An investigation into the Empirical Modelling of physical devices, in an educational context, illustrated with the Enigma machine example

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Abstract

This paper investigates the extent to which Empirical Modelling principles are appropriate for modelling physical devices, and the advantages and disadvantages of doing so, illustrated with a 'prototype' model of the series of German encryption machines known as Enigma. The paper discusses how effectively such models of physical devices can be used in an educational environment, any considerations that may need to be taken into account when attempting such a task, and ultimately concludes that despite a few weaknesses, the potential for creating a useful model that aids learning is high.

1 Introduction

Empirical Modelling (EM) has already shown itself to be well suited to modelling concepts or general principles. EM is rooted in the creation of models via the expression of links or dependencies between components of that model. Can this type of modelling lend itself to the representation of intricate physical devices? This paper aims to find out, and discusses issues as they arise in conjunction with the development of a prototype model of an Enigma machine.

2 Modelling Physical Devices

There are many situations in which a physical device may be unavailable for interaction or exploration. For example, the artefact may be a historical instrument that no longer exists, a machine that exists only in a museum, or a machine that a given user cannot afford to buy. In these situations, it would likely be beneficial to have access to an interactive model of the machine, which would both allow the use of such a machine, if computational in nature, and facilitate exploratory learning and development of an understanding of the design and mechanisms involved.

Constructionism suggests that people learn by making things. An alternative side to this principle is the benefit that can be gained by taking things apart, which can be highly educational in many instances, especially with technically complex devices or machines. It is with this approach in mind that providing users with the ability to see a working model of a given device, and then to examine individual components within that device could be a very powerful method of learning, and one to which EM may well be ideally suited.

2.1 Model Perspectives

When learning anything, it is valuable to have several different explanations, or perspectives, on the same concept. This variety increases the student's ability to grasp the material at hand. In a similar vein, it would seem that a model of a physical device for the purpose of education would be most effective if there were several different perspectives that the user could select from.

The Enigma model begins, therefore, by defining four separate views that the user can select.

2.1.1 Conceptual

The purpose of this view is to most closely relate the look and feel of an actual Enigma device. That is, there are rotor diagrams appearing where the rotors would have been, the lampboard appears where the lampboard would have been etc. Furthermore, it 'behaves' like an Enigma machine does. For example, when a key is pressed, the lamp corresponding to the enciphered letter is lit for the duration of the key press, and once the key is released, the rotors move positions. This helps the user to get a good feel for how the actual machine works.

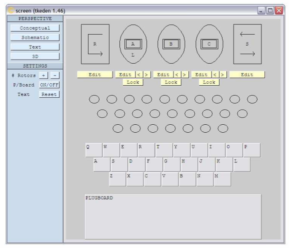

Figure 1: Screenshot of the Conceptual perspective

2.1.2 Schematic

The purpose of the Schematic perspective is to illustrate how the Enigma device works in more detail. It remembers the last key that was pressed, and shows how the output letter was derived from the input letter by a series of lines linking the individual components. i.e. it shows the path that the electric circuit took from entering the stator, through the rotor, back from the reflector and out to the lampboard.

Note: The Enigma model presented is only a prototype that illustrates some of the principles under discussion. The Schematic view is therefore limited to only one rotor at present, and does not take into consideration the turning of the rotor, and hence is only accurate when one rotor is used in the "A" position. This in itself, however, does serve to show the user how the turning of the rotor affects the output, and so is not an entirely negative aspect.

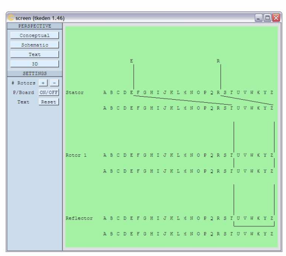

Figure 2: Screenshot of the Schematic perspective

2.1.3 Text

The Text perspective is a simple view that keeps track of the input text and the corresponding output text. The format of the text is kept to the style that was used by radio operators during the war, i.e. grouped in blocks of five letters, and hence this perspective serves not only to allow the user to user the machine to encipher/decipher longer passages, but also provides a greater feel for the context in which the original device was used.

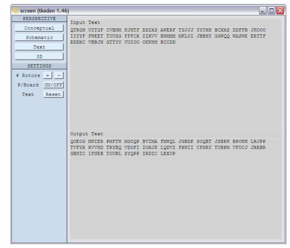

Figure 3: Screenshot of the Text perspective

2.1.4 3D

For any type of model of any device, a three dimensional view is very useful in visualising how the device was constructed and behaved. Furthermore, EM has a specific advantage over other modelling techniques, in that it lends itself directly to building three dimensional models with dependencies built in. For example, the configuration and rotation of the rotors that are viewed in the 3D image can directly represent the same configuration that the user has created in the Conceptual perspective. This interaction can allow the user to visualise changes that they make to the settings, vastly contributing to a more thorough understanding of the device.

Again, the model presented here is only a prototype, and as such a complete model is not given. What is shown, however, is an outline of one rotor divided into it's constituent components. The production of such 3D models is time consuming and involved, as is discussed later, which has limited the development of the model for this paper, although further work is planned!

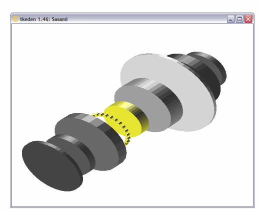

Figure 4: Screenshot of the 3D perspective

2.2 Violation of Constraints

EM is based upon dependencies. Such dependencies are essential for the correct operation of physical devices, and are therefore accurately reflected by the EM 'dependencies'. However, when attempting to obtain an understanding of how a device works, it is beneficial to 'break' some dependencies to observe the result, allowing the user a greater understanding of what is going on.

With the Enigma example, various constraints can be broken. For example, the user can choose to lock individual rotors, preventing them from turning. This stops the Enigma model from performing as it should, causing it to function in a slightly different manner. Giving the user the opportunity to observe what happens when the rotors are prevented from turning encourages them to understand why they need to turn, and hence is an effective learning technique.

2.3 Interface

In order to facilitate user interaction with the device being modelled, it is important to simplify the controls. This is perhaps one area of weakness for EM. Requiring the user to redefine specific variables in the EDEN window to alter the dependencies in the model is awkward and unintuitive for the user. A better approach is to build in buttons, for example, to control the settings. Whilst this is possible in EM, the EDEN environment is not conducive to elaborate HCI development, and hence the appearance of models is likely to suffer.

This can be seen in the Enigma model, with overly simplified diagrammatic form representation of, e.g. the rotors. However, despite this lack of realism, there is an advantage. That advantage is that the environment forces attention to focus on the concepts involved by removing any distracting flourishes to the appearance, thereby improving the conceptual clarity.

2.4 Sasami Notation

As noted in the previous section, a realistic appearance is not easy to achieve through the standard EM notations. However, the Sasami notation provides a strong platform from which a 3D model can be developed.

In the Enigma model, a very basic 3D model of the outline rotor components has been produced. This model was created by calculating the relative location of all coordinates of the necessary vertices, and then creating the required surfaces. The disadvantage to such a detailed approach is that it is very long winded and can take a long time to produce even simple models.

3 Previous Work

3.1 Constructionism

There has already been discussion regarding the use of EM in education, specifically in relation to the concept of Constructionism. A common theme among papers on the subject is the requirement for users to experience the model in their own way. To break what would normally be considered constraints necessary for the given system to work, making sense of the concepts for themselves.

The Enigma model developed for this paper aims to address several of those themes, allowing users to experience the model from several perspectives and to set the configuration of the system for themselves.

3.2 planimeterCare2005

This model is particularly relevant as it is a very good example of an Empirical Model created to represent a detailed mechanical machine, the Planimeter device. This model focuses largely on the 3D representation of the device and performs this task very effectively. Similarities between the Enigma and Planimeter models exist not in their technical details, but in the motivation behind each model.

The Planimeter model demonstrates very well the use of dependencies to link the 3D model to the current configuration of the underlying device. This is a powerful visualisation and one that will hopefully be applied to the Enigma model in due course.

4 The Enigma Model

The Enigma model has been developed in conjunction with this paper, with the purpose of evaluating the potential of modelling such a device. The model presented, therefore, is effectively a prototype, and should not be considered to be complete.

For example, the plugboard can currently only be turned on or off. There is no detailed Conceptual diagram for the plugboard or interface to alter its configuration. However, this could easily be done, as has been shown by the rotor, stator and reflector components.

4.1 Limitations

The model has a few inherent limitations in its design, i.e. features which differ from the actual Enigma machines. These include:

- The model is limited to only 5 rotors. There were several series of Enigma devices, some with more than 5 rotors. It would be beneficial from an educational perspective to remove this limitation and let users experiment with more rotors, and as such is a possible future improvement.
- The keyboard layout. The model shows a QWERTY layout, but in fact the original machines had a different key layout. Although the QWERTY layout is more familiar to users, allowing them to use the model more easily, it is historically inaccurate.

Time permitting, this would have been added in the model as a configuration option

Furthermore, the action of editing any of the rotor configurations is very slow indeed. This performance issue could be resolved by recoding the relevant sections in a more efficient manner. However, for the time being, be aware that the model will take a few seconds to respond to editing rotor configurations.

5 Conclusions

The process of developing the Enigma prototype in conjunction with this written evaluation has highlighted several key points with respect to the modelling of physical artefacts, specifically technically intricate machines. There are weaknesses to the EM approach, but also many strengths.

Despite the occasional awkwardness in describing all of the individual components, the ability of EM to efficiently represent dependencies between the components, and to facilitate easy manipulation of those dependencies, is encouraging and it is the conclusion of this paper, therefore, that EM has strong potential for the representation of mechanical artefacts, and that this potential will continue to grow as the respective software and notations develop further.

References

Regarding EM and education:

C. Roe and M. Beynon, Computer Support for Constructionism in Context
M. Beynon and C. Roe , Empirical Modelling Principles to Support Learning in a Cultural Context
M. Beynon , Empirical Modelling for Educational Technology
C. Care , planimeterCare2005, *Models Archive*

Regarding the design of the Enigma:

S. Singh ,The Science of Secrecy, 4th Estate
Churchhouse, Codes and Ciphers: Julius Caesar, the ENIGMA and the Internet
http://en.wikipedia.org/wiki/Enigma_machine
http://www.codesandciphers.org.uk/enigma/index.htm
http://www.mlb.co.jp/linux/science/genigma/enigma-referat/enigma-referat.html