Realizing Default Logic over Description Logic Knowledge Bases

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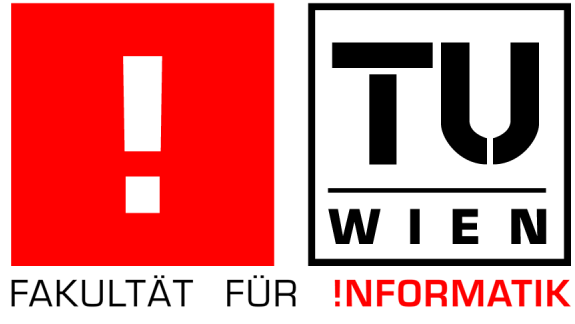
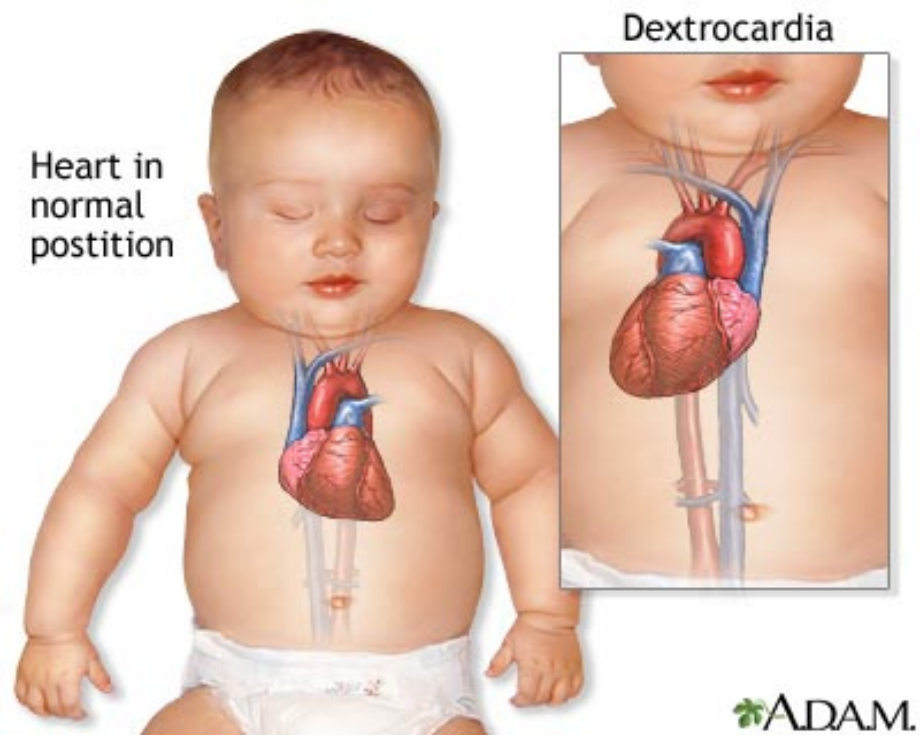


The need of common-sense reasoning on top of ontologies



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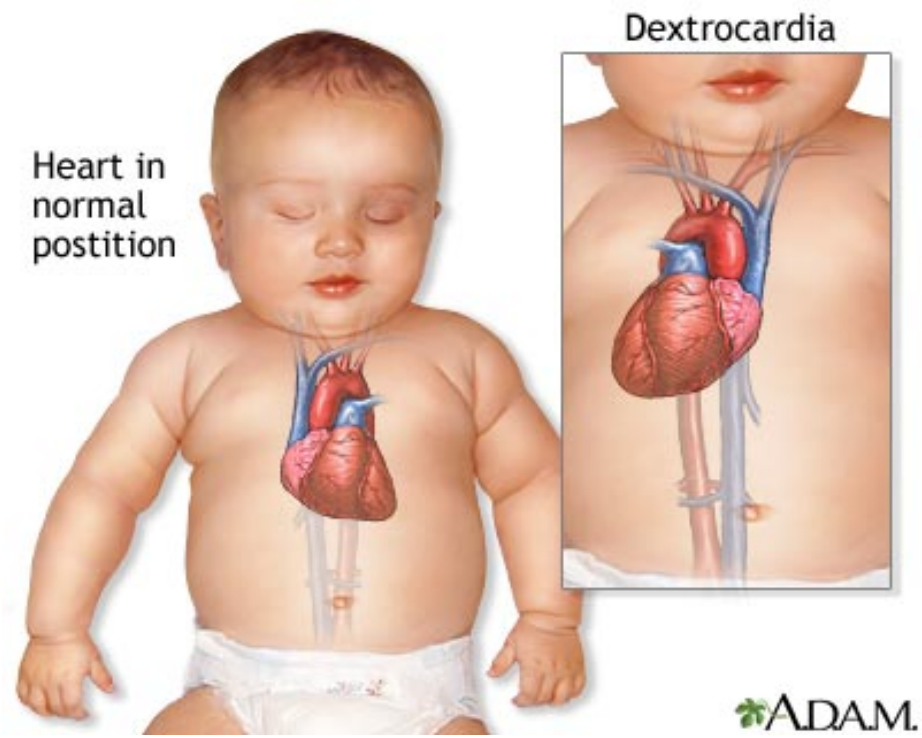

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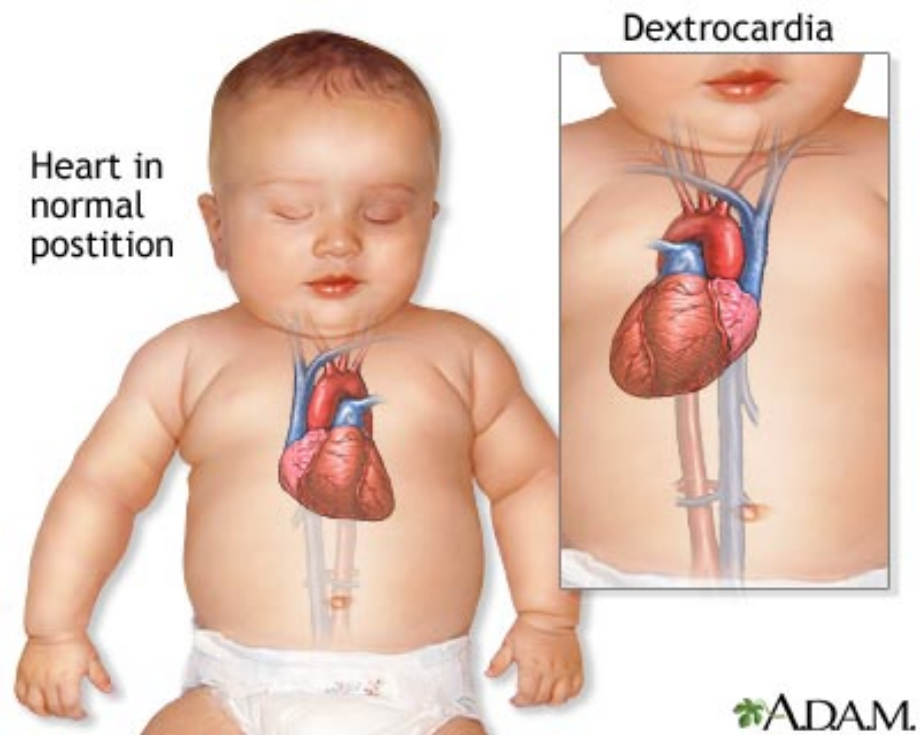

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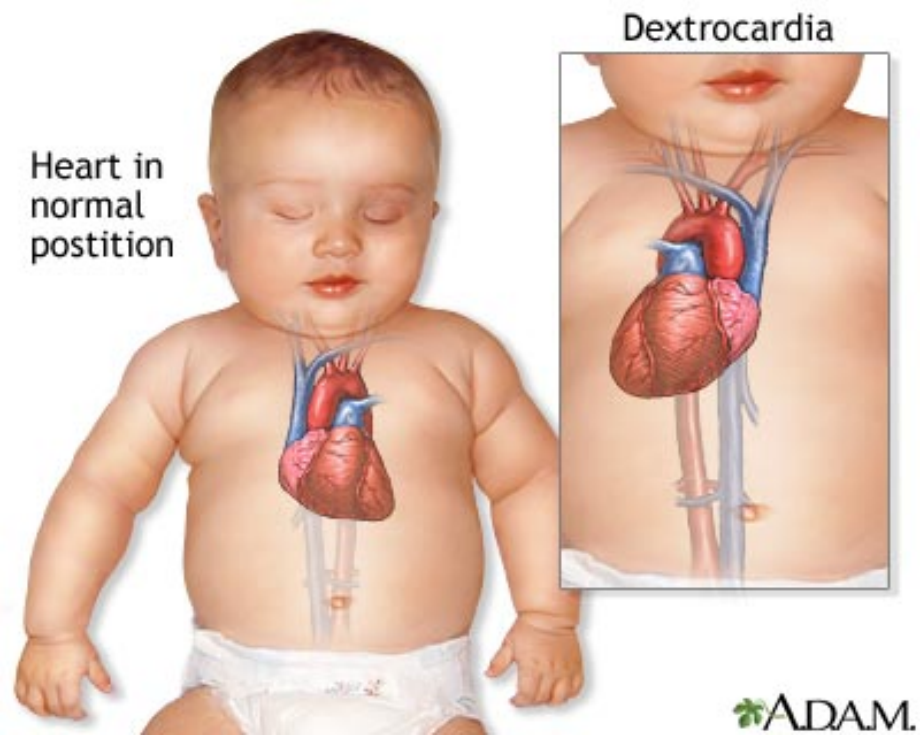

- *default reasoning* on top of ontologies?

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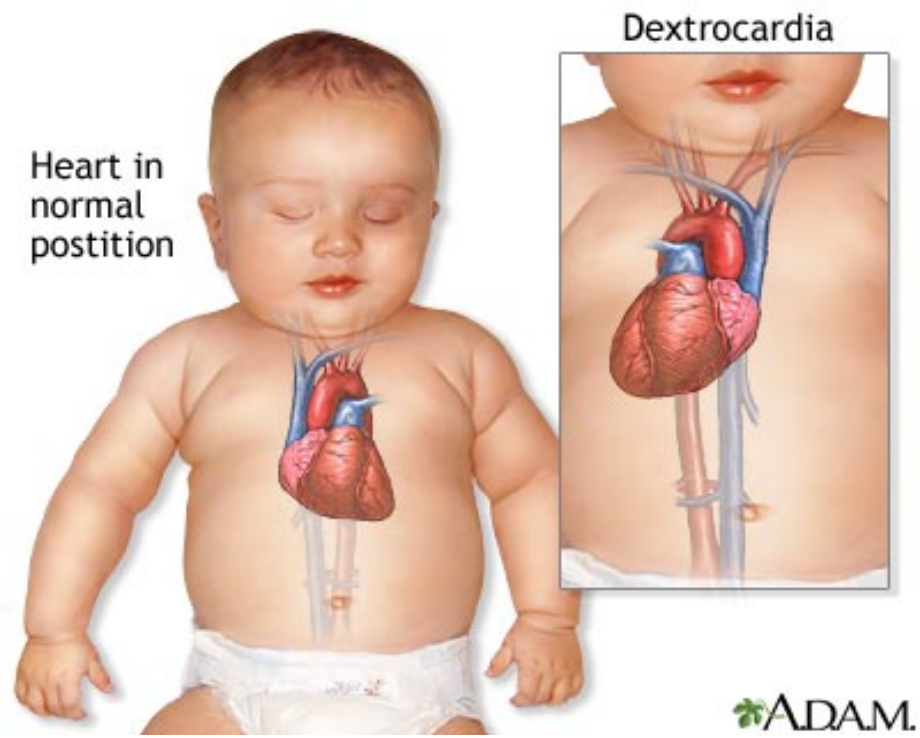

- *default reasoning* on top of ontologies?
- *integrations of rules and ontologies*: *cq-programs*

Description Logic Knowledge Bases (DL-KBs)

Syntax and Semantics

Name	Syntax	Semantics
Top/Bottom	$\top / \bot$	$\Delta^{\mathcal{I}} / \emptyset$
Intersection	$C \sqcap D$	$C^{\mathcal{I}} \cap D^{\mathcal{I}}$
Union	$C \sqcup D$	$C^{\mathcal{I}} \cup D^{\mathcal{I}}$
Negation	$\neg C$	$\Delta^{\mathcal{I}} \setminus C^{\mathcal{I}}$
Value restriction	$\forall R.C$	$\{a \in \Delta^{\mathcal{I}} \mid \forall b.(a,b) \in R^{\mathcal{I}} \rightarrow b \in C^{\mathcal{I}}\}$
Existential quant.	$\exists R.C$	$\{a \in \Delta^{\mathcal{I}} \mid \exists b.(a,b) \in R^{\mathcal{I}} \wedge b \in C^{\mathcal{I}}\}$

Modeling: TBox & ABox

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Modeling: TBox & ABox

Translation to first-order logic

$$\pi_x(A) = A(x)$$
$$\pi_x(C \sqcap D) = \pi_x(C) \wedge \pi_x(D) \qquad \pi_x(\forall R.C) = \forall y.R(x,y) \supset \pi_y(C)$$
$$\pi_x(C \sqcup D) = \pi_x(C) \vee \pi_x(D) \qquad \pi_x(\exists R.C) = \forall y.R(x,y) \wedge \pi_y(C)$$

Default Theories over DL-KBs $\Delta = \langle L, D \rangle$

similar to [Baader and Hollunder, 1995]

Default rule

$$\frac{\overbrace{\alpha_1(\vec{X_1}) \wedge \cdots \wedge \alpha_k(\vec{X_k})}^{\alpha(\vec{X})} : \beta_1(\vec{Y_1}), \ldots, \overbrace{\beta_{i,1}(\vec{Y}_{i,1}) \wedge \cdots \wedge \beta_{i,\ell_i}(\vec{Y}_{i,\ell_i})}^{\beta_i(\vec{Y}_i)}, \ldots, \beta_m(\vec{Y_m})}{\underbrace{\gamma_1(\vec{Z_1}) \wedge \cdots \wedge \gamma_n(\vec{Z_n})}_{\gamma(\vec{Z})}}$$

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Semantics: based on the Γ_Δ *operator*

- Let S be a set of assertions, then $\Gamma_\Delta(S)$ is the smallest set that
  - contains $Cn(L)$
  - is deductively closed
  - if $\alpha(\vec{X}) \in \Gamma_\Delta(S)$ and $\neg\beta_i(\vec{Y}_i) \notin S$, then $\gamma(\vec{Z}) \in \Gamma_\Delta(S)$

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- E is an *extension* of Δ iff $\Gamma_\Delta(E) = E$

Example

$$\Delta = \langle L, D \rangle$$

$$L = \left\{ \begin{array}{l} Flier \sqsubseteq \neg NonFlier, Penguin \sqsubseteq Bird, \\ Penguin \sqsubseteq NonFlier, Bird(tweety) \end{array} \right\}$$

$$D = \left\{ \frac{Bird(X) : Flier(X)}{Flier(X)} \right\}$$

$$E = Cn(L \cup \{Flier(tweety)\})$$

Example

$$\Delta' = \langle L', D \rangle$$

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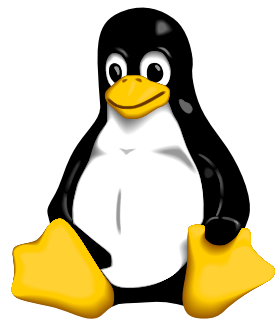

$$E' = Cn(L')$$

Conjunctive Query Programs [Eiter *et al.*, 2008a]

- (union of) conjunctive queries:

$$q(X) = \{X \mid AirCraft(X) \vee (UFO(X) \wedge \neg Hoax(X))\}$$

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- cq-rule:

$$flying\_thing(X) \leftarrow thing(X),$$
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- cq-program: $KB = (L, P)$ — based on *answer set semantics*

Answer Set Semantics of cq-Programs

generalized [Gelfond and Lifschitz, 1991]

P is a set of rules of form $a \leftarrow b_1, \ldots, b_m, \text{not } c_1, \ldots, \text{not } c_n.$

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  P^I is constructed by
  - removing rules $r \in P$ such that $c_i \in I$
  - removing all c_i and nonmonotonic cq-atoms from remaining rules

Transformation Ω (inspired by [Eiter *et al.*, 2008b])

D is a set of defaults of form

$$\frac{\alpha(\vec{X}) : \beta_1(\vec{Y}_1), \ldots, \overbrace{\beta_{i,1}(\vec{Y}_{i,1}) \wedge \cdots \wedge \beta_{i,\ell_i}(\vec{Y}_{i,\ell_i})}^{\beta_i(\vec{Y}_i)}, \ldots, \beta_m(\vec{Y}_m)}{\underbrace{\gamma_1(\vec{Z}_1) \wedge \cdots \wedge \gamma_n(\vec{Z}_n)}_{\gamma(\vec{Z})}}$$

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- Concluding rules $\mathcal{R} = \{in_{\gamma_i}(\vec{Z}_i) \leftarrow in_{\gamma}(\vec{Z}) \mid 1 \leq i \leq n\}$
- A rule which simulates the Γ_Δ operator

$$in_\gamma(\vec{Z}) \leftarrow \mathrm{DL}[\lambda; \alpha(\vec{X})](\vec{X}),$$
$$\mathrm{not\ DL}[\lambda; \neg\beta_{1,1}(\vec{Y}_{1,1}) \vee \cdots \vee \neg\beta_{1,\ell_1}(\vec{Y}_{1,\ell_1})](\vec{Y}_1),$$
$$\vdots$$
$$\mathrm{not\ DL}[\lambda; \neg\beta_{m,1}(\vec{Y}_{m,1}) \vee \cdots \vee \neg\beta_{m,\ell_m}(\vec{Y}_{m,\ell_m})](\vec{Y}_m).$$

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where $\lambda = (\gamma_i^* \uplus in_{\gamma_i}, \gamma_i^* \uplus in_{\neg\gamma_i} \mid \delta \in D)$; γ_i^* is γ_i without $\neg$

Transformation Ω - Bird Example

$$in_{Flier}(X) \leftarrow \mathrm{DL}[Flier \uplus in_{Flier}, Flier \uplus in_{\neg Flier}; Bird(X)](X),$$
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Add $\left\{ \begin{array}{r} in_{\neg Flier}(X) \leftarrow broken\_wing(X). \\ broken\_wing(tweety). \end{array} \right\}$

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Add $\left\{ \begin{array}{r} in_{\neg Flier}(X) \leftarrow broken\_wing(X). \\ broken\_wing(tweety). \end{array} \right\}$

Then $I_\Omega = \{broken\_wing(tweety), in_{\neg Flier}(tweety)\}$; $E_\Omega = Cn(L)$

Transformation Υ

based on [Cholewinski and Truszczynski, 1994]

- Concluding rules $\mathcal{R} = \{in_{\gamma_i}(\vec{Z}_i) \leftarrow in_{\gamma}(\vec{Z}) \mid 1 \leq i \leq n\}$

Transformation Υ

based on [Cholewinski and Truszczynski, 1994]

- Concluding rules $\mathcal{R} = \{in_{\gamma_i}(\vec{Z}_i) \leftarrow in_{\gamma}(\vec{Z}) \mid 1 \leq i \leq n\}$
- Rules that select justifications:

$$cons_{\beta_i}(\vec{Y}_i) \leftarrow \text{ not } \overline{cons}_{\beta_i}(\vec{Y}_i).$$
$$\overline{cons}_{\beta_i}(\vec{Y}_i) \leftarrow \text{ not } cons_{\beta_i}(\vec{Y}_i).$$

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Transformation Υ - cont.

- Constraints that check the compliance of our guess with the result

$$fail \leftarrow \mathrm{DL}[\lambda; \neg\beta_{i,1}(\vec{Y}_{i,1}) \vee \cdots \vee \neg\beta_{i,\ell_i}(\vec{Y}_{i,\ell_i})](\vec{Y}_i), cons_{\beta_i}(\vec{Y}_i), \text{not } fail.$$

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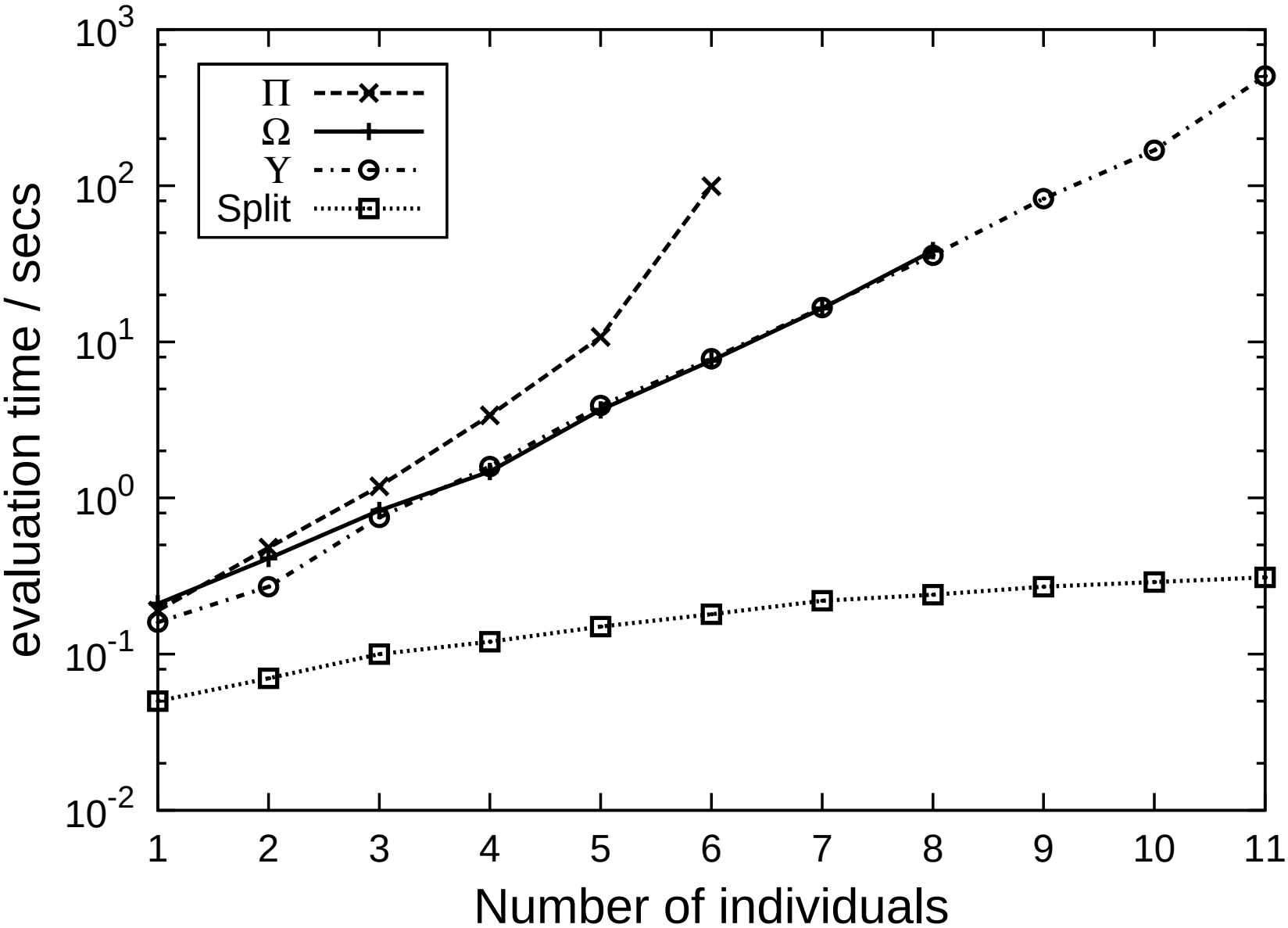
$L = L \cup \{Penguin(tweety)\}$, then $I_\Upsilon = \{\overline{cons}_{Flier}(tweety)\}$; $E_\Omega = Cn(L)$

Comparison


Π
Ω
Υ
Split
evaluation time / secs
Number of individuals
10^3
10^2
10^1
10^0
10^-1
10^-2
1
2
3
4
5
6
7
8
9
10
11

Conclusion & Future Work

- Conclusions:
  - Consider default theories over DL-KBs $\Delta = \langle L, D \rangle$
  - Adapt Reiter's Default Logic using Γ_Δ operator
  - Two new transformations to cq-programs (Ω and Υ)
  - Ω and Υ perform better than an old transformation in [Eiter *et al.*, 2008b]

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  - Consider default theories over DL-KBs $\Delta = \langle L, D \rangle$
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- Future work:
  - Investigate special default theories (normal/semi-normal defaults)
  - Implement caching for cq-programs
  - Interface to different DL-reasoners, eg., Pellet, KAON2

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