FuzzyLite v0.9
A Fuzzy Inference System written in C++

by Juan Rada-Vilela
Supported by Fundación para el Progreso del Soft Computing

January, 2010

1 Introduction

FuzzyLite v0.9 is a multiplatform, free, and open-source Fuzzy Inference System (FIS) written in C++ and released under the Apache License 2.0, which makes this software freely available for commercial and non-commercial use. The idea behind this FIS is to have a very simple and light FIS. Simple as in simple to use, simple to understand, and simple to extend, without sacrificing performance. And light because it requires no additional libraries more than the Standard Template Library included in the C++ Standard Library. It has an object-oriented approach and a clear separation between the headers and sources, so it is easier to extend. Furthermore, it is GUI-agnostic, meaning that the FIS does not require a GUI to run, encouraging its use as a library. Nevertheless, a Qt-based GUI is provided using FuzzyLite v0.9 as a shared library.

2 Features

- Membership functions are continuous and the following are available: triangular, trapezoidal, rectangular, shoulder, singleton, and compound (multiple functions).
- Defuzzification using center of gravity (COG).
- Mamdani rule parsing with grammar checking.
- TNorm: minimum, product, bounded difference.
- SNorm: maximum, sum, bounded sum.
- Modulation: clipping, scaling.
- Accumulation: maximum, sum, bounded sum.
- Variable sampling size for membership functions to compute area and centroid.
- Area and centroid are calculated by means of a precise triangulation algorithm.
- Hedges: not, somewhat, very. Easily extendible.
- No restriction on inner parenthesis expressions in rules.

3 Known bugs

- Hedges in the consequent of rules are parsed correctly but do not work well. However, in the antecedent of rules they work just fine.
- Parenthesis in rules must be separated from terms by means of a blank space. For example, instead of `(Term is BIG)` use `( Term is BIG )` .

4 What is next?

- Implement Takagi Sugeno rules.
- Implement ANFIS.
- Implement the Fuzzy Controller Language (FCL).
- Incorporate sigmoidal, gaussian, cosine, and discrete membership functions.
- Incorporate the following defuzzifiers: Right Most Maximum, Left Most Maximum, Mean Maximum.
- Parse the weighting factor of a consequence.
- Incorporate rule blocks and other aspects required by the FCL.
- Function based deffuzifiers (e.g. TERM drainage := FUNCTION (-2 * pressure * Ln(pressure)) + (temp * 4);). Idea taken from the jFuzzyLogic project.
- Make some functions inline to increase performance and check those that are already inline to ensure they do increase performance.
- Evaluate the performance hit of using exceptions to consider whether they should be removed.
- Create the `configure` script using the `GNU Autotools` in order to easily build `FuzzyLite v0.9` from sources.

5 Building from source

5.1 `FuzzyLite v0.9`

At the moment, due to the lack of a building script like `./configure`, the following steps could build `FuzzyLite v0.9`:

1. Create a `C++` Project either in Eclipse IDE or Netbeans IDE.
2. Add all the source files and include files to the project.
3. Add `.` to the includes path in the project properties.
4. Add `FL_USE_LOG` to enable the use of logging via `FL_LOG(message)`. In `./include/defs.h` there are more symbols that can be defined for further customization.
5. Decide whether to build a shared library or an executable (in project properties).
6. Use the IDE's normal build.

5.2 GUI

In order to build the graphical user interface of `FuzzyLite v0.9`, it is necessary to first install `Qt` which can be freely downloaded from `http://qt.nokia.com/`.

The `Makefile` included within the `./gui` is quite easy to read. Basically, the most important thing here is to copy the `libfuzzylite.dylib` (or whatever the extension be according to your platform) into the folder `./gui/dist` which is where the executable will be put. An alternative is to copy the library into `/usr/local/lib` and comment those lines in the `Makefile` that build and copy the library into the `./gui/dist` directory.

After configuring the `Makefile` to fit your system, a `make all` from `./gui` would build the graphical user interface of `FuzzyLite v0.9`. To run, it suffices to execute `./gui` from `./gui/dist`.

6 Example

The following is a basic example of how to setup the FIS.

```
1  fl::FuzzyOperator* fo = &fl::FuzzyOperator::DefaultFuzzyOperator();
2  fl::FuzzyEngine* fe = new FuzzyEngine(*fo);
3
4  fe->addHedge(*new fl::HedgeNot);
5  fe->addHedge(*new fl::HedgeSomewhat);
6  fe->addHedge(*new fl::HedgeVery);
7
8  fl::InputLVar* energy = new fl::InputLVar("Energy");
9  energy->addTerm(*new fl::ShoulderTerm("LOW", 0.25, 0.5, true));
10 energy->addTerm(*new fl::TriangularTerm("MEDIUM", 0.25, 0.75));
11 energy->addTerm(*new fl::ShoulderTerm("HIGH", 0.50, 0.75, false));
12 fe->addInputLVar(*energy);
13
14 fl::OutputLVar* health = new fl::OutputLVar("Health");
15 health->addTerm(*new fl::TriangularTerm("BAD", 0.0, 0.50));
16 health->addTerm(*new fl::TriangularTerm("REGULAR", 0.25, 0.75));
17 health->addTerm(*new fl::TriangularTerm("GOOD", 0.50, 1.00));
18 fe->addOutputLVar(*health);
19
20 fl::MamdaniRule* rule1 = new fl::MamdaniRule();
21 fl::MamdaniRule* rule2 = new fl::MamdaniRule();
22 fl::MamdaniRule* rule3 = new fl::MamdaniRule();
23 rule1->parse("if Energy is LOW then Health is BAD", fe);
24 rule2->parse("if Energy is MEDIUM then Health is REGULAR", fe);
25 rule3->parse("if Energy is HIGH then Health is GOOD", fe);
26
27 fe->addRule(*rule1);
28 fe->addRule(*rule2);
29 fe->addRule(*rule3);
```

Once the FIS is configured, the control process may begin anytime by setting the input value to the input variables and processing. For example,

```
30 for (fl::flScalar in = 0.0; in < 1.1; in += 0.1){
31   energy->setInput(in);
32   fe->process();
33   fl::flScalar out = health->output().defuzzify();
34   FL_LOG("Energy=" << in);
35   FL_LOG("Energy is " << energy->fuzzify(in));
36   FL_LOG("Health=" << out);
37   FL_LOG("Health is " << health->fuzzify(out));
38 }
```

The previous code would yield the following results in console (assuming that `FL_USE_LOG` was defined):

```
Energy=0
Energy is 1.000/LOW + 0.000/MEDIUM + 0.000/HIGH
Health=0.249902
Health is 1.000/BAD + 0.000/REGULAR + 0.000/GOOD
--
Energy=0.1
Energy is 1.000/LOW + 0.000/MEDIUM + 0.000/HIGH
Health=0.249902
Health is 1.000/BAD + 0.000/REGULAR + 0.000/GOOD
--
Energy=0.2
Energy is 1.000/LOW + 0.000/MEDIUM + 0.000/HIGH
Health=0.249902
Health is 1.000/BAD + 0.000/REGULAR + 0.000/GOOD
--
Energy=0.3
Energy is 0.800/LOW + 0.200/MEDIUM + 0.000/HIGH
Health=0.309985
Health is 0.760/BAD + 0.240/REGULAR + 0.000/GOOD
--
Energy=0.4
Energy is 0.400/LOW + 0.600/MEDIUM + 0.000/HIGH
Health=0.394929
Health is 0.420/BAD + 0.580/REGULAR + 0.000/GOOD
--
Energy=0.5
Energy is 0.000/LOW + 1.000/MEDIUM + 0.000/HIGH
Health=0.499902
Health is 0.000/BAD + 1.000/REGULAR + 0.000/GOOD
--
Energy=0.6
Energy is 0.000/LOW + 0.600/MEDIUM + 0.400/HIGH
Health=0.604537
Health is 0.000/BAD + 0.582/REGULAR + 0.418/GOOD
--
Energy=0.7
Energy is 0.000/LOW + 0.200/MEDIUM + 0.800/HIGH
Health=0.689444
Health is 0.000/BAD + 0.242/REGULAR + 0.758/GOOD
--
Energy=0.8
Energy is 0.000/LOW + 0.000/MEDIUM + 1.000/HIGH
Health=0.749902
Health is 0.000/BAD + 0.000/REGULAR + 1.000/GOOD
--
Energy=0.9
Energy is 0.000/LOW + 0.000/MEDIUM + 1.000/HIGH
Health=0.749902
Health is 0.000/BAD + 0.000/REGULAR + 1.000/GOOD
--
Energy=1
Energy is 0.000/LOW + 0.000/MEDIUM + 1.000/HIGH
Health=0.749902
Health is 0.000/BAD + 0.000/REGULAR + 1.000/GOOD
--
```

7 License

Version 2.0, January 2004
http://www.apache.org/licenses/

TERMS AND CONDITIONS FOR USE, REPRODUCTION, AND DISTRIBUTION

1. Definitions.

"License" shall mean the terms and conditions for use, reproduction, and distribution as defined by Sections 1 through 9 of this document.

"Licensor" shall mean the copyright owner or entity authorized by the copyright owner that is granting the License.

"Legal Entity" shall mean the union of the acting entity and all other entities that control, are controlled by, or are under common control with that entity. For the purposes of this definition, "control" means (i) the power, direct or indirect, to cause the direction or management of such entity, whether by contract or otherwise, or (ii) ownership of fifty percent (50%) or more of the outstanding shares, or (iii) beneficial ownership of such entity.

"You" (or "Your") shall mean an individual or Legal Entity exercising permissions granted by this License.

"Source" form shall mean the preferred form for making modifications, including but not limited to software source code, documentation source, and configuration files.

"Object" form shall mean any form resulting from mechanical transformation or translation of a Source form, including but not limited to compiled object code, generated documentation, and conversions to other media types.

"Work" shall mean the work of authorship, whether in Source or Object form, made available under the License, as indicated by a copyright notice that is included in or attached to the work (an example is provided in the Appendix below).

"Derivative Works" shall mean any work, whether in Source or Object form, that is based on (or derived from) the Work and for which the editorial revisions, annotations, elaborations, or other modifications represent, as a whole, an original work of authorship. For the purposes of this License, Derivative Works shall not include works that remain separable from, or merely link (or bind by name) to the interfaces of, the Work and Derivative Works thereof.

"Contribution" shall mean any work of authorship, including the original version of the Work and any modifications or additions to that Work or Derivative Works thereof, that is intentionally submitted to Licensor for inclusion in the Work by the copyright owner or by an individual or Legal Entity authorized to submit on behalf of

the copyright owner. For the purposes of this definition, "submitted" means any form of electronic, verbal, or written communication sent to the Licensor or its representatives, including but not limited to communication on electronic mailing lists, source code control systems, and issue tracking systems that are managed by, or on behalf of, the Licensor for the purpose of discussing and improving the Work, but excluding communication that is conspicuously marked or otherwise designated in writing by the copyright owner as "Not a Contribution."

"Contributor" shall mean Licensor and any individual or Legal Entity on behalf of whom a Contribution has been received by Licensor and subsequently incorporated within the Work.

2. Grant of Copyright License. Subject to the terms and conditions of this License, each Contributor hereby grants to You a perpetual, worldwide, non-exclusive, no-charge, royalty-free, irrevocable copyright license to reproduce, prepare Derivative Works of, publicly display, publicly perform, sublicense, and distribute the Work and such Derivative Works in Source or Object form.

3. Grant of Patent License. Subject to the terms and conditions of this License, each Contributor hereby grants to You a perpetual, worldwide, non-exclusive, no-charge, royalty-free, irrevocable (except as stated in this section) patent license to make, have made, use, offer to sell, sell, import, and otherwise transfer the Work, where such license applies only to those patent claims licensable by such Contributor that are necessarily infringed by their Contribution(s) alone or by combination of their Contribution(s) with the Work to which such Contribution(s) was submitted. If You institute patent litigation against any entity (including a cross-claim or counterclaim in a lawsuit) alleging that the Work or a Contribution incorporated within the Work constitutes direct or contributory patent infringement, then any patent licenses granted to You under this License for that Work shall terminate as of the date such litigation is filed.

4. Redistribution. You may reproduce and distribute copies of the Work or Derivative Works thereof in any medium, with or without modifications, and in Source or Object form, provided that You meet the following conditions:

   (a) You must give any other recipients of the Work or Derivative Works a copy of this License; and

   (b) You must cause any modified files to carry prominent notices stating that You changed the files; and

   (c) You must retain, in the Source form of any Derivative Works that You distribute, all copyright, patent, trademark, and attribution notices from the Source form of the Work, excluding those notices that do not pertain to any part of

the Derivative Works; and

(d) If the Work includes a "NOTICE" text file as part of its distribution, then any Derivative Works that You distribute must include a readable copy of the attribution notices contained within such NOTICE file, excluding those notices that do not pertain to any part of the Derivative Works, in at least one of the following places: within a NOTICE text file distributed as part of the Derivative Works; within the Source form or documentation, if provided along with the Derivative Works; or, within a display generated by the Derivative Works, if and wherever such third-party notices normally appear. The contents of the NOTICE file are for informational purposes only and do not modify the License. You may add Your own attribution notices within Derivative Works that You distribute, alongside or as an addendum to the NOTICE text from the Work, provided that such additional attribution notices cannot be construed as modifying the License.

You may add Your own copyright statement to Your modifications and may provide additional or different license terms and conditions for use, reproduction, or distribution of Your modifications, or for any such Derivative Works as a whole, provided Your use, reproduction, and distribution of the Work otherwise complies with the conditions stated in this License.

5. Submission of Contributions. Unless You explicitly state otherwise, any Contribution intentionally submitted for inclusion in the Work by You to the Licensor shall be under the terms and conditions of this License, without any additional terms or conditions. Notwithstanding the above, nothing herein shall supersede or modify the terms of any separate license agreement you may have executed with Licensor regarding such Contributions.

6. Trademarks. This License does not grant permission to use the trade names, trademarks, service marks, or product names of the Licensor, except as required for reasonable and customary use in describing the origin of the Work and reproducing the content of the NOTICE file.

7. Disclaimer of Warranty. Unless required by applicable law or agreed to in writing, Licensor provides the Work (and each Contributor provides its Contributions) on an "AS IS" BASIS, WITHOUT WARRANTIES OR CONDITIONS OF ANY KIND, either express or implied, including, without limitation, any warranties or conditions of TITLE, NON-INFRINGEMENT, MERCHANTABILITY, or FITNESS FOR A PARTICULAR PURPOSE. You are solely responsible for determining the appropriateness of using or redistributing the Work and assume any risks associated with Your exercise of permissions under this License.

8. Limitation of Liability. In no event and under no legal theory, whether in tort (including negligence), contract, or otherwise,

unless required by applicable law (such as deliberate and grossly negligent acts) or agreed to in writing, shall any Contributor be liable to You for damages, including any direct, indirect, special, incidental, or consequential damages of any character arising as a result of this License or out of the use or inability to use the Work (including but not limited to damages for loss of goodwill, work stoppage, computer failure or malfunction, or any and all other commercial damages or losses), even if such Contributor has been advised of the possibility of such damages.

9. Accepting Warranty or Additional Liability. While redistributing the Work or Derivative Works thereof, You may choose to offer, and charge a fee for, acceptance of support, warranty, indemnity, or other liability obligations and/or rights consistent with this License. However, in accepting such obligations, You may act only on Your own behalf and on Your sole responsibility, not on behalf of any other Contributor, and only if You agree to indemnify, defend, and hold each Contributor harmless for any liability incurred by, or claims asserted against, such Contributor by reason of your accepting any such warranty or additional liability.

END OF TERMS AND CONDITIONS