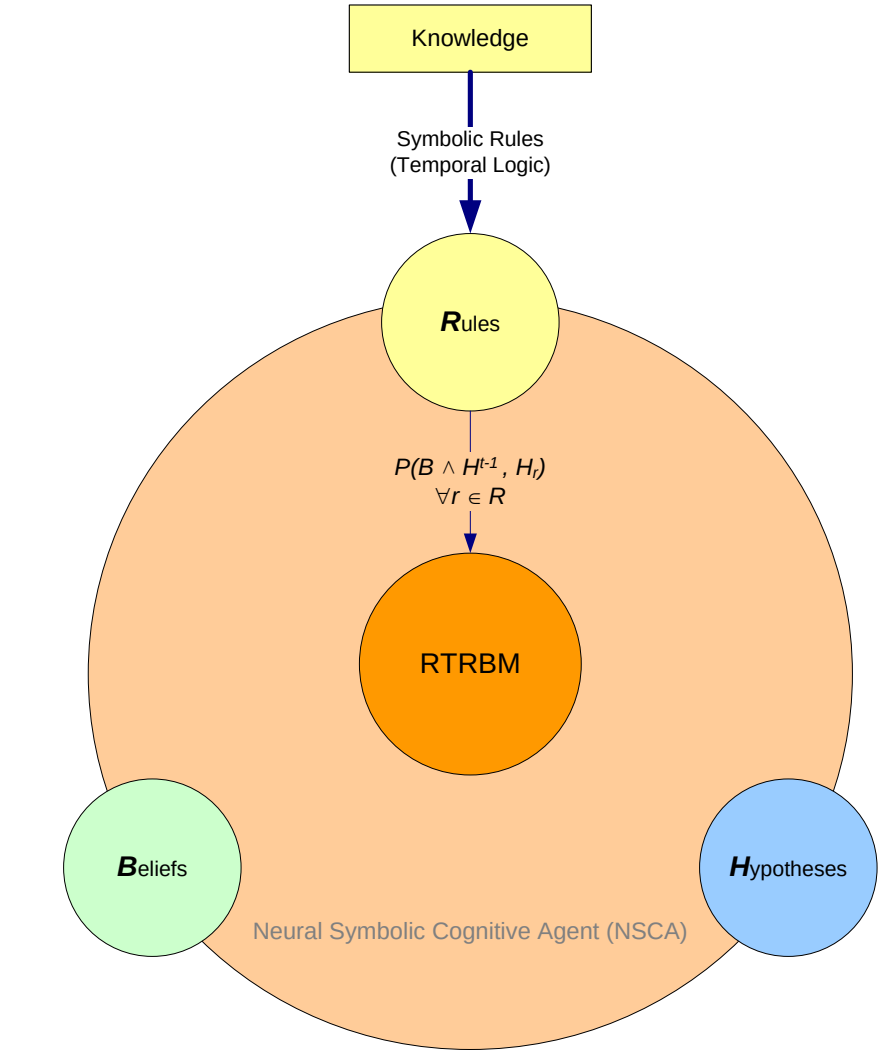


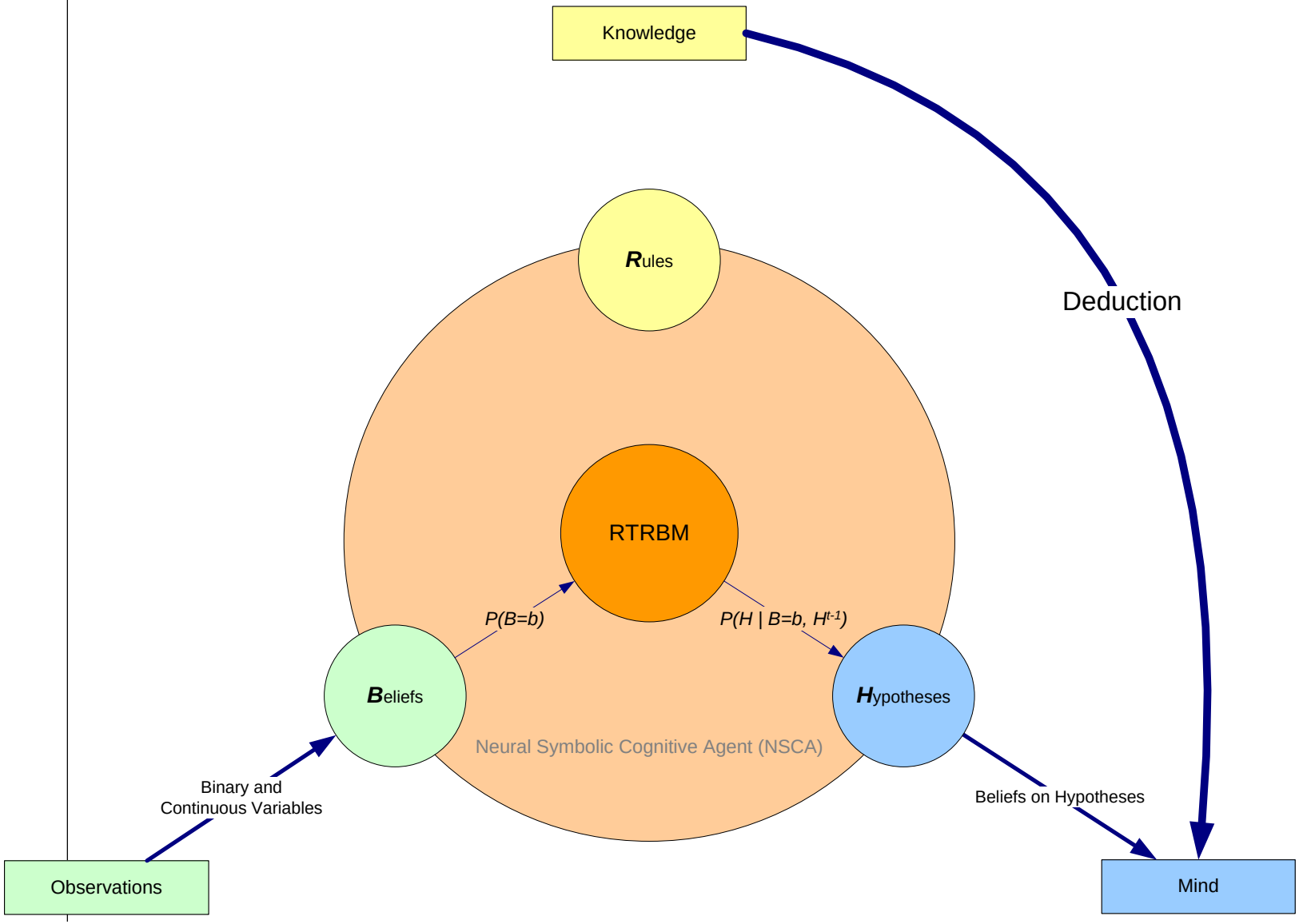
0.80: $H_0 \leftrightarrow V_0 \wedge V_2$

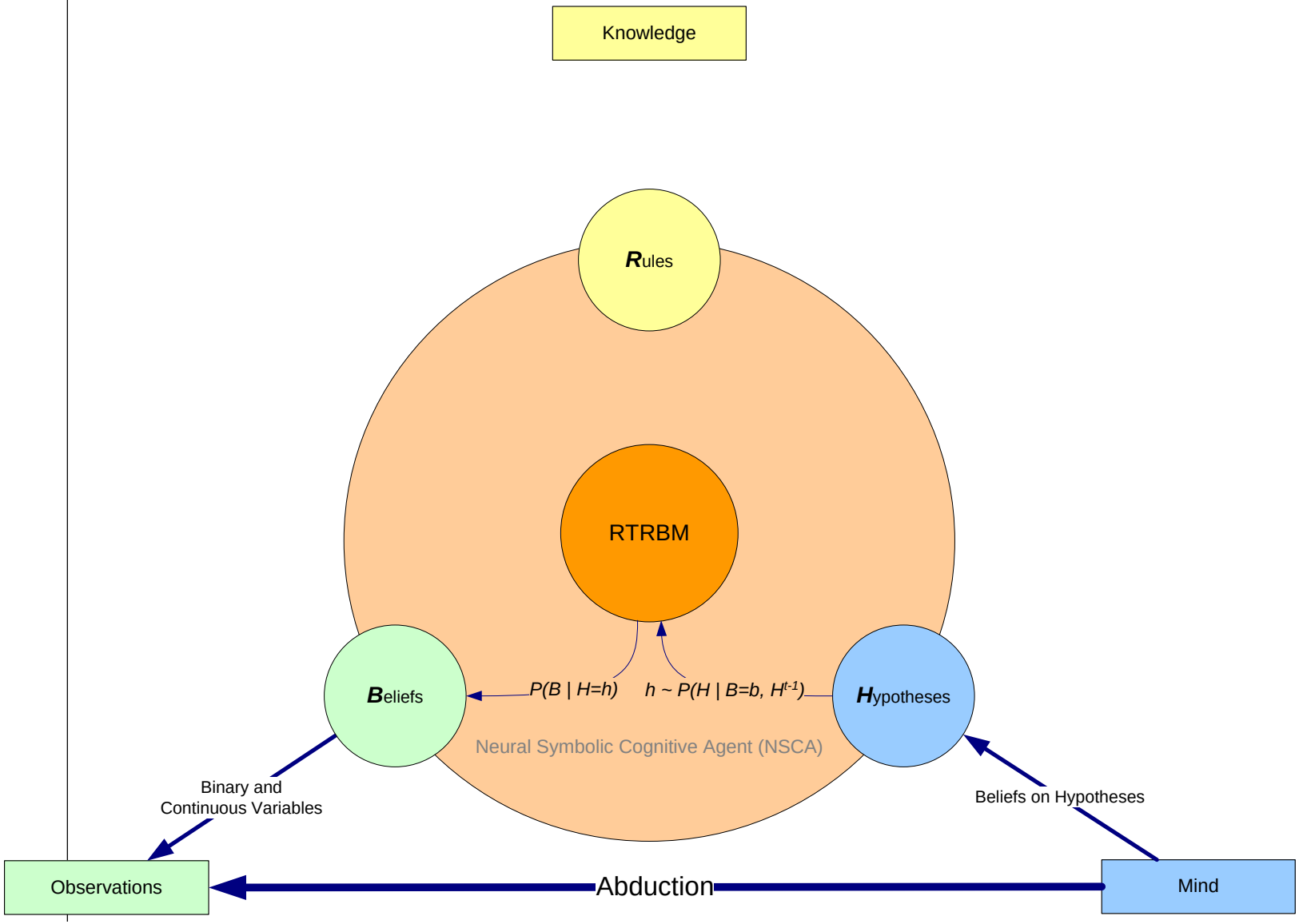
Recurrent Temporal Restricted Boltzmann Machine (RTRBM)

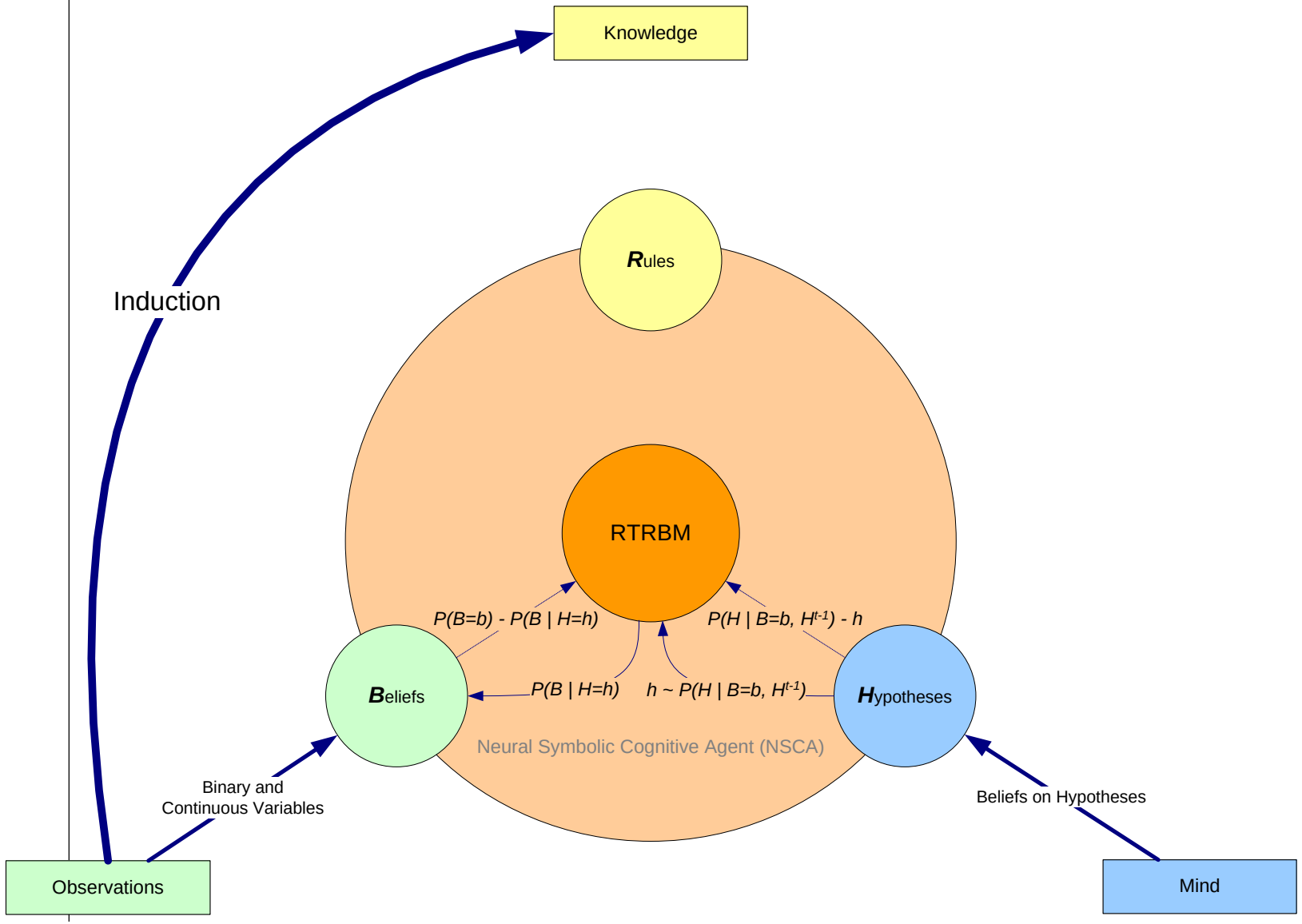


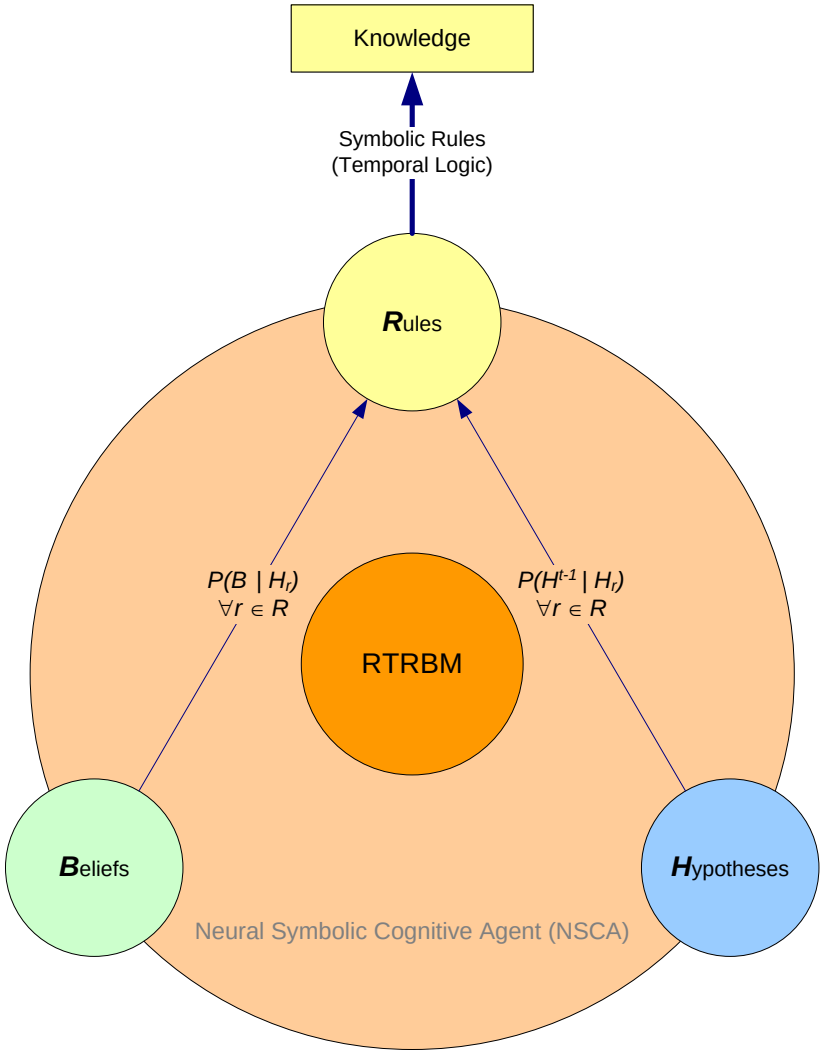
0.80: $H_0 \leftrightarrow V_0 \wedge V_2 \wedge \bullet H_2$


Knowledge
Symbolic Rules
(Temporal Logic)
Rules
$P(B \wedge H^{t-1}, H_l)$
$\forall r \in R$
RTRBM
Beliefs
Hypotheses
Neural Symbolic Cognitive Agent (NSCA)
Observations
Mind


Knowledge
Deduction
Rules
RTRBM
P(B=b)
P(H | B=b, H^t-1)
Beliefs
Hypotheses
Neural Symbolic Cognitive Agent (NSCA)
Binary and
Continuous Variables
Beliefs on Hypotheses
Observations
Mind

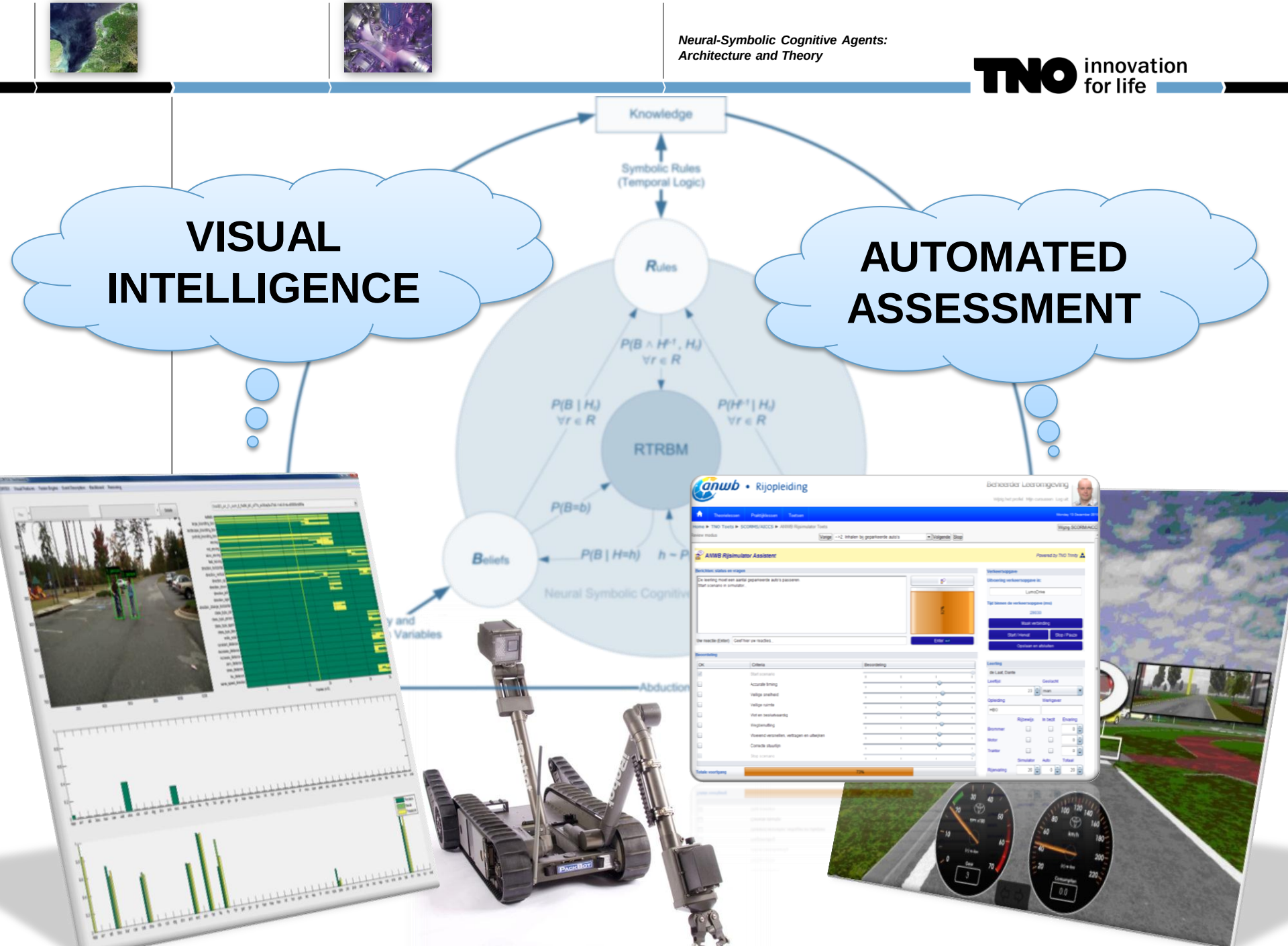

Knowledge
Rules
RTRBM
Beliefs
Hypotheses
P(B | H=h)
h ~ P(H | B=b, H^t-1)
Neural Symbolic Cognitive Agent (NSCA)
Binary and
Continuous Variables
Beliefs on Hypotheses
Observations
Abduction
Mind

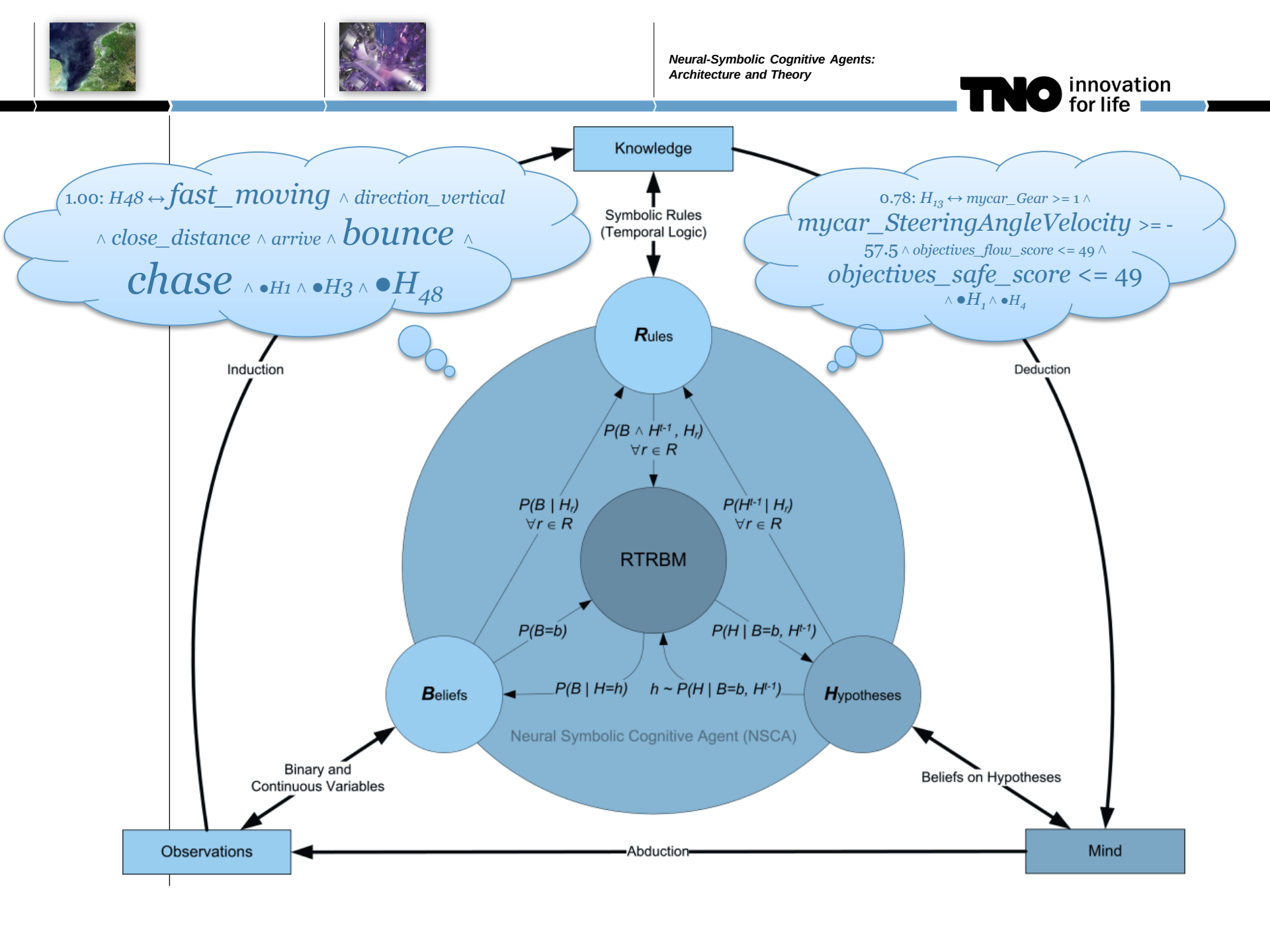

Knowledge
Induction
Rules
RTRBM
P(B=b) - P(B | H=h)
P(H | B=b, H^t-1) - h
Beliefs
P(B | H=h)
h ~ P(H | B=b, H^t-1)
Hypotheses
Neural Symbolic Cognitive Agent (NSCA)
Binary and
Continuous Variables
Beliefs on Hypotheses
Observations
Mind



Observations

Mind


Knowledge
Symbolic Rules
(Temporal Logic)
Rules
RTRBM
Beliefs
Abduction
Neural Symbolic Cognitive
VISUAL
INTELLIGENCE
AUTOMATED
ASSESSMENT
anwb • Rijopleiding
ANWB Rijsimulator Assistent


Knowledge
1.00: H48 ↔ fast_moving ∧ direction_vertical ∧ close_distance ∧ arrive ∧ bounce ∧ chase ∧ •H1 ∧ •H3 ∧ •H48
Symbolic Rules (Temporal Logic)
0.78: H13 ↔ mycar_Gear >= 1 ∧ mycar_SteeringAngleVelocity >= -57.5 ∧ objectives_flow_score <= 49 ∧ objectives_safe_score <= 49 ∧ •H1 ∧ •H4
Induction
Deduction
Rules
P(B ∧ Ht-1 , Hr) ∀r ∈ R
P(B | Hr) ∀r ∈ R
P(Ht-1 | Hr) ∀r ∈ R
RTRBM
P(B=b)
P(H | B=b, Ht-1)
Beliefs
P(B | H=h)
h ~ P(H | B=b, Ht-1)
Hypotheses
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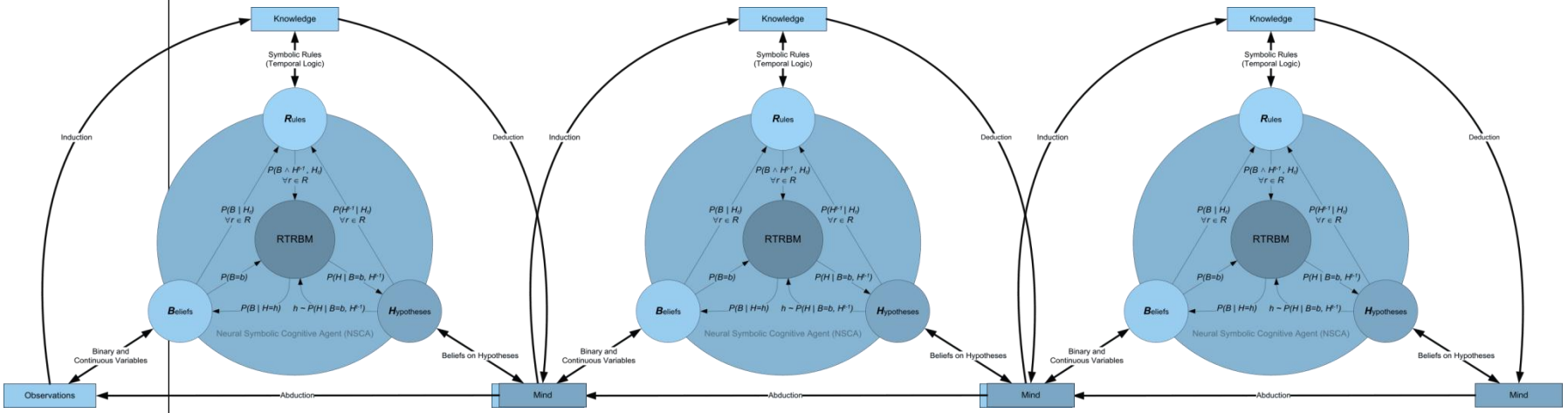
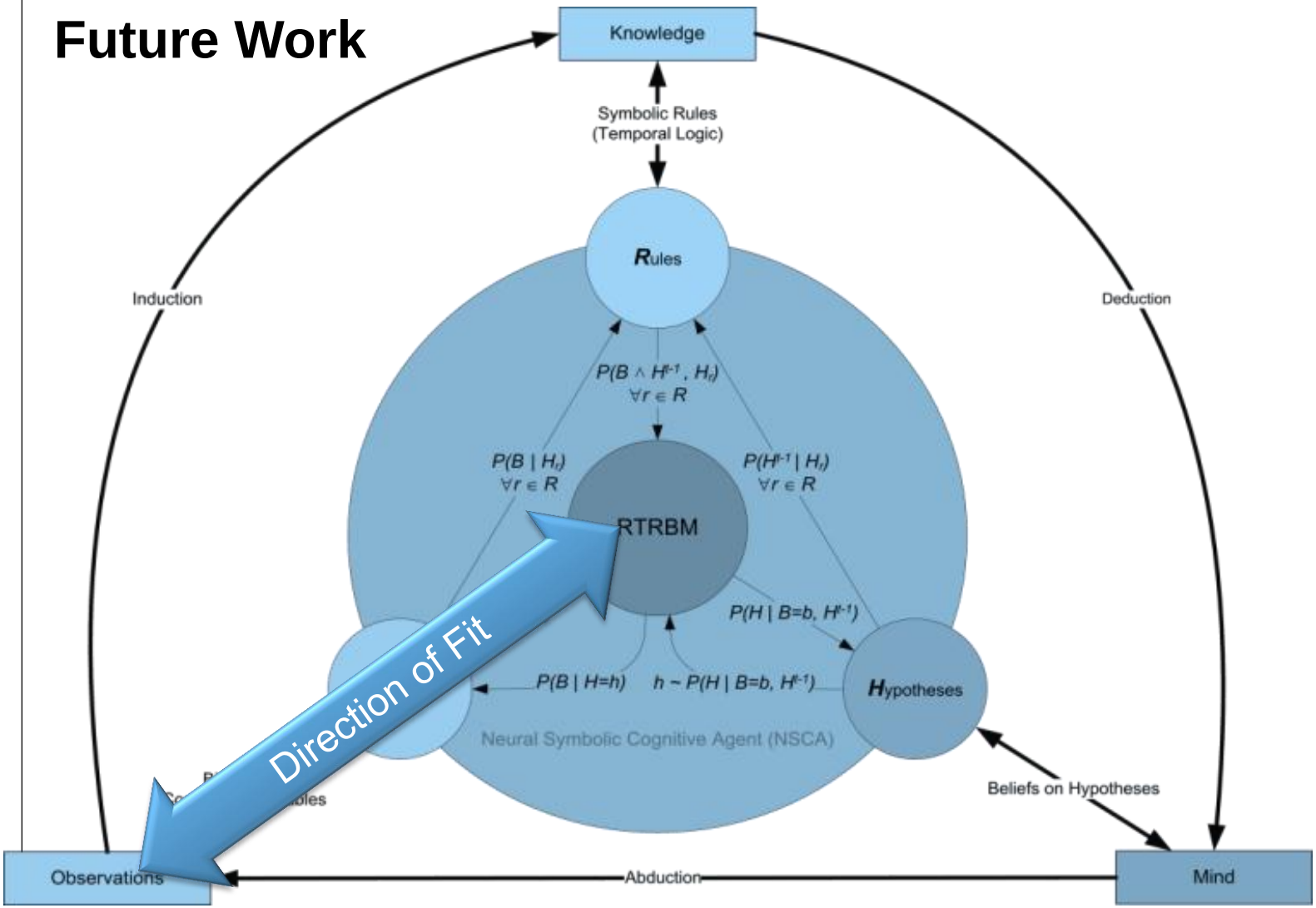
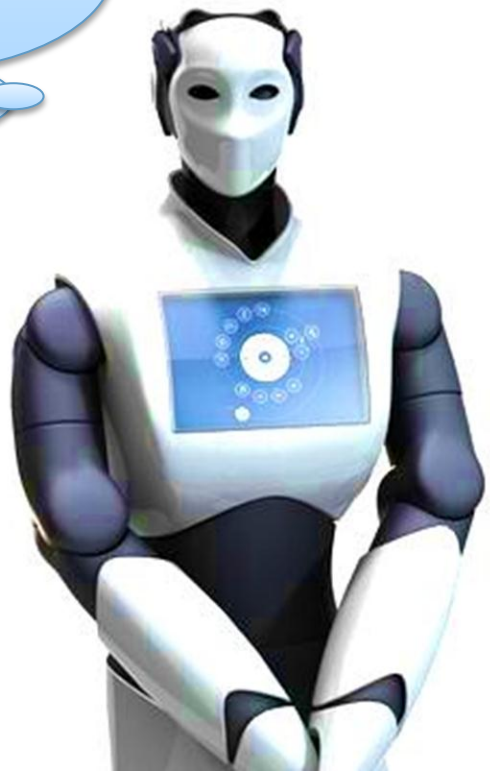
Future Work



Deep Belief Networks & Deep Reasoning

Future Work


Knowledge
Symbolic Rules
(Temporal Logic)
Rules
Induction
Deduction
$P(B \wedge H^{t-1}, H_i)$
$\forall r \in R$
$P(B \mid H_i)$
$\forall r \in R$
$P(H^{t-1} \mid H_i)$
$\forall r \in R$
RTRBM
$P(H \mid B=b, H^{t-1})$
$P(B \mid H=h)$
$h \sim P(H \mid B=b, H^{t-1})$
Hypotheses
Neural Symbolic Cognitive Agent (NSCA)
Direction of Fit
Beliefs on Hypotheses
Observations
Abduction
Mind

INTERESTED IN THE FUTURE?
CHECK OUT MY BRAIN!