Temporal and Procedural Reasoning with OpenCog

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SingularityNET & OpenCog Foundations

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

```
And <TV>
  P
  Q
```
$\equiv$ $\mathcal{P}(P, Q) \approx TV.strength$

```
Not <TV>
  P
```
$\equiv$ $\mathcal{P}(P) \approx 1 - TV.strength$

```
Implication <TV>
  P
  Q
```
$\equiv$ $\mathcal{P}(Q|P) \approx TV.strength$

PLN rules: Implication Direct Introduction

```
Evaluation
  P
  Ei
...
Evaluation
  Q
  Ei
|-
Implication <TV>
  P
  Q
```

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

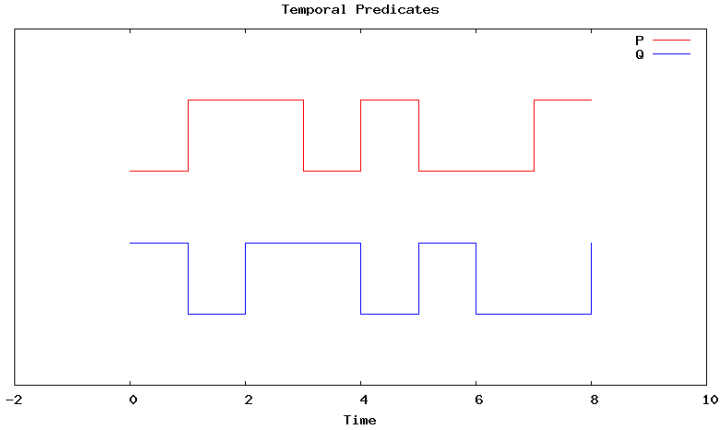
PLN rules: Deduction

```
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

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



LagLink and LeadLink

- Lag: brings past into present

```
LagLink
  P
  T
```

≡

```
LambdaLink
  x, t
  P(x, t-T)
```

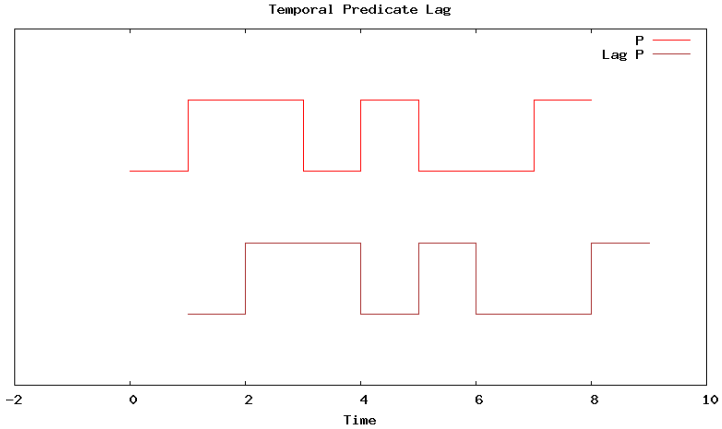
- Lead: brings future into present

```
LeadLink
  P
  T
```

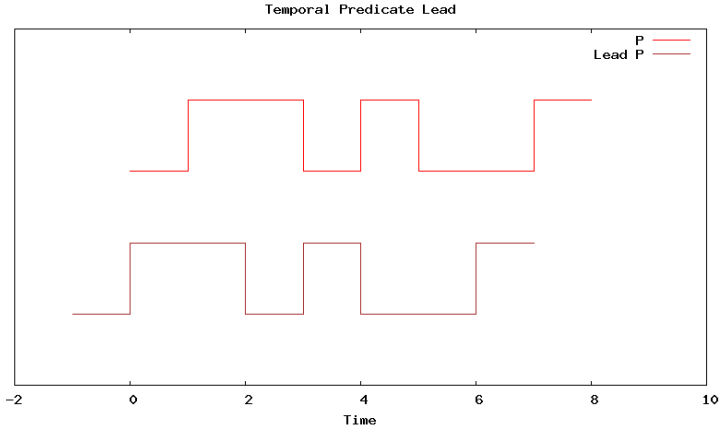
≡

```
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
```

```
Implication <TV>
  Lag
    P
    T
  Q
```

```
ForePredictiveImplication <TV>
  T
  P                          ≡
  Q
```

```
Implication <TV>
  P
  Lead
    Q
    T
```

PredictiveImplication

```
BackPredictiveImplication <TV>
  T
  P                          ≡
  Q
```

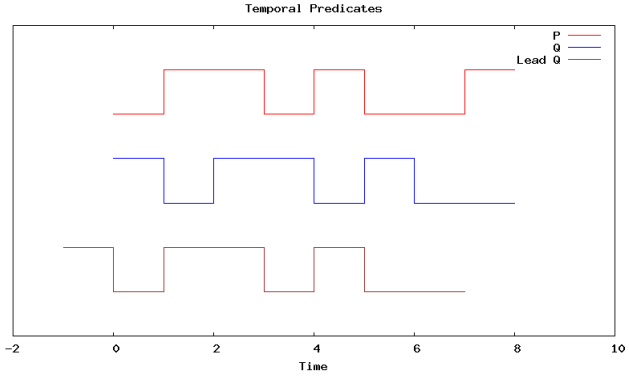
```
Implication <TV>
  Lag
    P
    T
  Q
```

```
ForePredictiveImplication <TV>
  T
  P                          ≡
  Q
```

```
Implication <TV>
  P
  ForeSequentialAnd
    T
    P
    Q
```

PredictiveImplication

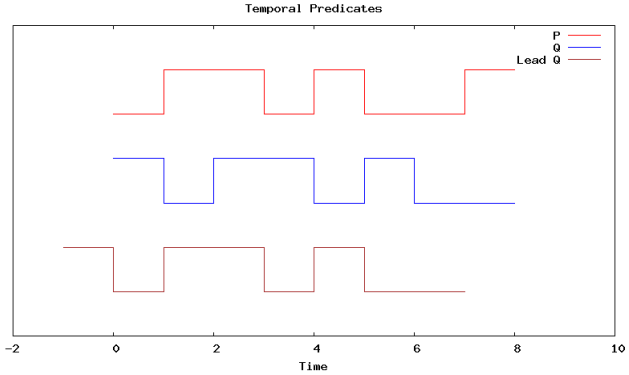
```
Implication <s=0.25>
  P
  Q
```



PredictiveImplication

```
Implication <s=0.25>
  P
  Q

Implication <s=0.75>
  P
  Lead
    Q
    1
```

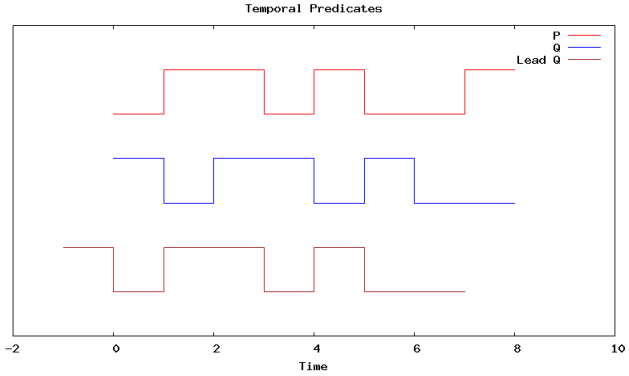


PredictiveImplication

```
Implication <s=0.25>
  P
  Q

Implication <s=0.75>
  P
  Lead
    Q
    1

PredictiveImplication <s=0.75>
  1
  P
  Q
```



Temporal Deduction (notations)

- `Implication`
  `P`
  `Q` $\equiv$ $P \rightarrow Q$

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- `Implication`
  `P`
  `Q` $\equiv$ $P \rightarrow Q$
- `PredictiveImplication`
  `T`
  `P`
  `Q` $\equiv$ $P \rightsquigarrow^{T} Q$

Temporal Deduction (notations)

- `Implication`
  `P`
  `Q`
  $\equiv$ $P \rightarrow Q$
- `PredictiveImplication`
  `T`
  `P`
  `Q`
  $\equiv$ $P \rightsquigarrow^{T} Q$
- `Lag`
  `P`
  `T`
  $\equiv$ $\overrightarrow{P}^{T}$

Temporal Deduction (notations)

- `Implication`
  `P`
  `Q` $\equiv$ $P \rightarrow Q$
- `PredictiveImplication`
  `T`
  `P`
  `Q` $\equiv$ $P \rightsquigarrow^{T} Q$
- `Lag`
  `P`
  `T` $\equiv$ $\overrightarrow{P}^{T}$
- `Lead`
  `P`
  `T` $\equiv$ $\overleftarrow{P}^{T}$

Temporal Deduction

$$\frac{P \to Q \qquad Q \to R \qquad P \qquad Q \qquad R}{P \to R} \text{ (Deduction)}$$

Temporal Deduction

$$\frac{P \to Q \qquad Q \to R \qquad P \qquad Q \qquad R}{P \to R} \text{ (Deduction)}$$

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

Temporal Deduction $\mapsto$ Deduction

$$\dfrac{\dfrac{P \rightsquigarrow^{T_1} Q}{P \rightarrow \overleftarrow{Q}^{T_1}}\,(\text{PI2I}) \quad \dfrac{\dfrac{Q \rightsquigarrow^{T_2} R}{Q \rightarrow \overleftarrow{R}^{T_2}}\,(\text{PI2I})}{\overleftarrow{Q}^{T_1} \rightarrow \overleftarrow{R}^{T_1+T_2}}\,(\text{TS}) \quad P}{\dfrac{P \rightarrow \overleftarrow{R}^{T_1+T_2}}{P \rightsquigarrow^{T_1+T_2} R}\,(\text{I2PI})} \quad \dfrac{Q}{\overleftarrow{Q}^{T_1}}\,(\text{TS}) \quad \dfrac{R}{\overleftarrow{R}^{T_1+T_2}}\,(\text{TS}) \quad (\text{Deduction})$$

- 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

  $\equiv$ $\widehat{A}$

Cognitive Schematics

- Monoaction plan

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

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

- 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

$$\dfrac{\dfrac{\dfrac{P \wedge \widehat{A} \rightsquigarrow^{T_1} Q}{P \wedge \widehat{A} \rightarrow \overleftarrow{Q}^{T_1}}\,(\text{PI2I}) \quad \dfrac{\widehat{B}}{\overleftarrow{\widehat{B}}^{T_1}}\,(\text{TS})}{P \wedge \widehat{A} \wedge \overleftarrow{\widehat{B}}^{T_1} \rightarrow \overleftarrow{Q}^{T_1} \wedge \overleftarrow{\widehat{B}}^{T_1}}\,(\text{CI}) \quad \dfrac{\dfrac{Q \wedge \widehat{B} \rightsquigarrow^{T_2} R}{Q \wedge \widehat{B} \rightarrow \overleftarrow{R}^{T_2}}\,(\text{PI2I})}{\overleftarrow{Q}^{T_1} \wedge \overleftarrow{\widehat{B}}^{T_1} \rightarrow \overleftarrow{R}^{T_1+T_2}}\,(\text{TS}) \quad P \wedge \widehat{A} \wedge \overleftarrow{\widehat{B}}^{T_1} \quad \dfrac{Q \wedge \widehat{B}}{\overleftarrow{Q}^{T_1} \wedge \overleftarrow{\widehat{B}}^{T_1}}\,(\text{TS}) \quad \dfrac{R}{\overleftarrow{R}^{T_1+T_2}}\,(\text{TS})}{\dfrac{P \wedge \widehat{A} \wedge \overleftarrow{\widehat{B}}^{T_1} \rightarrow \overleftarrow{R}^{T_1+T_2}}{\left((P \wedge \widehat{A}) \prec^{T_1} \widehat{B}\right) \rightsquigarrow^{T_1+T_2} R}\,(\text{I2PI})}\,(\text{D})$$

- 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

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

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

  - Temporal Truth Value

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

- Behavior Tree

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

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

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

- Dependent Truth Value (or Density Truth Value)

Conclusion

Demo Time