

Temporal Reasoning with OpenCog

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SingularityNET & OpenCog Foundations



SingularityNET



Why Temporal Reasoning?

- 1 Lag between cause and effect
- 2 Learn and operate in the world
- 3 Meta-reasoning: Think about think about think about think about ...

PLN Recall

$P, Q, \dots: Atom^n \rightarrow \{True, False\}$ (possibly fuzzy)

And <TV>

P

≡

$$\mathcal{P}(P, Q) \approx TV.strength$$

Q

Not <TV>

P

≡

$$\mathcal{P}(P) \approx 1 - TV.strength$$

Implication <TV>

P

≡

$$\mathcal{P}(Q|P) \approx TV.strength$$

Q

PLN rules: Implication Direct Introduction

Evaluation

P

Ei

...

Evaluation

Q

Ei

|-

Implication <TV>

P

Q

$$TV.strength = \frac{\sum_x f_{\wedge}(P(x).strength, Q(x).strength)}{\sum_x P(x).strength}$$

PLN rules: Deduction

Implication

P

Q

Implication

Q

R

| -

Implication <TV>

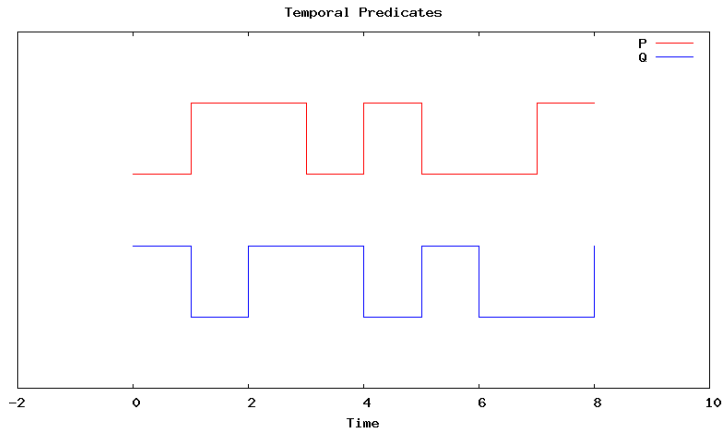
P

R

$$TV.strength = \mathcal{P}(R|Q, P) \times \mathcal{P}(Q|P) + \mathcal{P}(R|\neg Q, P) \times \mathcal{P}(\neg Q|P)$$

Temporal Predicate

$P, Q, \dots: Atom^n \times Time \rightarrow \{True, False\}$ (possibly fuzzy)



LagLink and LeadLink

- **Lag**: brings **past** into present

LagLink

P

T

≡

LambdaLink

x, t

P (x, t-T)

- **Lead**: brings **future** into present

LeadLink

P

T

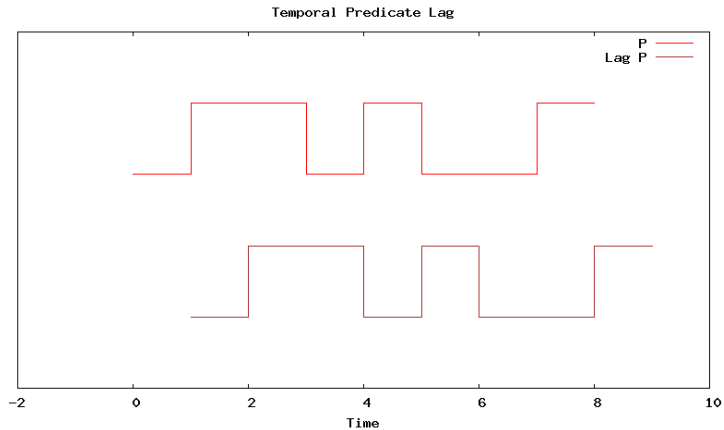
≡

LambdaLink

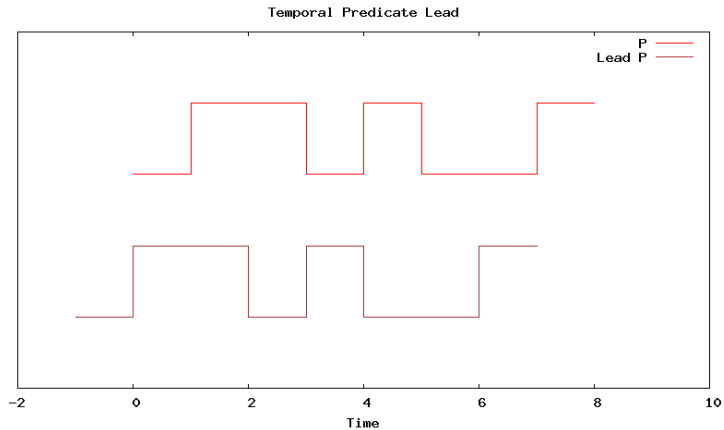
x, t

P (x, t+T)

Lag: example



Lead: example



SequentialAnd

BackSequentialAnd <TV>

T

P

Q

≡

And <TV>

Lag

P

T

Q

ForeSequentialAnd <TV>

T

P

Q

≡

And <TV>

P

Lead

Q

T

PredictiveImplication

BackPredictiveImplication <TV>

T

P

Q

≡

ForePredictiveImplication <TV>

T

P

Q

≡

Implication <TV>

Lag

P

T

Q

Implication <TV>

P

Lead

Q

T

PredictiveImplication

BackPredictiveImplication <TV>

T

P

Q

≡

ForePredictiveImplication <TV>

T

P

Q

≡

Implication <TV>

Lag

P

T

Q

Implication <TV>

P

ForeSequentialAnd

T

P

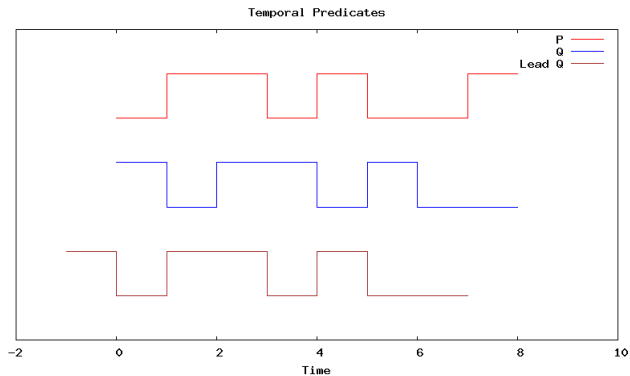
Q

Predictive Implication

Implication $\langle s=0.25 \rangle$

P

Q



Predictive Implication

Implication $\langle s=0.25 \rangle$

P

Q

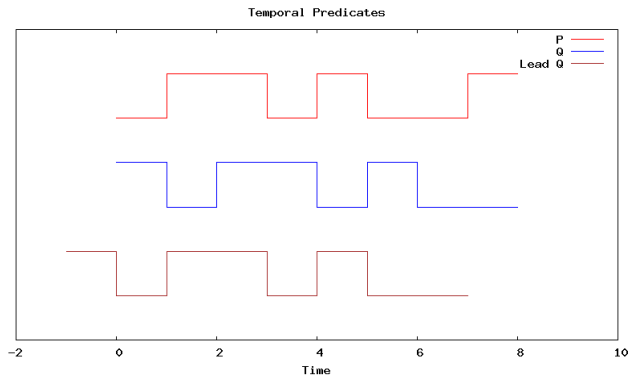
Implication $\langle s=0.75 \rangle$

P

Lead

Q

1



PredictiveImplication

Implication $\langle s=0.25 \rangle$

P

Q

Implication $\langle s=0.75 \rangle$

P

Lead

Q

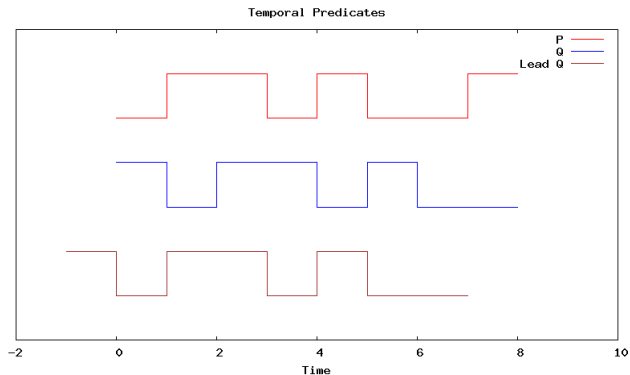
1

PredictiveImplication $\langle s=0.75 \rangle$

1

P

Q



Temporal Deduction (notations)

- Implication

P

Q

\equiv

$P \rightarrow Q$

Temporal Deduction (notations)

- Implication

P

 \equiv $P \rightarrow Q$

Q

- PredictiveImplication

T

 \equiv $P \rightsquigarrow^T Q$

P

Q

Temporal Deduction (notations)

- Implication

P

 \equiv $P \rightarrow Q$

Q

- PredictiveImplication

T

 \equiv $P \rightsquigarrow^T Q$

P

Q

- Lag

P

 \equiv \vec{P}^T

T

Temporal Deduction (notations)

- Implication

$$\begin{array}{c} P \\ \Rightarrow \\ Q \end{array} \equiv P \rightarrow Q$$

- PredictiveImplication

$$\begin{array}{c} T \\ P \\ \rightsquigarrow^T \\ Q \end{array} \equiv P \rightsquigarrow^T Q$$

- Lag

$$\begin{array}{c} P \\ \Rightarrow^T \\ T \end{array} \equiv \overrightarrow{P}^T$$

- Lead

$$\begin{array}{c} P \\ \Leftarrow^T \\ T \end{array} \equiv \overleftarrow{P}^T$$

Temporal Deduction

$$\frac{P \rightarrow Q \quad Q \rightarrow R \quad P \quad Q \quad R}{P \rightarrow R} \text{ (Deduction)}$$

Temporal Deduction

$$\frac{P \rightarrow Q \quad Q \rightarrow R \quad P \quad Q \quad R}{P \rightarrow R} \text{ (Deduction)}$$

$$\frac{P \rightsquigarrow^{T_1} Q \quad Q \rightsquigarrow^{T_2} R \quad P \quad Q \quad R}{P \rightsquigarrow^{T_1+T_2} R} \text{ (Temporal Deduction?)}$$

Temporal Deduction \mapsto Deduction

$$\begin{array}{c}
 \frac{P \rightsquigarrow^{T_1} Q}{P \rightarrow \overleftarrow{Q}^{T_1}} \text{ (PI2I)} \quad \frac{\frac{Q \rightsquigarrow^{T_2} R}{Q \rightarrow \overleftarrow{R}^{T_2}} \text{ (PI2I)}}{\overleftarrow{Q}^{T_1} \rightarrow \overleftarrow{R}^{T_1+T_2}} \text{ (TS)} \quad P \quad \frac{Q}{\overleftarrow{Q}^{T_1}} \text{ (TS)} \quad \frac{R}{\overleftarrow{R}^{T_1+T_2}} \text{ (TS)} \\
 \hline
 \frac{P \rightarrow \overleftarrow{R}^{T_1+T_2}}{P \rightsquigarrow^{T_1+T_2} R} \text{ (I2PI)}
 \end{array}
 \quad \text{(Deduction)}$$

- TS: Temporal Shift
- PI2I: PredictiveImplication to Implication
- I2PI: Implication to PredictiveImplication

Procedural Reasoning (notations)

- SequentialAnd

T

P

Q

 \equiv

$$P \prec^T Q$$

Procedural Reasoning (notations)

- SequentialAnd

T

P

Q

 \equiv $P \prec^T Q$

- Lambda

T

AtTime

Execution

A

T

 \equiv \hat{A}

Cognitive Schematics

- Monoaction plan

$$C \wedge \hat{A} \rightsquigarrow^T G$$

Cognitive Schematics

- Monoaction plan

$$C \wedge \widehat{A} \rightsquigarrow^T G$$

- Diaction plan

$$\left((C \wedge \widehat{A}_1) \prec^{T_1} \widehat{A}_2 \right) \rightsquigarrow^{T_1+T_2} G$$

Cognitive Schematics

- Monoaction plan

$$C \wedge \widehat{A} \rightsquigarrow^T G$$

- Diaction plan

$$\left((C \wedge \widehat{A}_1) \prec^{T_1} \widehat{A}_2 \right) \rightsquigarrow^{T_1+T_2} G$$

- Polyaction plan

$$\left(\left(\left(Inside \wedge \widehat{WalkToDoor} \right) \prec^2 \widehat{OpenDoor} \right) \prec^3 \widehat{StepOut} \right) \rightsquigarrow^6 Outside$$

Temporal Deduction for Procedural Reasoning

$$\begin{array}{c}
 \frac{P \wedge \hat{A} \rightsquigarrow^{T_1} Q}{P \wedge \hat{A} \rightarrow \overleftarrow{Q}^{T_1}} \text{ (PI2I)} \quad \frac{\hat{B}}{\overleftarrow{B}^{T_1}} \text{ (TS)} \\
 \frac{P \wedge \hat{A} \rightarrow \overleftarrow{Q}^{T_1} \quad \overleftarrow{B}^{T_1}}{P \wedge \hat{A} \wedge \overleftarrow{B}^{T_1} \rightarrow \overleftarrow{Q}^{T_1} \wedge \overleftarrow{B}^{T_1}} \text{ (CI)} \quad \frac{Q \wedge \hat{B} \rightsquigarrow^{T_2} R}{Q \wedge \hat{B} \rightarrow \overleftarrow{R}^{T_2}} \text{ (PI2I)} \\
 \frac{\overleftarrow{Q}^{T_1} \wedge \overleftarrow{B}^{T_1} \rightarrow \overleftarrow{R}^{T_1+T_2}}{\overleftarrow{Q}^{T_1} \wedge \overleftarrow{B}^{T_1} \rightarrow \overleftarrow{R}^{T_1+T_2}} \text{ (TS)} \quad P \wedge \hat{A} \wedge \overleftarrow{B}^{T_1} \quad \frac{Q \wedge \hat{B}}{\overleftarrow{Q}^{T_1} \wedge \overleftarrow{B}^{T_1}} \text{ (TS)} \quad \frac{R}{\overleftarrow{R}^{T_1+T_2}} \text{ (TS)} \\
 \hline
 \frac{P \wedge \hat{A} \wedge \overleftarrow{B}^{T_1} \rightarrow \overleftarrow{R}^{T_1+T_2}}{((P \wedge \hat{A}) \prec^{T_1} \hat{B}) \rightsquigarrow^{T_1+T_2} R} \text{ (I2PI)} \quad \text{(D)}
 \end{array}$$

- D: Deduction
- CI: Conjunction Introduction
- TS: Temporal Shift
- PI2I: PredictiveImplication to Implication
- I2PI: Implication to PredictiveImplication

Procedural Reasoning Example

$$\left(\left(Inside \wedge \widehat{WalkToDoor} \right) \prec^2 \widehat{OpenDoor} \right) \rightsquigarrow^3 OpenDoorStep$$

$$OpenDoorStep \wedge \widehat{StepOut} \rightsquigarrow^1 Outside$$

$$\vdash$$

$$\left(\left(\left(Inside \wedge \widehat{WalkToDoor} \right) \prec^2 \widehat{OpenDoor} \right) \prec^3 \widehat{StepOut} \right) \rightsquigarrow^6 Outside$$

Temporal and Procedural Reasoning: next steps

- More rules
 - Temporal Abduction
 - ...

Temporal and Procedural Reasoning: next steps

- More rules
 - Temporal Abduction
 - ...
- Distributional Time
 - Temporal Interval

$$(((Inside \wedge \widehat{WalkToDoor}) \prec^{[1,2]} \widehat{OpenDoor}) \prec^{[1.5,3]} \widehat{StepOut}) \rightsquigarrow^{[1.6,4]} Outside$$

- Temporal Truth Value

$$(((Inside \wedge \widehat{WalkToDoor}) \prec \widehat{OpenDoor}) \prec \widehat{StepOut}) \rightsquigarrow Outside$$

Temporal and Procedural Reasoning: next steps

- More rules
 - Temporal Abduction
 - ...
- Distributional Time
 - Temporal Interval

$$(((Inside \wedge \widehat{WalkToDoor}) \prec^{[1,2]} \widehat{OpenDoor}) \prec^{[1.5,3]} \widehat{StepOut}) \rightsquigarrow^{[1.6,4]} Outside$$

- Temporal Truth Value

$$(((Inside \wedge \widehat{WalkToDoor}) \prec \widehat{OpenDoor}) \prec \widehat{StepOut}) \rightsquigarrow Outside$$

- Behavior Tree

$$(((Inside \wedge \widehat{WalkToDoor}) \prec (\widehat{Locked} ? \widehat{SmashDoor} : \widehat{OpenDoor})) \prec \widehat{StepOut}) \rightsquigarrow Outside$$

Conclusion

Demo Time