

Application: KEEL[®] Technology Used to Determine Causes of Anemia in Adults

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Abstract

This paper describes a computer software application that is intended to be integrated into major brands of hematological analyzers. This application uses Compsim's KEEL[®] (Knowledge Enhanced Electronic Logic) technology to interpret the data generated by the analyzers and provides an output report that indicates the possibility of certain causes of anemia in adults. The purpose of the application is to enhance the report formats of hematological analyzers and provide more useful information to the physicians or nursing practitioners to handle anemia; one of the most common hematological diseases.

1. Problem Statement

At this time, we believe that many physicians do not use much of the data provided in routine CBC (complete blood cell counts) and reticulocyte count reports for determining the causes of anemia (such as iron deficiency anemia, thalassemia, anemia of chronic disease, or megaloblastic anemia). In addition, the hematological analyzers that are used in hospitals and clinics do not provide any degree of interpretation of any these parameters; the Pathologist must review each of the analyzer's results themselves.

This paper describes the first phase of the Anemia Application which includes a Visual Basic front-end data entry screen where the data is manually entered. The first test included 125 blood tests results that originally came from a hematological analyzer. The second phase of the project will include integrating the application to the analyzer and testing 1000s of blood tests.

2. KEEL Overview¹

KEEL Technology provides a mechanism for incorporating human-like reasoning in embedded systems and software applications. KEEL Technology encapsulates three concepts: 1) The KEEL Toolkit and support tools, 2) a model for decision-making /

reasoning, and 3) an execution engine that is created from the design developed with the KEEL Toolkit.

KEEL Technology incorporates a graphical language that allows a designer (the "Expert") to develop the system without writing textual formulas to describe functionality. This allows the cognitive problems to be addressed at a higher level, where the solution can be addressed without as much concern for the coded implementation. The graphics representing the KEEL source code are also dynamic (decisions are continually executed during development). This allows the designer to see the impact of the design while it is being developed.

KEEL Technology can be considered in the "expert system" category, because it uses a human designer to define the rules. Since it is a rules-based system, the decisions or actions can be viewed, understood, and audited. When the design is complete and satisfactorily evaluated in the design environment, it is translated to conventional computer "source code", which describes a KEEL engine. The KEEL engine is very small and does not require any support libraries. The rules are maintained in tables that are iteratively processed to determine a result or results. The API for the KEEL engine is very simple. It was easily integrated into the Visual Basic Front-End data entry application that is described below (part of the Anemia Application).

3. The Process

Compsim LLC started a project with a Pathologist from the Medical College of Wisconsin in Milwaukee, Wisconsin. The goal of the project was to use KEEL Technology to create an application that takes the results of a hematological analyzer and creates a report for the doctor that aides him/her in the prognosis of the causes of anemia in adults. The application that we created not only identifies the various causes of anemia, but explains the reasoning behind the decisions. In addition, the application will, upon selecting a menu item, explain exactly why the other causes of anemia were **not** considered appropriate,

which might ultimately prove useful to the physician. We also believe that the application's final report will significantly reduce human error. [There are numerous blood test results listed on the paper printout from existing hematological analyzers. The Pathologist has to interpret many combinations of the resulting data items to make an accurate diagnosis.]

The process that Compsim used to define and create the application is as follows:

1) First, the application needed to be defined. Compsim worked with the Pathologist to determine the thought process a pathologist uses as he/she reviews blood tests in order to identify a potential cause of anemia. A flow chart was developed that defined a forward chaining process. This process looks at one blood test at a time and navigates through a decision tree to determine whether a particular disease might be identified or if an unidentified disease might exist. [An unidentified test is when symptoms and test results do not match a pattern for a specific disease. An unidentified disease may indicate the need for additional tests or that some other disease may exist.]

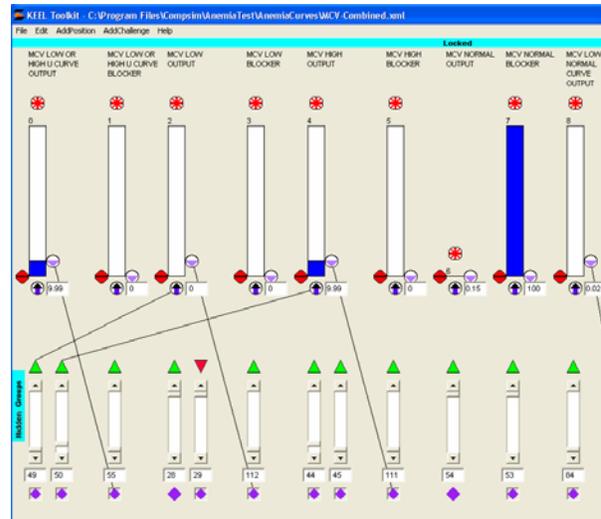
During the discussion process, an Excel spreadsheet was developed that identified the characteristics of the different diseases: Iron Deficiency, Thalassemia, Megaloblastic, ACD (Anemia of Chronic Disease), Hemolytic Anemia, No Anemia, Unspecified Blood Disorder, and No Significant Abnormality Detected. (Normal). The spreadsheet also documented the normal range of values for each blood parameter for each disease, and the absolute minimum and absolute maximum reading for each blood parameter. In some cases, AGE and GENDER impact the normal ranges for each disease. This information was also included in the spreadsheet.

The blood parameters used were: HGB (hemoglobin), HCT (hematocrit), MCV (mean cell volume), MCHC (mean cell hemoglobin concentration), MCH (mean cell hemoglobin), RDW (red cell distribution width), WBC (white blood cell), PLT (platelet), %Retic (reticulocyte count), and RBC (red blood cell).

The information in the spreadsheet was used to identify possible characteristics of each of the above diseases. Should a patient exhibit the characteristics that are inconsistent with that disease, then that disease is eliminated from the list of possible diseases. As the system reviews each blood test it eliminates each disease that is inconsistent with the test results. Blood tests that are not used in evaluating a particular disease are not used to eliminate that disease.

2) The KEEL Toolkit was used to graphically create the rules for the Anemia Application using the data from the Excel spreadsheet. Since there were many blood parameters, and many relationships between the parameters, individual "engines" were designed so that the application could be segmented.

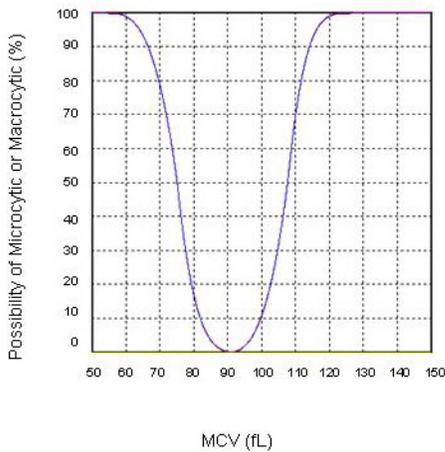
The KEEL Toolkit's graphical representation of a section of one of the blood types (MCV) is shown below.



The bars on the upper level represent items or actions. The bars on the second level are the inputs to the system. Green and red arrows on the top of these inputs represent supporting or blocking inputs.

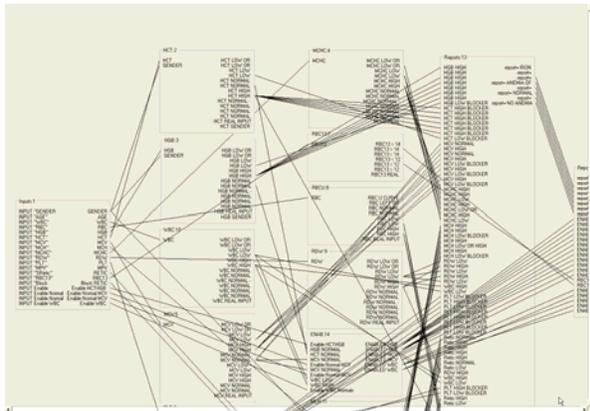
The wires show the relationships between the items. When each of the engines' designs were completed, they were translated to Visual Basic code and they were "glued together" using Compsim's Function Block tool. [Note: We used Visual Basic, but the KEEL Toolkit supports translation to conventional C, Microsoft C#, Java, Visual Basic Version 5/6, Visual Basic .NET, Macromedia Flash, Macromedia Flash (Object) format, and PLC Structured Text.]

Each of the blood parameter engines that were created defines a "U CURVE" for that particular blood parameter. This curve is tuned to define the upper and lower "normal" ranges for that particular blood parameter.



4. The Function Block Tool

As previously mentioned, when each of the blood test's engines were completed, they were translated to Visual Basic code, and they were "glued together" using Compsim's Function Block tool.



The image above shows a screen shot of the KEEL Function Block Tool that supports the integration of multiple KEEL engines into a single unit. Each of the boxes in the image represents a separate KEEL engine. The wires show linkages between engines.

5. The System

The interface to the KEEL engine's decision-making function is very simple. The following pseudo-code snippet is for VB. It sets a busy flag, loads the inputs, and then repeatedly calls the decision-making function until the busy flag is set false, at which time the outputs are unloaded and used for control or messaging.

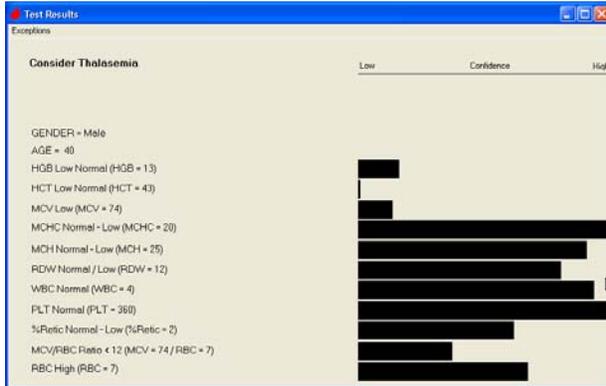
```
'If busyMCV = False Then 'If routine is not
busy then
```

```
' busyMCV = True 'Set it busy
' '{add code to load external inputs into
argvalues() table}
' '(Replace 'x' below with the appropriate
values normalized between 0 and 100.)
' argvaluesMCV(0) = x '65
' argvaluesMCV(1) = x '0
' argvaluesMCV(2) = x '0
' argvaluesMCV(3) = x '0
' (etc)
|
|
' While (busyMCV = True) 'Loop until a stable
output is achieved
' busyMCV = dodecisionsMCV
'calculate outputs based on buffered inputs
' Wend
' '{post the output values or derived values
from modposvaluesMCV(),
' posvaluesMCV(), threshvaluesMCV()}
toexternal control functions.}
'End If
```

The picture below shows the front end to the KEEL based Anemia system. Note: The initial system uses this VB generated front end so that someone can manually enter known patient data into the system. Later this application would be integrated directly into the hematological analyzer (as an "add-on") so that it would generate the final report instead of simply generating test result data which needs further analysis by the Pathologist...

After the blood test data is keyed into the software application, the person entering the data clicks on the RUN button to generate the report.

Based on the data that was typed in the form, a report is then displayed that indicates which type of anemia the person might have (see below). In this case, the KEEL engines determined that the person might have Thalassemia. Note that the report uses the word “Consider” (“Consider Thalassemia”) which supports the goal of creating a tool for the Pathologist to use for diagnosis, or for further analysis...



At the top of this report there is a menu item called “Exceptions”. If the person entering data wished to understand why all the *other* causes of anemia weren’t applicable, they could select this function. All the data would be displayed, along with information explaining

why the other causes of anemia were not considered appropriate.

6. Summary

The goal of this KEEL Application was to create an expert system which enhances current technology for determining the causes of anemia based on data from hematological analyzers. Based on the preliminary tests that were done, this goal was accomplished.

This application was written for blood samples obtained from Adults. Currently, age is not always taken into account when laboratory data is reported on children. There are as many as twenty-two (22) age groups in children that should be considered for causes of anemia. The next phase of this application will be to consider Age as a **continuous dynamic variable as part of the analysis**. Using KEEL Technology the curve for age impacts will be used to adjust the curves for the different blood tests.

After all the enhancements are added, and after the system is fully tested, the intention is to integrate it into a hematological analyzer.



Compsim LLC is a provider of next generation cognitive technology for application in automotive, industrial automation, medical, military, governmental, enterprise software and electronic gaming markets. The company is headquartered in Brookfield, Wisconsin.

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¹ “Decisions and Actions in KEEL”, Compsim,
http://www.compsim.com/papers/Decisions_and_Actions_in_KEEL.pdf