A Framework for Easing the Development of Applications Embedding Answer Set Programming*

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Outline

Introduction

Answer Set Programming (ASP)

The Framework

- Abstract Architecture
- Implementing embASP

Embedding ASP Programs

ASP-based Applications

Related Work

Conclusions

Introduction

Motivations

- *Declarative* and *Imperative* languages integration
- *Answer Set Programming (ASP)* is mature for practical applications and it is used all around the world
- Ease the development of *ASP-based applications*, in both educational and real-world contexts
- Separation of Concerns (or Levels of Analysis)

- ICT industry is moving towards the mobile scenario
- Lack of works about ASP systems natively running on *mobile devices*

Contributions

- EMBASP: an abstract framework for the integration of ASP in external systems for generic applications
- An actual Java implementation of the framework with specialized libraries for two state-of-the-art ASP systems
- Some fully functional applications developed in the educational context

Answer Set Programming (ASP)

ASP - Introduction

A purely *declarative* AI formalism for *Knowledge Representation and Reasoning* developed in the field of *Logic Programming and Nonmonotonic Reasoning*

- language based on *rules*, allowing for both *disjunction in rule heads* and *nonmonotonic negation in the body*
- use *logic program* to represent a given computational problem
- an *answer set solver* is used to find the *models*, called *answer sets*, which correspond one-to-one to solutions of the computational problem

ASP - Syntax i

As in the ASP-Core-2 standard [CFG+12]

- A *term* is a variable or a constant
- An *atom* is $a(t_1, \ldots, t_n)$, where
    - a is a *predicate* of arity n
    - $t_1, \ldots, t_n$ are *terms*
- A *literal* is either
    - *positive literal* p
    - or a *negative literal* `not` p

  where p is an *atom*.

ASP - Syntax ii

A (*disjunctive*) *rule* r is of the form

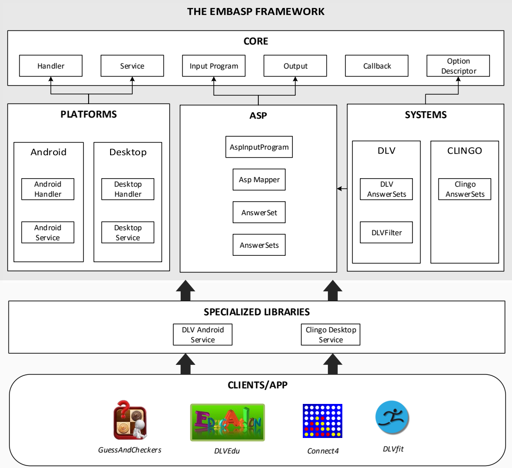
$$\underbrace{a_1 | \ldots | a_n}_{\text{head}} \text{:-}\ \underbrace{b_1, \ldots, b_k, \texttt{not}\ b_{k+1}, \ldots, \texttt{not}\ b_m.}_{\text{body}}$$

where:

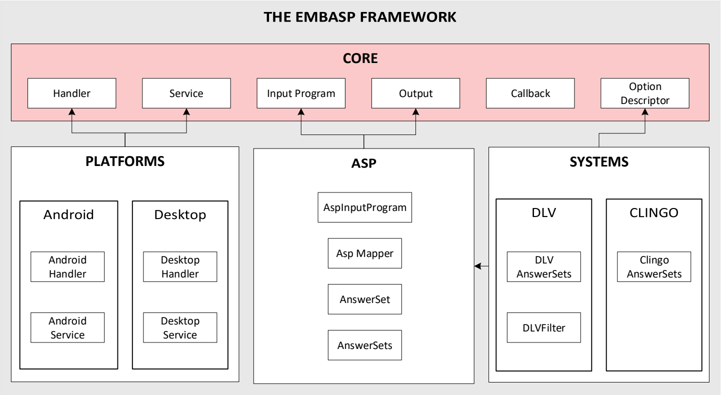
- $a_1, \cdots, a_n, b_1, \cdots, b_m$ are atoms and $n \geq 0$, $m \geq k \geq 0$
- $a_1 \mid \cdots \mid a_n$ is the *head* of r
- $b_1, ..., b_k,$ `not` $b_{k+1}, ...,$ `not` b_m is the *body* of r
- If the *head* is empty (i.e. $n = 0$), it is called an *integrity constraint*
- If the *body* is empty (i.e. $k = m = 0$), it is called a *fact*
- $H(r)$ denotes the set $\{a_1, ..., a_n\}$ of the head atoms
- $B(r)$ the set $\{b_1, ..., b_k, \texttt{not}\ b_{k+1}, \ldots, \texttt{not}\ b_m\}$ of the body literals
- $B^+(r)$ (resp., $B^-(r)$) denotes the set of atoms occurring positively (resp., negatively) in $B(r)$
- A rule r is *safe* if each variable appearing in r appears also in $B^+(r)$

The Framework

EMBASP - A visual overview

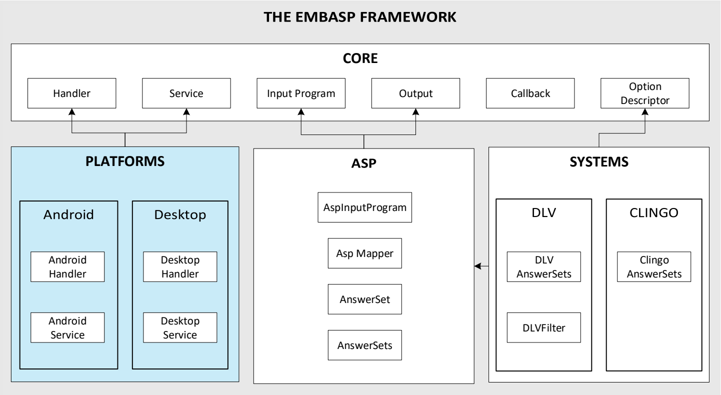


EMBASP - *Core*



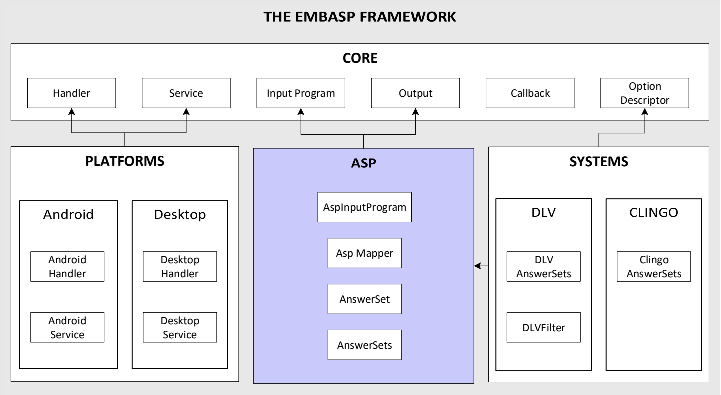
Defines the basic components of the *Framework*

EMBASP - *Platforms*



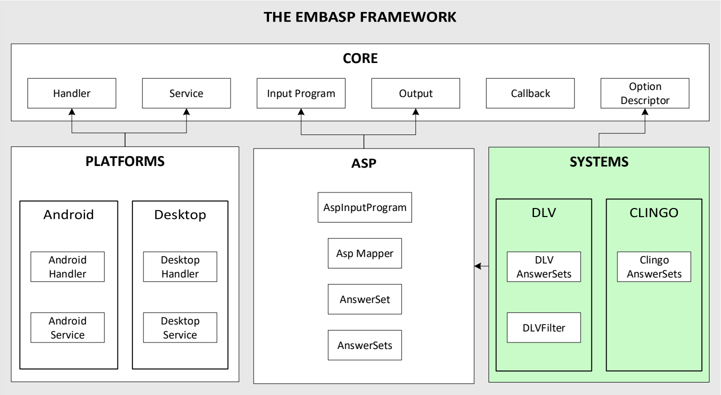
Contains what is platform-dependent

EMBASP - *ASP Language*



Defines specific facilities for ASP

EMBASP - *Systems*

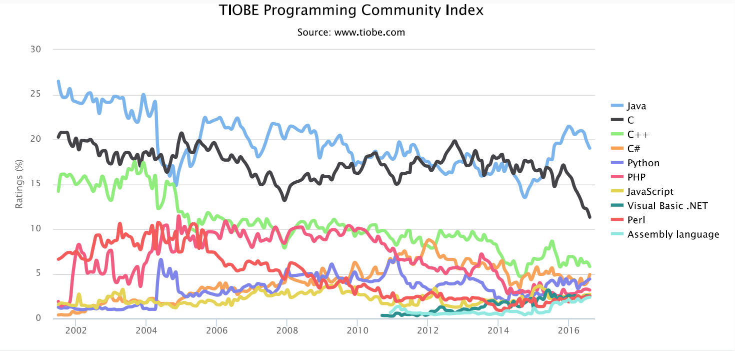


Defines what is system-dependent

Implementing EMBASP

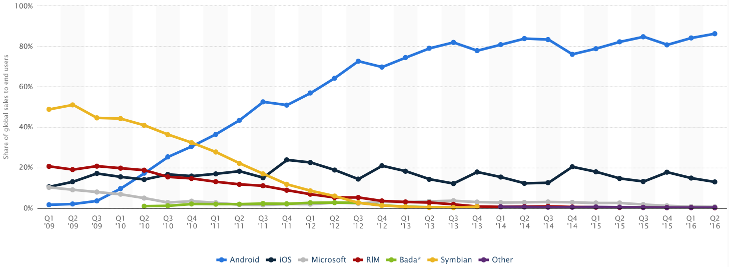
- Java implementation of the Framework
- Specializations for two of the state-of-the-art ASP systems

Why Java? i


TIOBE Programming Community Index
Source: www.tiobe.com
Ratings (%)
30
25
20
15
10
5
0
2002
2004
2006
2008
2010
2012
2014
2016
Java
C
C++
C#
Python
PHP
JavaScript
Visual Basic .NET
Perl
Assembly language

Why Java? ii

Global mobile OS market share in sales to end users from 1st quarter 2009 to 1st quarter 2016



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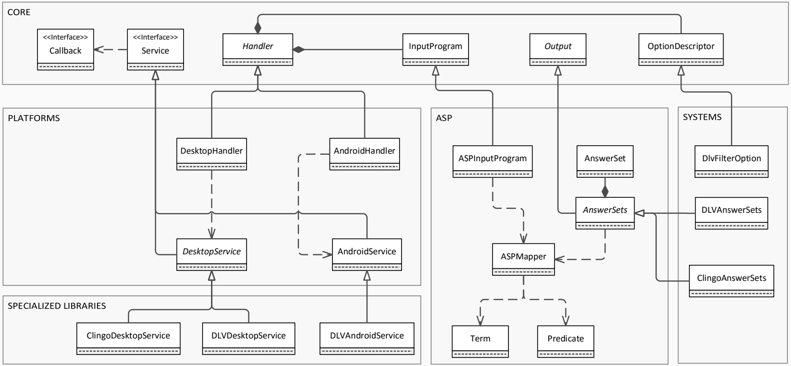
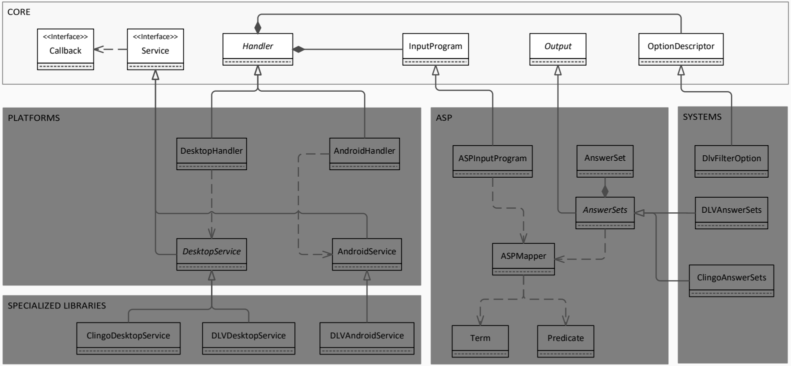
Additional Information:
Worldwide; Gartner

Source:
Gartner

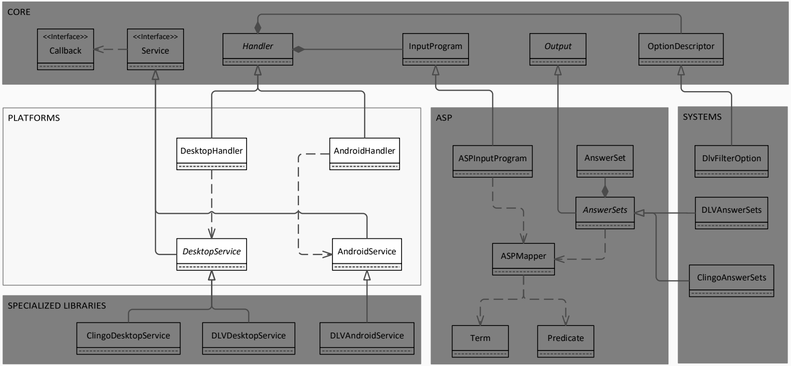
Architecture



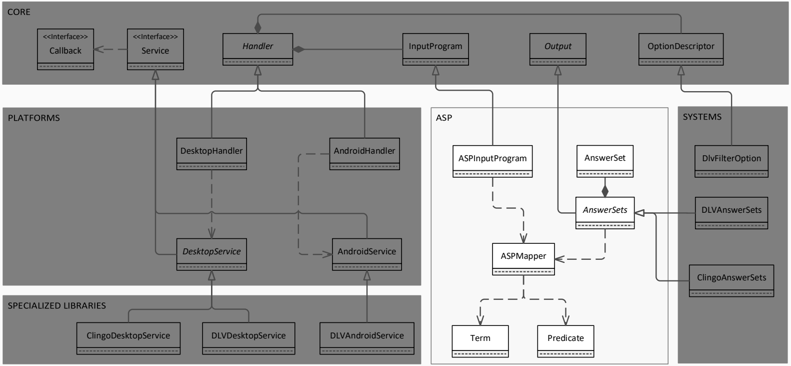
EMBASP - *Core*


CORE
<<Interface>>
Callback
<<Interface>>
Service
Handler
InputProgram
Output
OptionDescriptor
PLATFORMS
DesktopHandler
AndroidHandler
DesktopService
AndroidService
SPECIALIZED LIBRARIES
ClingoDesktopService
DLVDesktopService
DLVAndroidService
ASP
ASPInputProgram
AnswerSet
AnswerSets
ASPMapper
Term
Predicate
SYSTEMS
DlvFilterOption
DLVAnswerSets
ClingoAnswerSets

EMBASP - *Platforms*



EMBASP - *ASP Language*



The `ASPMapper`

Two-way “translator” between strings recognizable by the ASP solver at hand and Java objects directly employable within the application

- Guided by the following Java Annotations:

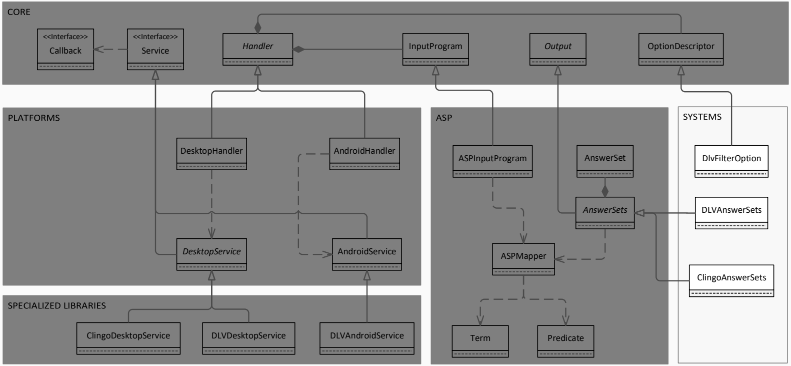
  @Predicate (string_name)

  Defines the predicate name a class is mapped to

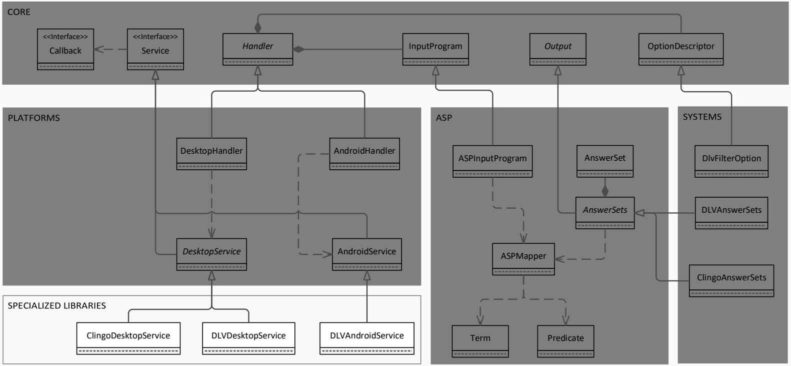
  @Term (integer_position)

  Defines the term (and its position) in the ASP atom the field is mapped to
- Uses the Java Reflection mechanisms to examine the Annotation at run-time and perform the translation
- Give developers the possibility to work separately on the ASP-based modules and on the Java side

EMBASP - *Systems*



EMBASP - *Specialized Libraries*



Specializing the Framework - The Android case

JNI (Java Native Interface) [JNI] and *Android NDK (Native Development Kit)* [And]

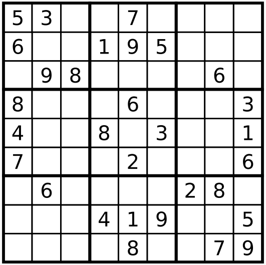
- The use of *JNI* grants the access to the API provided by the *Android NDK*, and to the exposed DLV functionalities directly from the Java code of an Android application
- The *NDK* allows developers to implement parts of an Android application as “native-code” languages, such as *C* and *C++*
- These technologies represent the general and standard way to realize the porting of a *C++* software in an Android context

Embedding ASP Programs

How to use EMBASP to build an app

Build an (Android) app for solving Sudoku puzzles using EMBASP

- We have a proper logic program to solve a sudoku puzzle
- We have also an initial schema



5	3			7				
6			1	9	5			
	9	8					6	
8				6				3
4			8		3			1
7				2				6
	6					2	8	
			4	1	9			5
				8			7	9

Full code available at:

`https://www.mat.unical.it/calimeri/projects/embasp/`

How to use EMBASP to build an app - The Mapping

The class **`Cell`**

```
@Predicate("cell")
public class Cell {

  @Term(1)
  private int row;

  @Term(2)
  private int column;

  @Term(3)
  private int value;

  [...]

}
```

Thanks to the *annotations* the **`ASPMapper`** will be able to map **`Cell`** objects into strings properly recognizable from the ASP solver as *logic facts* of the form:

$$cell(Row, Column, Value)$$

How to use EMBASP to build an app - The Activity I

```
public class MainActivity extends AppCompatActivity {
  [...]

  private Handler handler;

  @Override
  protected void onCreate(Bundle bundle) {
    handler = new AndroidHandler(getApplicationContext(),
        DLVAndroidService.class);
    [...]
  }

  public void onClick(final View view){
    [...]
    startReasoning();
  }
[...]
```

How to use EMBASP to build an app - The Activity II

```
[...]
  public void startReasoning() {

    InputProgram inputProgram = new ASPInputProgram();
    for (int i = 0; i < 9; i++)
      for (int j = 0; j < 9; j++)
        try {
          if(sudokuMatrix[i][j] != 0)
            inputProgram.addObjectInput(new Cell(i, j,
                sudokuMatrix[i][j]));
        } catch (Exception e) { // Handle Exception }
    handler.addProgram(inputProgram);

    String sudokuEncoding = getEncodingFromResources();
    handler.addProgram(new ASPInputProgram(sudokuEncoding));

    Callback callback = new MyCallback();
    handler.startAsync(callback);
}}
```

How to use EMBASP to build an app - The Callback

```
private class MyCallback implements Callback {
  @Override
  public void callback(Output o) {
    if(!(o instanceof AnswerSets)) return;

    AnswerSets answerSets = (AnswerSets)o;
    if(answerSets.getAnswersets().isEmpty()) return;

    AnswerSet as = answerSets.getAnswersets().get(0);
    try {
      for(Object obj : as.getAtoms()) {
        Cell cell = (Cell) obj;
        sudokuMatrix[cell.getRow()][cell.getColumn()] = cell.
            getValue();
      }
    } catch (Exception e) { // Handle Exception }

    displaySolution();
}}
```

Other Language Implementations of EMBASP

The *abstract architecture* of EMBASP can be made concrete by means of other *object-oriented* programming languages

- It uses features that are typical of any object-oriented language, such as *inheritance* and *polymorphism*
- The unique exception is the *ASPMapper* component which uses *annotations* and *reflection*
    - Some languages have similar constructs
    - In other these constructs can be simulated applying typical *Software Engineering patterns* [GHJV94]

ASP-based Applications: some Examples in the Educational Setting

Some Examples in the Educational Setting

ASP-based applications developed by means of EMBASP for educational purposes, and, in particular, in the context of a university course that covers ASP topics

- Engagement of university undergraduate students in ASP capabilities
- ASP looks well-fitted for the use in the development of educational/training software

GuessAndCheckers

A native mobile application that works as an helper for users that play “live” games of the (Italian) checkers (i.e., by means of physical board and pieces)

GuessAndCheckers

A native mobile application that works as an helper for users that play “live” games of the (Italian) checkers (i.e., by means of physical board and pieces)

- by means of the device camera a picture of the board is taken
- the information about the current status of the game is properly inferred thanks to the *OpenCV* library
- an ASP-based artificial intelligence module then suggests the move

DLVEdu

An educational Android App for children, that is able to guide the child throughout the learning tasks, by proposing a series of educational games

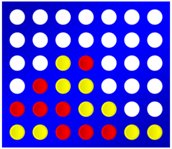
DLVEdu

An educational Android App for children, that is able to guide the child throughout the learning tasks, by proposing a series of educational games

- dynamically builds and updates a customized educational path along the different games
- uses well-known mobile technologies, such as voice or drawn text recognition
- features a “Parent Area”, that allows parents to monitor child’s achievements and to express some preferences

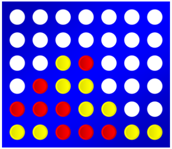
Connect4

An Android application that allows a user to play the game against an ASP-based artificial player



Connect4

An Android application that allows a user to play the game against an ASP-based artificial player



- different AIs designed and implemented
  - from the most powerful one (with advanced techniques for the perfect play)
  - to the simplest one (with some classical heuristic strategies)
- using EMBASP, two different versions of the same app have been built:
  - one for Android, making use of DLV
  - one for Java-enabled desktop platforms, making use of clingo.

DLVfit

A health app that aims at suggesting the owner of a mobile device the “best” way to achieve some fitness goals

DLVfit

A health app that aims at suggesting the owner of a mobile device the “best” way to achieve some fitness goals

- goals and preferences about habits and activities can be expressed in a customizable way
- using the Google Activity Recognition APIs [Goo], the app, in the background, constantly detects the current user activity
- at any time, the user might ask for a suggestion about a workout plan for the rest of the day

Related Work

Related Work

Clingo4 [GKKS14]

- Enables a form of control over the computational tasks of the embedded ASP solver *Clingo* with scripting languages *lua* and *python*
- The main purpose is the support of dynamic and incremental reasoning

Java Wrapper [Ric03]

- Acts like a versatile wrapper wherewith the Java developers can interact with the ASP solver (DLV)
  - Differently, EMBASP makes use of Java Annotations, allowing an easy mapping of input/output to Java Objects

Related Work

JDLV [FGLR12]

- Based on JASP, an hybrid language that allows a bilateral interaction between ASP and Java
- Uses JPA annotations to define how Java classes map to relations, similarly to ORM frameworks
    - Differently, EMBASP exploits custom annotations, almost effortless to define, in order to deal with the mapping

Moreover, EMBASP is not specifically bound to a single or specific solver and it can be easily extended to deal with any solver, and with different solvers at the same time.

Related Work

Tweety [Thi14]

- A set of Java libraries that allow to make use of several knowledge representation systems supporting different logic formalisms
- The use is very similar to EMBASP, both provide libraries to incorporate proper calls to external declarative systems from within “traditional” applications
- Tweety implementation is very rich, covering a wide range of KR formalisms, yet looking less general
    - Differently, EMBASP is mainly focused on fostering the use of ASP in the widest range of contexts and supports the mobile setting

Conclusions

Conclusions

- A general framework for embedding the reasoning capabilities of ASP into external systems
- The fully abstract architecture makes the framework general enough to be adapted to a wide range of scenarios
- Actual Java implementation and two specialized libraries for embedding *DLV* on Android applications and *clingo* on any Java-based desktop application are provided
- Has been tested within some university courses featuring ASP topics, for implementing a set of applications, ranging from AI-based games to educative apps

The framework, documentation, an application showcase and further details are freely available at:

`https://www.mat.unical.it/calimeri/projects/embasp/`

Questions?

EmbASP

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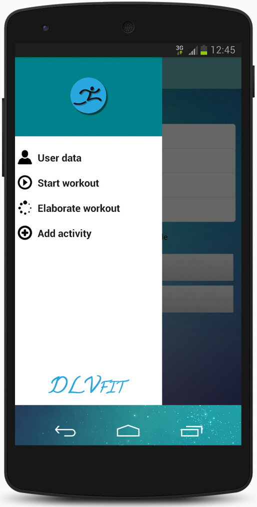
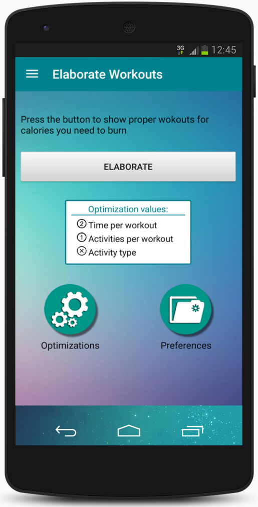
Questions?

Thank you for your attention.

DLVFIT



3G 12:45
User data
Start workout
Elaborate workout
Add activity
DLVFIT



3G 12:45
Elaborate Workouts
Press the button to show proper wokouts for calories you need to burn
ELABORATE
Optimization values:
② Time per workout
① Activities per workout
⊗ Activity type
Optimizations
Preferences

DLVfit - ASP Reasoning Module

- The app *dynamically* builds a suitable ASP program whose answer sets represent workout plans that comply with the *very personal goals* and *preferences* previously expressed
- A classic *Guess/Check/Optimize* paradigm is used:

Guess Compute how much time should be spent on each exercise

Check Find only admissible workout plans

Optimize Try to satisfy the user's preferences to the largest possible extent

DLVFIT- ASP program: relevants concepts

`calories_burnt_per_activity(A, C)`

the calories burnt (C), in each unit of time, per each Activity (A)

DLVFIT- ASP program: relevants concepts

`calories_burnt_per_activity(A, C)`

the calories burnt (C), in each unit of time, per each Activity (A)

`remaining_calories_to_burn(R)`

the calories that remain to burnt in the current day

DLVFIT- ASP program: relevants concepts

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`how_long(A, D)`

the amount of the time that can be spent for each activity

DLVFIT- ASP program: relevants concepts

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the amount of the time that can be spent for each activity

`max_time(T)`

the duration of the workout

DLVFIT- ASP program: relevants concepts

`calories_burnt_per_activity(A, C)`

the calories burnt (C), in each unit of time, per each Activity (A)

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the calories that remain to burnt in the current day

`how_long(A, D)`

the amount of the time that can be spent for each activity

`max_time(T)`

the duration of the workout

`surplus(C)`

the maximum surplus of calories to burn of the suggested workouts

DLVFIT- ASP program: relevants concepts

`calories_burnt_per_activity(A, C)`

the calories burnt (C), in each unit of time, per each Activity (A)

`remaining_calories_to_burn(R)`

the calories that remain to burnt in the current day

`how_long(A, D)`

the amount of the time that can be spent for each activity

`max_time(T)`

the duration of the workout

`surplus(C)`

the maximum surplus of calories to burn of the suggested workouts

`optimize(T, W, P)`

the specific optimization operation(s) that the user wants to perform

DLVfit - An example of Input I (Basic Concepts)

```
calories_burnt_per_activity("ON_BICYCLE", 5).
calories_burnt_per_activity("WALKING", 2).
calories_burnt_per_activity("RUNNING", 11).

remaining_calories_to_burn(200).

how_long("ON_BICYCLE", 10).
how_long("ON_BICYCLE", 20).
how_long("WALKING", 10).
how_long("WALKING", 20).
how_long("RUNNING", 10).
how_long("RUNNING", 20).

max_time(20).

surplus(100).
```

DLVfit - An example of Input II (Custom Optimizations)

```
optimize("RUNNING", 1, 3).
optimize("WALKING", 2, 3).
optimize("ON_BICYCLE", 3, 3).
```

maximize the number of favourite activities to perform

DLVFIT - An example of Input II (Custom Optimizations)

```
optimize("RUNNING", 1, 3).
optimize("WALKING", 2, 3).
optimize("ON_BICYCLE", 3, 3).
```

maximize the number of favourite activities to perform

```
optimize(time,0,2).
```

minimize total time spent exercising

DLVfit - An example of Input II (Custom Optimizations)

```
optimize("RUNNING", 1, 3).
optimize("WALKING", 2, 3).
optimize("ON_BICYCLE", 3, 3).
```

maximize the number of favourite activities to perform

```
optimize(time,0,2).
```

minimize total time spent exercising

```
optimize(activities, 0, 1).
```

minimize total number of activities to perform

DLVFit

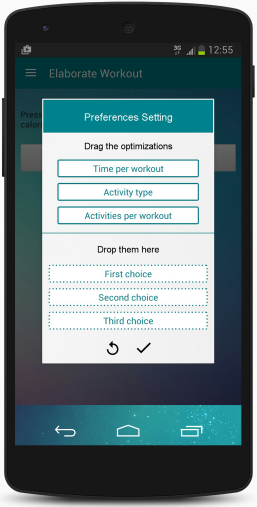
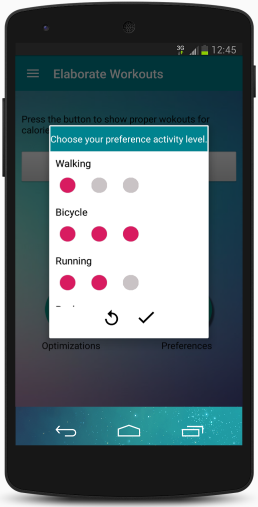


Figure 1: Expressing priorities



Press the button to show proper wokouts for calorie

Choose your preference activity level.

Walking ● ○ ○

Bicycle ● ● ●

Running ● ● ○

Figure 2: Expressing preferences

DLVfit - Logic rules composing the ASP program

```
activity_to_do(A, HL) | not_activity_to_do(A, HL) :- how_long(A, HL).
```

DLVfit - Logic rules composing the ASP program

```
activity_to_do(A, HL) | not_activity_to_do(A, HL) :- how_long(A, HL).
```

```
:- activity_to_do(A, HL1), activity_to_do(A, HL2), HL1 != HL2.

:- remaining_calories_to_burn(RC), total_calories_activity_to_do(CB),
   RC > CB.
:- remaining_calories_to_burn(RC), total_calories_activity_to_do(CB),
   CB > RCsurplus, RCsurplus = RC + surplus.

:- max_time(MTS), total_time_activity_to_do(TS), MTS < TS.
```

DLVFIT - Logic rules composing the ASP program

```
activity_to_do(A, HL) | not_activity_to_do(A, HL) :- how_long(A, HL).
```

```
:- activity_to_do(A, HL1), activity_to_do(A, HL2), HL1 != HL2.

:- remaining_calories_to_burn(RC), total_calories_activity_to_do(CB),
   RC > CB.
:- remaining_calories_to_burn(RC), total_calories_activity_to_do(CB),
   CB > RCsurplus, RCsurplus = RC + surplus.

:- max_time(MTS), total_time_activity_to_do(TS), MTS < TS.
```

```
:~ optimize(A, W, P), activity_to_do(A, _). [W:P]

:~ optimize(time, _, P), activity_to_do(_, HL). [HL:P]

:~ optimize(activities, _, P), #int(HM),
        HM = #count{A, HL : activity_to_do(A, HL)}. [HM:P]
```

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