Labelled Variables in Logic Programming:

A First Prototype in tuProlog

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Outline

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2. The Labelled Variables Model in Logic Programming
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   - Examples
3. Prototype in tuProlog
   - System architecture
   - The language extension
4. Case studies
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   - Dress Selection
5. Conclusions & Further Work

Context and Motivation

Explore models and technologies to face the challenges of *pervasive system*

- complex
- distributed
- situated
- intelligent

From *distributed intelligence* towards *distributed situated intelligence*

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situated (intelligent) component for pervasive (intelligent) systems
Logic Programming (LP) extensions for *interacting* with the *environment*

Prodromes of situated LP

- Forms of control which generalises data-driven computation, e.g. CLP [Jaffar and Lassez, 1987]
- Ability to be domain-specific – e.g. CHR [Fruhwirth, 1998]

However they are designed against a landscape different from nowadays pervasive systems.

Archeology

[Jaffar and Lassez, 1987] defines CLP as a merger of two declarative paradigms: constraint solving and logic programming $\rightarrow$ capability for reasoning in the *specific finite domain* of application

[Fruhwirth, 1998] introduces CHR as a high-level and declarative language for implementing constraint solver. *User-defined constraints* led to widely domain applications (constraint solving, type checking, natural language processing, multi-agent systems,...)

[Neumerkel, 1990] presentes metastructures to extend syntactic unification: data types whose (unification) semantics are specified by *user-defined predicates*

[Holzbaur, 1992] introduces attributed variables as mechanism to *support of CLP languages*, yet inside the LP context

[Gabbay, 1996] introduces Labelled Deductive System: general notion of label and a *new unifying methodology* for logic

Goals

Aim

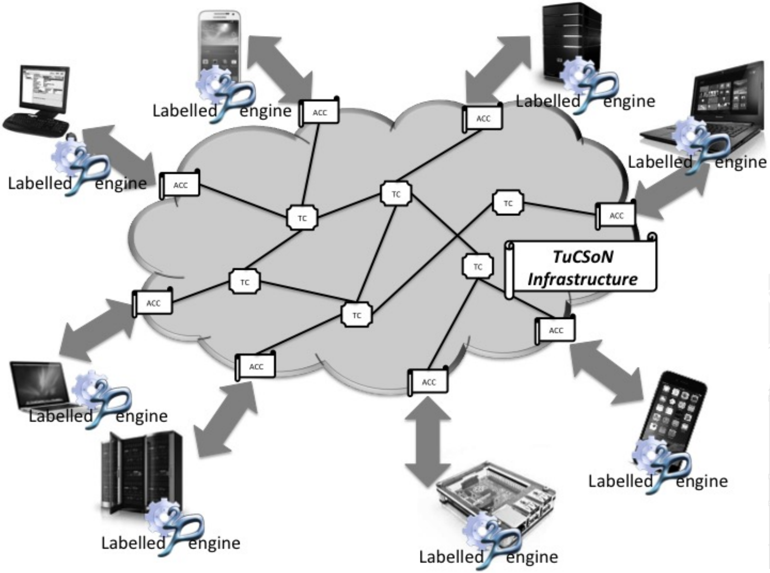
- To devise out simple and expressive *mechanisms* enabling *data-driven and domain specific within a LP framework*
- To acquire information from any source of data (constraint store, data base, sensors,...) $\rightarrow$ infer knowledge

Method

Investigating LP extension based on *labelled variables*

1. To define a *labelled variables logic programming* model where labels are exploited to define computations in *domain-specific contexts*
2. To exploit labelled variables for enabling computations at a separate level, while retaining the general coherence of the LP approach
3. To present a first prototype of Labelled tuProlog

Conceptual Architecture



Outline

The Labelled Variables Model in Logic Programming

Defined by:

- a set of *basic labels* $\mathscr{B}$, where $b \in \mathscr{B}$ is the generic *basic label* here taking the form of a logic term, i.e. $\mathscr{B} \subseteq \mathscr{T}$;
- a set of *labels* $\mathscr{L}$, where $l \in \mathscr{L}$ is a generic *label* defined as a *set of basic labels*, i.e. $l = \{b_1, .., b_n\}$;
- a *labelling association* denoted as $\langle v, l \rangle$ that associates the label l to the variable v.

Unification of two labelled variables

Represented by tuple **(true/false, θ, label)**:

- *true/false* represents if there is an answer
- θ represents the most general substitution
- *label* represents the new label associated to the unified variables

Outline

Unification Rules

Combining function

f_L to synthesise a new label from two given ones. i.e. combine two different labels:

$$f_L : \mathscr{L} \text{x} \mathscr{L} \rightarrow \mathscr{L}$$

The function embeds the *scenario-specific criterion* for defining a new label $\rightarrow$ *domain specific* computation

T_2 \ T_1	constant C_2	variable X_2	labelled variable X_2^{l2}	compund term S_2
constant C_1	true if $C_1 = C_2$	true - $\{X_2/C_1\}$	false	false
variable X_1	true - $\{X_1/C_2\}$	true - $\{X_1/X_2\}$	true - $\{X_1/X_2\} - l_2$	true - $\{X_1/S_2\}$
labelled variable X_1^{l1}	false	true - $\{X_1/X_2\}$ - l_1	true if not $\{\,\}$ - $\{X_1/X_2\} - f_L(l_1, l_2)$	false
compund term S_1	false	true - $\{X_2/S_1\}$	false	true if S_1 and S_2 unify

Outline

Examples I

Arithmetic Inequalities 1/2

- Basic labels are arithmetic intervals: $b \in \mathscr{B}$ takes one of the following forms (where a_3, a_5 can also be $-\infty$, while a_4, a_8 can also be $+\infty$)

$$b = [a_1, a_2] = \{x \in \mathbb{R} \mid a_1 \leq x \leq a_2, a_1, a_2 \in \mathbb{R}\}$$
$$b =]a_3, a_4[= \{x \in \mathbb{R} \mid a_3 < x < a_4, a_3, a_4 \in \mathbb{R}\}$$
$$b =]a_5, a_6] = \{x \in \mathbb{R} \mid a_5 < x \leq a_6, a_5, a_6 \in \mathbb{R}\}$$
$$b = [a_7, a_8[= \{x \in \mathbb{R} \mid a_7 \leq x < a_8, a_7, a_8 \in \mathbb{R}\}$$

- The *combining function* f_L intersects intervals
  Given $l_1 = \{b_{11}, ..b_{1n}\}$ and $l_2 = \{b_{21}, ..b_{2m}\}$, the resulting label defined as the union of all the possible intersections:

$$f_L : (l_1, l_2) = f_L(\{b_{11}, ..b_{1n}\}, \{b_{21}, ..b_{2m}\}) =$$
$$\{\{(b_{11} \cap b_{21}) \cup .. \cup (b_{11} \cap b_{2m})\}, ..., \{(b_{1n} \cap b_{21}) \cup .. \cup (b_{1n} \cap b_{2m})\}\}$$

Examples II

Arithmetic Inequalities 2/2

For instance, let X and Y two variables involved in two inequalities, with the following constraints:

$$X^{\{[3..5],[9..10]\}} \qquad Y^{\{[8..10]\}}$$

If these labels are eventually combined, the new label l_3 obtained by applying f_L results:

$$l_1 = \{[3..5],[9..10]\}$$
$$l_2 = \{[8..10]\}$$
$$l_3 = f_L(l_1, l_2) = f_L(\{[3..5],[9..10]\},[8..10]) =$$
$$= \{([3..5] \cap [8..10]) \cup ([9..10] \cap [8..10])\} = [9..10]$$

Examples III

RGB colour space 1/2

- Basic labels assume the syntax of RGB triplet, so that

$$b = (r, g, b) = \{r, g, b \in \mathbb{N} \mid 0 \leq r, g, b \leq 255\}$$

- Label $l \in \mathscr{L}$ becomes the singleton

$$l = (r, g, b)$$

- The *combining function* f_L is supposed to blend colours according to the specific application needs: computing the arithmetic mean of the colour component labels

$$f_L(l_1, l_2) = f_L((r_1, g_1, b_1), (r_2, g_2, b_2)) = \left(\frac{r_1 + r_2}{2}, \frac{g_1 + g_2}{2}, \frac{b_1 + b_2}{2}\right) = l_3$$

Examples IV

RGB colour space 2/2

Let X represent a red object, Y a yellow one and Z a blue one:

$$X^{(255,0,0)} \quad Y^{(255,255,0)} \quad Z^{(0,0,255)}$$

Combining X with Y according to the combine criterion embedded in f_L leads to:

$$l_1 = (255, 0, 0) \qquad l_2 = (255, 255, 0)$$

$$l_3 = f_L(l_1, l_2) = ((255, 0, 0), (255, 255, 0)) = (255, 128, 0) = l_3$$

Combining X with Z, instead, would lead to a violet label

$$l_4 = (128, 0, 128)$$

Outline

Outline

System architecture

tuProlog Architecture

- minimal Prolog virtual machine
- available as a self-contained object
- featuring a simple interface
- dynamically linkable and dischargeable libraries of predicates

Labelled tuProlog extension

- libraries of Prolog predicates
- suitable Java methods

⇒

Extend the built-in unification by user-definition semantics

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enabling data-driven & domain specific computation

Outline

The language extension I

The Prolog language level

Variable/Label association — `label_associate(+Var, +Label)`
to associate variable *Var* to label *Label* — as °/2 operator

Function f_L — `label_generate(+Label1, +Label2, -Label3)`
to specify how to build a new label from two given ones

Label-interpreted terms — `label_interpret(+Label, +Term)`
to enable terms to influence label computation, i.e. to be interpreted in the labels world
success if *Term* can potentially be unified with *Label* in the label world, fail otherwise – only if this check succeeds, the labelled variable is actually unified with the term.

The language extension II

The Java language level

Variable/Label association — `Label`
is a just a new property of the existing `Variable` class

Function f_L — `Label labelGenerate(Label l1, Label l2)`
Java method to embed f_L behaviour

Label-interpreted terms — `boolean labelInterpret(Label l, Term t)`
to enable terms to be interpreted in labels world

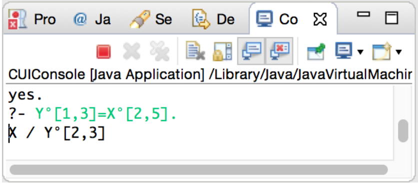
The abstract class `LabelUnifier` is provided for the user's convenience: to define a new Labelled Variable Model, the user can just extend it.

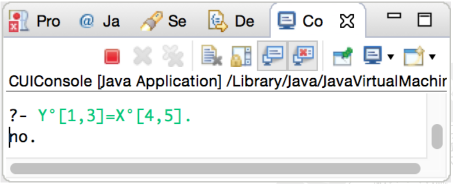
Outline

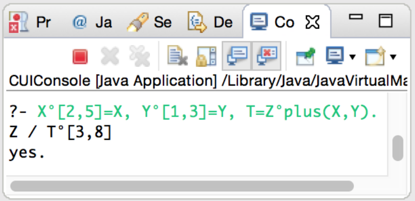
Outline

Interval CLP

- Variables are labelled with their admissible numeric interval—that is, `X°[A,B]` means that `X` can span over the range $[A..B]$
- Unification succeeds if two numeric intervals overlap, in which case the intersected interval is the newly-computed label.







Outline

Dress Selection Colour Constraints I

- The goal is to select from the wardrobe all the shirts that respect some given colour constraints: domain of labels → shirts and colours
- `shirt(`*Colour*`,`*Description*`)` represents a shirt with of colour *Colour* (in RGB `rgb(`*Red*`,`*Green*`,`*Blue*`)`), described by *Description*
- Wardrobe content representation:
  - shirt($A^{rgb(255,240,245)}$, pink_blouse).
  - shirt($B^{rgb(255,222,173)}$, yellow_tshirt).
  - shirt($C^{rgb(119,136,153)}$, army_tshirt).
  - shirt($D^{rgb(188,143,143)}$, periwinkle_blouse).
  - shirt($E^{rgb(255,245,238)}$, cream_blouse).
- Two RGB colours are considered similar if their distance is below a given threshold

Dress Selection Colour Constraints II

- f_L function, checking if two given labels are to be considered similar:

$$f_L(c_1, c_2) = \begin{cases} c_2 & \text{if } \mathit{euclidean\_distance}(c_1, c_2) \leq \mathit{threshold} \in [0..100] \\ \{\} & \text{if } \mathit{euclidean\_distance}(c_1, c_2) > \mathit{threshold} \in [0..100] \end{cases}$$

No constraints on target colour

```
CUIConsole [Java Application] /Library/Java/JavaVirtu
?- shirt(Colour, Desc).
Desc / pink_blouse
 ? ;
Desc / yellow_tshirt
 ? ;
Desc / army_tshirt
 ? ;
Desc / periwinkle_blouse
 ? ;
Desc / cream_blouse
 ? ;
no.
```

Target colour papaya

```
CUIConsole [Java Application] /Library/Java/JavaVirtualMa
?- shirt(Colour°rgb(255,239,213), Desc).
Desc / pink_blouse
 ? ;
Desc / yellow_tshirt
 ? ;
Desc / cream_blouse
 ? ;
no.
```

Outline

Conclusions

- We presented the new Labelled tuProlog
- Our first step for making logic-based technologies fit the requirements of nowadays pervasive system

Labelled tuProlog

Making it possible to spread intelligence via a light-weight Prolog engine supporting domain-specific situated computations via labelled variables

Further Work

Several extensions and further comparisons, in different directions, are worth considering, we intend to:

- formalise, with Labelled tuProlog, some well-known scenarios like Constraints Logic Programming, Attributed Variable and Modal Logic
- extend labelling to formulas $\rightarrow$ we believe the issue of applying labels to formulas, as suggested by [Gabbay, 1996], can open the way to more complex scenarios like fuzzy logic and stochastic computing
- analyse and integrate other LP frameworks
- explore and model, with Labelled tuProlog, domain specific application (e.g. health-care, home-based devices, sensor networks,...)

Thanks

Thank you for your attention

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