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| *Soils Interpretations Generator FY20* |
| **Introduction, Background and HL System Requirements** |
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Contents

[1 Introduction to Soils Interpretation Generators 2](#_Toc41646388)

[2 Background 3](#_Toc41646389)

[3 Out of Scope 4](#_Toc41646390)

[4 Assumptions 4](#_Toc41646391)

[5 System Requirements 5](#_Toc41646392)

[5.1 EPIC: Service Requests 5](#_Toc41646393)

[5.2 Epic: Creation and Management of Soil Interpretation Generators 5](#_Toc41646394)

[5.3 Epic: Creators and Reviewers need the ability to run a draft or review status Soil Interpretation Generator to obtain interpretation test results. 6](#_Toc41646395)

[5.4 Epic: All Internal users need the ability to run Released Interpretation Models against various input data sets, review results, create new interpretations. 9](#_Toc41646396)

[5.5 Epic: Deliver Soil Interpretations that support downstream application delivering to public 9](#_Toc41646397)

[5.6 Deliver Soil Interpretations to applications requiring special formats 9](#_Toc41646398)

[6 Introduction to Fuzzy Logic Models 10](#_Toc41646399)

[6.1 Fuzzy Inference systems FIS 11](#_Toc41646400)

[6.2 Fuzzy Logic Rules 11](#_Toc41646401)

[6.3 Fuzzy Logic Cognitive Mapping 12](#_Toc41646402)

[6.4 Fuzzy Logic Model Software Tools 12](#_Toc41646403)

# Introduction to Soils Interpretation Generators

A Soil Interpretations Generator is a type of Fuzzy Logic Inference System Model created by

Soil Scientist Experts to use as a decision tool.

A Soil Interpretations Generator uses soil and site property data from the soils database to generate soil ratings for land use based on specific interpretation criteria. The criteria used are based on the proposed use of the soil and the result is usually provided as a list of soil limitations or characteristics for the intended use. An example would be a soil used for landfill. If a soil has properties that would result in contamination of groundwater, the soil would have limitations for landfill. Soil properties affecting groundwater contamination would be particle–size (water would flow through sandy soils quickly and contaminate groundwater), or the soil may be on a steep slope resulting in water running off from the landfill and contaminating the surface water.

The current Interpretations Generator operates solely within the NASIS transactional database (as opposed to the public-facing Web Soil Survey Database) by generating interpretive output based on evaluations and ratings of soil properties stored in the database.

Improvements to the whole process of modeling soil properties could be improved allowing users within the agency, outside users, and cooperators to develop their own interpretations using data from the public-facing database. Internal users would have the option to use either database, as needed. The new Interpretations Generator will be able to assist the public and the agency conservation planners by providing custom interpretive output that they prefer in a timely and more flexible manner.

* Ability to adjust the soil properties from site specific locations and generate on the fly interpretations (from ready-to-use interpretations) for desktop and mobile applications.
* Ability for users to create new interpretations outside of the transactional NASIS database.
* Ability to use geospatial layers from many formats to integrate into the soils data for developing more spatially explicit interpretations.
* Ability to design and build engaging maps for our partners, both within and outside the NRCS, using a variety of technologies including using some open source statistical, GIS, and model building tools This document is further supported by the NRCS Requirements Development and Management Plan. This effort will give the Investment Review Board (IRB) the necessary information for project prioritization and approve the project for funding.

# Background

A soil interpretation is the result of running a fuzzy logic model whose purpose is to rate a soil’s suitability for some use, such as the likelihood of finding usable gravel, or the potential for problems when building a manure pit. Soil Interpretations are derived from the soil properties in the National Soil Information System (NASIS) database using a set of algorithms which can be tailored to model an interdisciplinary expert decision-making process. There are three components of a Soil interpretation Model, which are called

• Properties

• Evaluations

• Rules

The Rules, Properties, and Evaluations are available only to those who have permissions to use the transactional database. Each of these is a class of business object consisting of a set of tables captured in the NASIS Database. Each of the three components has a specialized data entry module in the NASIS Local Workstation Client application. A Soil Interpretation Generator (model) is run to create a Soil Interpretation.

Soil Interpretations Models (Generators) are usually developed and tested by highly trained and experienced users. Interpretations are run against a selected set of soils input data queries from the NASIS DB. In order to run an interpretation a ‘Report’ is scripted in C# that consists of query for input data, invoking the Interpretation Model, and format of results which can be viewed by the user. The results are shown as a report for the selected data and the selected interpretations. Interpretation results or ratings are also computed and stored during the process of exporting data from NASIS. Instructions on developing and using interpretations are found in the NASIS documentation.

The current Interpretations Generator components are created using the NASIS client, and may be run with small data sets as input on the client itself. Prior to release the interpretations need to be run against larger volumes of data. The NASIS client provides a graphical interface for viewing some relationships between components. An Interface for composing C# scripts for components is also provided, and the resulting code is stored in the NASIS DB as column in a table row.

The NASIS Batch processing mode is used for the large volume runs. The ‘report’ is scripted on the NASIS client and the submitted as a batch job. Currently the Soil Interpretations are run only against the NASIS transactional database.

The running of an interpretation on either the client or as a batch job generates interpretive output based on evaluations and ratings of soil properties stored in the database.

The process of modeling soil properties could be improved by allowing users within the agency, outside users, and cooperators to develop their own interpretations using data from NASIS, the public-facing Soils database, or from other external or internal data sources. Internal users would have the option to use either database, as needed. The new Interpretations Generator will be able to assist the public and the agency conservation planners by providing custom interpretive output that they prefer in a timely and more flexible manner.

• Have the ability to adjust the soil properties from site specific locations and generate on the fly interpretations (from ready-to-use interpretations) for desktop and mobile applications.

• Modernize the technology and platforms to provide enhanced ability for users to create new interpretations using soils data.

• Improved ability to use geospatial layers from many formats as input into for developing more spatially explicit interpretations.

• Provide enhanced geospatial technologies to design and build maps as exportable products for our partners.

# Out of Scope

* The Data Delivery to the public and end users is a separate solution. The Soils Interpretations Generator will deliver completed models and Interpreted data to the databases and application that serve the public and end users.
* Initially the Soils Interpretations may be delivered via existing applications such as Web Soils Survey (WSS), Soil Data Access (SDA) or Soil Data Viewer (SDV) which use the Soil Data Mart (SDM) as the data source.
* As the existing Data Delivery applications are modernized, the Soils Interpretations Generator may need to be enhanced to accommodate new requirements defined for end user.

# Assumptions

* Web based Application will be piloted and or prototyped internally to validate and improve the solution prior to making it available to external users.
* Application will ultimately serve all user types; employees, affiliates, customers, TSPs and general public.
* Authentication is required for all users who have ability to create or modify records using a USDA Enterprise Authentication method.
* Role based authorization sing an enterprise solution will be used to distinguish users with permissions to create, modify or run interpretations.
* Users of the interpretation generator include administrators, soil scientists, data stewards, and external customers.
* The Soils Interpretations Generator will be used to create ‘models’ as rule sets that will be used users to create Soils Interpretations by submitting different data sets. Official Soils Interpretations will be delivered to the public and other users via a public access Data Delivery solution separate from the Interpretations Generator.
* Solution must conform to enterprise technical requirements examples of which are not limited to authentication, authorization, security, PII, 508 compliance, performance, availability, etc.

# System Requirements

Includes current system functionality as well as enhanced features required

## EPIC: Service Requests

## Epic: Creation and Management of Soil Interpretation Generators

1. Expert Soil Scientist Creators of Soil Interpretation Generators need a Graphical User interface where Fuzzy Logic Models consisting of individual component Rules, Properties and Evaluations can be copied, created, managed, and inter-relationships defined between the components create a model. The graphical interface will be used to show the component relationships.
   1. Users creating Interpretations, evaluations and reports are currently writing custom NASIS code written in Microsoft’s general-purpose “C#” computer language. This custom code manages data retrieval from the NASIS database and computation of reports, evaluations, interpretations and fuzzy “truth”.
      1. *Currently Soil Interpretation Components are scripted in CVIR which is using the C# programming language and ANTL C” library. The components scripts are stored in NASIS tables as varchar.*
      2. The “ANTLR” software library Third-party software is also used. The ANTLR library is used within the C# code to translate a user’s input (such as the definition of a report) into a data “structure” that drives the custom NASIS C# code. This data structure also drives the final report formatting, also performed by custom NASIS C# code.
      3. If new tools or platforms are being considered, then those must support migration of all existing models, components or models and ability to run then in the new solution.
   2. Soil Interpretation Components may be reused across models.
   3. Soil Scientist users to create Rule based fuzzy logic models (generators) used for generating interpretations of Soil data.
   4. Allow users to create interpretive model components in the form of Rules, Properties, and Evaluations, and define the relationships between these components. Allow access to interpretation components created and managed by other internal and external users in order to share and to use the interpretations effectively.
   5. New Interpretation Models may be created by copying all or a portion of an existing. Interpretation model,
   6. Allow effecting sharing of components and reduction of redundancy by provisioning Model components to include metadata that helps identify their purpose and allows searching to find them using keywords.
   7. The interpretations generator must provide the user the ability to parse out the reasons for a given interpretation and show them graphically on a map. As an example, providing the “very limited” rating along with its reason of ‘flooding’, ‘shrink-swell’, ‘depth to bedrock’, and/or ‘slope’.
   8. The Interpretation Generator has to allow users to preview results using data from the transactional NASIS.  Notes: not sure what this is asking for.  Is this for current system or is there new functionality being requested?
   9. Allow Creators to provide metadata and other documentation to fully explain the rules, evaluations, and properties used to generate a particular interpretation.  Use a content management system so that graphics as well as text can be used to explain the assumptions and document the methods for the child rules and parent rules and allow storage of notes related to each part of the interpretation.
   10. Enhanced Feature: In addition to fuzzy logic model the system should provide additional options to  process the input data, such as neural networks, and others to be determined.
   11. Enhanced Feature: The Interpretations Generator must have the capability to support more complex interpretations by interfacing with external applications that already contain logic to perform part of the interpretation.
   12. Enhanced Feature: Ability to use previous criteria and modeling techniques with new set of updated data, create a new version, to compare with an older version.
   13. Enhanced Feature: Interpretations are for determination of outcome for land use with soil types.  The system needs to allow optimization for a soil type for a land use in a specific interpretation, by calibrating and fine-tuning the model criteria.  Then finding the best fit of the model for the measured responses  (e.g. interpretation weights).  The current system runs the interpretation manually many times, with manual tweaking of criteria.  The new system should allow automated multiple runs with pre-determined inputs for alternative criteria.   for example:  a criteria defining a response curve might need to be tweaked using different scenarios.

## Epic: Creators and Reviewers need the ability to run a draft or review status Soil Interpretation Generator to obtain interpretation test results.

* 1. Soil Scientist Expert Creators of Soils Interpretations Generators (fuzzy logic models) need the ability to test the draft models they are creating. They must be able to run individual components and entire models. They must be able to run with both small, large and very large data sets as input.
  2. During an interpretation development process, data will need to exist temporarily for multiple soil component iterations which can be queried and viewed during the process, but is not retained after the interpretation has completed.
  3. Ability to run multiple versions of interpretations using the same data, but with different modeling criteria and/or different modeling techniques (fuzzy logic, neural networks, etc.).  Ability to compare tabular or mapping display of versions of related interpretive results using same data but different methodology. The current system will allow this, but the relationship between the version is not captured, it has to be defined manually by the user.
  4. Enhanced Feature: The Interpretations Generator must have an easy to use graphical interface that walks the user through the process of developing interpretations, running them, and obtaining the output.
  5. Enhanced Feature: The Interpretations Generator must have the ability to support both maps generated on the web as well as the ability to supply data to stand alone GIS systems and statistical analysis systems.
  6. The system must have the ability to allow the user to have the option to see what value of each soil attribute was fed into the evaluation system exposing the underlying numbers being used to derive the ratings. For example, “Depth to Bedrock 46 cm”.
  7. Although the ‘released official’ interpretations have to be consistent at any given point in time, the ability to update interpretations based upon new criteria (response curve,  examples?) must be maintained.
  8. Have functionality to facilitate troubleshooting of interpretive criteria.
  9. Internal soil scientist reviewers need ability to run models ready for internal review. Allow internal users with authorization access for generating interpretations and to test against newly developed models or data.
  10. Running Models in draft or review status must allow users to capture in progress results and display intermediate output as well as final output in report format or screen display.
  11. Generation of National, State, and Local Interpretation ratings using the transactional Soils Survey database (NASIS). Official data is defined by the National Soil Survey Handbook 644.02a.
  12. Enhanced Feature: The current system utilizes aggregated generalized data.  The new system would also allow option to integrate point data (specific location soil samples with characterization test results) for model development.
  13. Enhanced Feature: The new system should be more efficient and be able to process large volumes of data efficiently and quickly. Without impacting other Soil Application users.
  14. Enhanced Feature: The system must allow forms-based input of data into the interpretive system to allow generation of Interpretation ratings “on the fly” using:
      1. national criteria on locally collected site specific information,
      2. allowing measured and point data to be inserted into the system, such as slope, depth to bedrock, Saturated Hydraulic Conductivity ksat, Cation Exchange Capacity (CEC), and dynamic soil properties from desktop or mobile applications.
      3. Data for a single point, soil sample with soil characterization composition test results, could be exported to a mobile platform in a web service input formation such as json, geojson, html, REST, SOAP.  Note: need clarification from Dylan B. (graduate student at Davis working with Professor Bear, who is now and NRCS employee).  NRCS contracts with Davis to do this kind of mobile application.
  15. Enhanced Feature: Use Pedon data to generate a zonal statistics interpretation map.  NASIS aggregates Pedon soil analysis results for a county level.  SIG should allow use of Pedon for a single location rather than aggregated data.
  16. Enhanced Feature: Generation of National, State, and Local Interpretation ratings using additional sources of data, not just NASIS transactional Soils Survey Data, including public-facing Web Soil Survey (WSS) data (WSS includes SSURGO). The system utilization of Web Soil Survey data should not impact the performance, responsiveness, or user experience of WSS.
  17. Enhanced Feature: The system must allow integration of the laboratory data into the interpretive process.
  18. The system shall allow use of the most authoritative data available for attributes from spatial layers in order to provide spatially explicit data for an interpretation.such as:
      1. PRISM data - The new system must be able to use PRISM spatial and tabular climate data.
      2. LIDAR data - topographic data.
      3. Hydrologic Layer - proximity to other features like wells and surface water, streams and rivers,

## Epic: All Internal users need the ability to run Released Interpretation Models against various input data sets, review results, create new interpretations.

## Epic: Deliver Soil Interpretations that support downstream application delivering to public

1. Support Applications which delver Interpretations to the Public: System must provide the ability to deliver interpretation ratings from new models or new data. The official source of soil information to the public is the Web Soil Survey, a part of the National Soil Information System. This system provides for the collection, storage, manipulation, and dissemination of detailed and general soil survey information. The system includes certified tabular and spatial data at various scales. The new SIG will not replace Web Soil Survey, but will deliver public facing data to the Web Soil Survey.
   1. External users will not have access to the NASIS transactional data. External users will view and utilize only public facing data sources such as WSS and Soil Data Access (SDA).
   2. Ability to deliver the interpretation ratings on the public-facing database with a yearly refresh.
   3. Ability to deliver the interpretation ratings on the public-facing database prior to the yearly refresh date.
   4. Official data is defined by the National Soil Survey Handbook 644.02a. The official source of soil information is the Web Soil Survey, a part of the National Soil Information System. This system provides for the collection, storage, manipulation, and dissemination of detailed and general soil survey information. The system includes certified tabular and spatial data at various scales.
   5. The System should allow external users to export the interpretive results, and/or WSS data for use within other systems or tools.

## Deliver Soil Interpretations to applications requiring special formats

1. The interpretations are delivered in several forms in different applications. The Interpretation Generator supports the following types of data distribution, as described in detail below:
   1. Hard copy reports (Print Capability) for both internal use and external distribution.
   2. Reports in text or html format of interpretive output appropriate for export to PDF or other formats.
   3. Creation of maps using exported data from NASIS top MS Access.
   4. Electronic transfer of interpretation results to other applications such as APEX and Toolkit.
   5. Distribution process using exports to provide data to other applications, such as Web Soil Survey, Soil Data Viewer Microsoft Access databases and downloads of gridded SSURGO (raster based representation of the vector data).
2. Enhanced Features: The delivery of interpretations to various different applications needs to be improved. The Interpretation Generator should support the following types of data distribution, as described in detail below:
   1. Improved reporting capability for interpretations results resulting in hard copy reports (Print Capability) for both internal use and external distribution.
   2. Mapping reports integrated with the application and allowing direct query and on-screen viewing of maps and tables.
   3. Automated integration to provide data from interpretation results to other applications such as APEX (note: define APEX), Conservation Desktop (CD) (replacement for CST), Soil Data Access application, and Web Soil Survey.
   4. Improved integration and distribution of data to other products, such as Web Soil Survey, Soil Data Viewer Microsoft Access databases and downloads of gSSURGO.  Simply the processes and automate where possible.
   5. The current interpretations generator provides the user the ability to parse out the reasons for a given interpretation and show them graphically on a map. As an example, providing the “very limited” rating along with its reason of ‘flooding’, ‘shrink-swell’, ‘depth to bedrock’, and/or ‘slope’.  Additional features need to provide the capability to map the collective ‘rating and reasons’ for a given interpretation.
   6. Enhanced Feature: Larger volumes of data for export will first allow the user to define the data to be exported using filter criteria, such as location, soil type, land use, etc.  The user will then select an export format or thematic map requests.  Format options currently are pipe delimited text or html.  Other formats are needed such as MS Access, SQL, XML, etc.

# Introduction to Fuzzy Logic Models

**Fuzzy logic** is a form of [many-valued logic](https://en.wikipedia.org/wiki/Many-valued_logic) in which the [truth values](https://en.wikipedia.org/wiki/Truth_value) of variables may be any [real number](https://en.wikipedia.org/wiki/Real_number) between 0 and 1 both inclusive. It is employed to handle the concept of partial truth, where the truth value may range between completely true and completely false. By contrast, in [Boolean logic](https://en.wikipedia.org/wiki/Boolean_algebra), the truth values of variables may only be the integer values 0 or 1.

The term *fuzzy logic* was introduced with the 1965 proposal of [fuzzy set theory](https://en.wikipedia.org/wiki/Fuzzy_set_theory) by [Lotfi Zadeh](https://en.wikipedia.org/wiki/Lotfi_A._Zadeh" \o "Lotfi A. Zadeh).[[2]](https://en.wikipedia.org/wiki/Fuzzy_logic#cite_note-2)[[3]](https://en.wikipedia.org/wiki/Fuzzy_logic#cite_note-3) Fuzzy logic had, however, been studied since the 1920s, as [infinite-valued logic](https://en.wikipedia.org/wiki/%C5%81ukasiewicz_logic)—notably by [Łukasiewicz](https://en.wikipedia.org/wiki/Jan_%C5%81ukasiewicz" \o "Jan Łukasiewicz) and [Tarski](https://en.wikipedia.org/wiki/Alfred_Tarski).[[4]](https://en.wikipedia.org/wiki/Fuzzy_logic#cite_note-4)

Fuzzy logic is based on the observation that people make decisions based on imprecise and non-numerical information. Fuzzy models or sets are mathematical means of representing vagueness and imprecise information (hence the term fuzzy). These models have the capability of recognizing, representing, manipulating, interpreting, and utilizing data and information that are vague and lack certainty.

Fuzzy logic has been applied to many fields, from [control theory](https://en.wikipedia.org/wiki/Control_theory) to [artificial intelligence](https://en.wikipedia.org/wiki/Artificial_intelligence).

In **fuzzy logic**, the truth of any statement becomes a matter of a degree. **Fuzzy inference** is the process of formulating the mapping from a given input to an output using **fuzzy logic**. The mapping then provides a basis from which decisions can be made or patterns discerned.

## Fuzzy Inference systems FIS

***Fuzzy Inference Systems (FIS)*** take inputs and process them based on the prespecified rules to produce the outputs. Both the inputs and outputs are real valued, whereas the internal processing is based on fuzzy rules and fuzzy arithmetic.

In terms of **inference** process there are **two** main **types of fuzzy inference system** (FIS), namely the Mamdani **type** and the TSK (Takagi, Sugeno and Kang) **type**.

In the case of Mamdani FIS the consequent membership functions are also **fuzzy** in nature.

**Mamdani** type **fuzzy** inference gives an output that is a **fuzzy** set. **Sugeno**-type inference gives an output that is either constant or a linear (weighted) mathematical expression.

## Fuzzy Logic Rules

**Fuzzy rules** are used within [fuzzy logic systems](https://en.wikipedia.org/wiki/Fuzzy_logic) to infer an output based on input variables. [Modus ponens](https://en.wikipedia.org/wiki/Modus_ponens) and [modus tollens](https://en.wikipedia.org/wiki/Modus_tollens) are the most important rules of inference.[[1]](https://en.wikipedia.org/wiki/Fuzzy_rule#cite_note-1) A modus ponens rule is in the form

Premise: *x is A*

Implication: ***IF****x is A****THEN****y is B*

Consequent: *y is B*

In crisp logic, the premise *x is A* can only be true or false. However, in a fuzzy rule, the premise *x is A* and the consequent *y is B* can be true to a degree, instead of entirely true or entirely false.[[2]](https://en.wikipedia.org/wiki/Fuzzy_rule#cite_note-:0-2) This is achieved by representing the linguistic variables *A* and *B* using [fuzzy sets](https://en.wikipedia.org/wiki/Fuzzy_set).[[2]](https://en.wikipedia.org/wiki/Fuzzy_rule#cite_note-:0-2) In a fuzzy rule, modus ponens is extended to *generalised modus ponens:.*[[2]](https://en.wikipedia.org/wiki/Fuzzy_rule#cite_note-:0-2)

Premise: *x is A*\*

Implication: ***IF****x is A****THEN****y is B*

Consequent: *y is B*\*

The key difference is that the premise *x is A* can be only partially true. As a result, the consequent *y is B* is also partially true. Truth is represented as a [real number](https://en.wikipedia.org/wiki/Real_number) between 0 and 1, where 0 is false and 1 is true.

## Fuzzy Logic Cognitive Mapping

Fuzzy-Logic Cognitive Mapping (FCM) is a parameterized form of concept mapping where qualitative static models may be devleoped that are translated into semi-quantitative dynamic models. Bart Kosko originally developed FCM in 1986 as a way to structure expert knowledge using a soft systems programming approach that is "fuzzy", thought to be similar to the way that the human mind makes decisions.

FCM represents knowledge by defining three characteristics of a system:

* The components of the system
* The positive or negative relationships between the components
* The degree of influence that one component can have on another, defined using qualitative weightings (e.g. high, medium, or low influence)

The analytical mechanics of FCM are based on examining the structure and function of concept maps, using graph theory-based analyses of pairwise structural relationships between the concepts included in a model. These models can be used to examine perceptions of an environmental or social problem or to model a complex system where uncertainty is high and there is little empirical data available.

## Fuzzy Logic Model Software Tools

1. Mathworks Fuzzy Logic Toolbox used MatLab and Simulink
   1. <https://www.mathworks.com.html>
   2. Fuzzy Logic Toolbox™ provides MATLAB® functions, apps, and a Simulink® block for analyzing, designing, and simulating systems based on fuzzy logic. The product guides you through the steps of designing fuzzy inference systems. Functions are provided for many common methods, including fuzzy clustering and adaptive neurofuzzy learning.
2. Fuzzy Logic Tools – opensource SourceForge – C++framework for storage analysis and design of multiple-input multiple-outpus Fuzzy control systems without constraings in the order of either the inputs or output vectors.
3. LFLC - **LFLC 2000 (Linguistic Fuzzy Logic Controller)** is specialized software, which is based on results obtained in formal theory of fuzzy logic. It makes it possible to deduce conclusions on the basis of imprecise description of the given situation using fuzzy IF-THEN rules. The rules are interpreted either as fuzzy relations, or they can be taken as genuine linguistic expressions and interpreted using the original theory developed in IRAFM.
4. Mental Modeler – based upon Fuzzy Logic Cognitive Mapping
   1. Based in Fuzzy-logic Cognitive Mapping (FCM), users can easily develop semi-quantitative models of environmental issues, social concerns or social-ecological systems in Mental Modeler by:
      1. Defining the important components of a system
      2. Defining the relationships between these components
      3. Running "what if" scenarios to determine how the system might react under a range of possible changes.
   2. ***Mental Modeler*** allows you to build Fuzzy-logic Cognitive Maps easily and intuitively. Once models are built, increasing or decreasing the components included in the model allows you to examine different scenarios of change. Because of their flexibility, FCM have been used in a range of scientific disciplines, from political science to economics to ecology.
5. FuzzF
6. Mathematica Fuzzy Tool
7. FIDE
8. TILShell
9. Fuzzy Tech
10. RockOn Fuzzy Tool
11. SciLab Fuzzy Fuzzy Tool
12. UNFUZZY
13. XFUZZY
14. Fulsome – FUzzy Logic for SOftware MEtrics - used for project management software development decision making