# DRAWING DIAGRAMS IN AN ONLINE EXAMINATION

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**Abstract**

This paper describes part of a larger study into the computer understanding of diagrams. The diagrams used in the study were produced during an on-line examination using a simple drawing tool. The students' examination answers included a diagram and were submitted over the Internet to an automatic marking tool for grading and feedback. This paper focuses on the production of diagrams under examination conditions by describing the diagram drawing tool and discussing the students' reactions to its use. Whilst only a small number of students have been involved in the trials to-date, drawing simple diagrams using a software tool during an examination did not pose major problems for most of them. We conclude that the use of such a tool is feasible and should be investigated further.

**Introduction**

For several years we have been investigating the automatic grading of examinations taken online [15,16,17,18] in which student answers are all free-form text [1,2,20]. The students type their answers into a web form using a PC at home and submit their answers via the Internet to a server for grading. This electronic examination system gives immediate feedback by providing a grade and textual feedback for each answer. The results have been encouraging [5, 17].

However, until recently, the system would only deal with textual answers; there was no provision for the creation or marking of diagrams. Not only does this restrict the kinds of questions that can be asked, feedback from students had indicated that they would like to be able to draw diagrams as part of their (mainly textual) answers.

The provision of such a facility raises a number of issues, including:

- What features should a drawing tool provide?
- How familiar should students be with the tool prior to the examination?

- How should the tool be provided to students in order to be used under examination conditions?
- How should a diagram be represented for transmission to the server?
- How should a diagram be represented for grading purposes?
- How to grade a diagram?
- How to provide feedback on a student's diagram?

Whilst this paper is primarily concerned with the first three questions, the decisions taken in relation to questions 4 to 6 all had a bearing on the ultimate direction that was taken. The final question poses some fundamental questions that we have only just begun to address [14,18]

There is a great deal of literature on the representation and recognition of diagrams and a well-developed theory of visual languages [4,9]. Much of this work has been motivated by the desire to facilitate multimodal communication and interaction between humans with important applications in the CAD field, and more recently attention has turned to diagrammatic reasoning [10]. However, we have not seen this work applied to the needs of online examinations [8,13]. One diagrammatic grading system, DATsys [19], a diagrammatic front-end to the CourseMaster marking system, provides a method for creating bespoke diagram editors leaving others to provide the marking algorithm.

This paper examines the provision of a drawing tool for use during an online examination and discuses the students' reactions to the tool. Section 2 addresses the nature of the drawing tool that was used in the trials. Section 4 reviews student feedback on the use of the tool in the examination. Finally there is a discussion of the issues that arose from the trials and an outline of future work.

**The Drawing Tool**

Since the online examination consists of a 'conventional' three-hour unseen paper in Computer Science associated with a course that does not require the use of a drawing tool, we concluded that a simple tool requiring minimal familiarisation would be essential. In addition, the tool should also allow the drawing of diagrams appropriate to the examination – in order to minimise the time of use during the examination.

Furthermore, our long-term goals include the computer understanding of diagrams that commonly occur in the teaching of computing (such as E-R and UML diagrams). Therefore, we adopted an approach in which the drawing tool supported the creation of diagrams that are limited to boxes and links. A box is a rectangle that can contain text. A link is a directed line (arrow) and can also be associated with some text. The text associated with each object can be used for labelling and explanation purposes. Furthermore, a link is limited to joining two boxes and can be used to indicate a relationship between them.

Objects are placed on the drawing canvas using a drag-and-drop technique. Boxes can be placed anywhere on the canvas, but links must join two boxes. A range of editing and file handling facilities are also provided. However, if the user wishes to delete a box from the diagram, any associated links will also be removed (but not before the user has been prompted with an appropriate warning). A link can be removed at any time.

Figure 1 shows an example of a drawing constructed with the drawing tool that will be used throughout the remainder of the paper. The drawing illustrates a computer processor architecture known as a 4-stage pipeline. The boxes represent the four stages of execution of a machine code instruction (fetch, decode, execute and write) and the links shows the order in which the stages occur. In this example, there are two pipelines and an association labelled "forward" between the two execution stages.
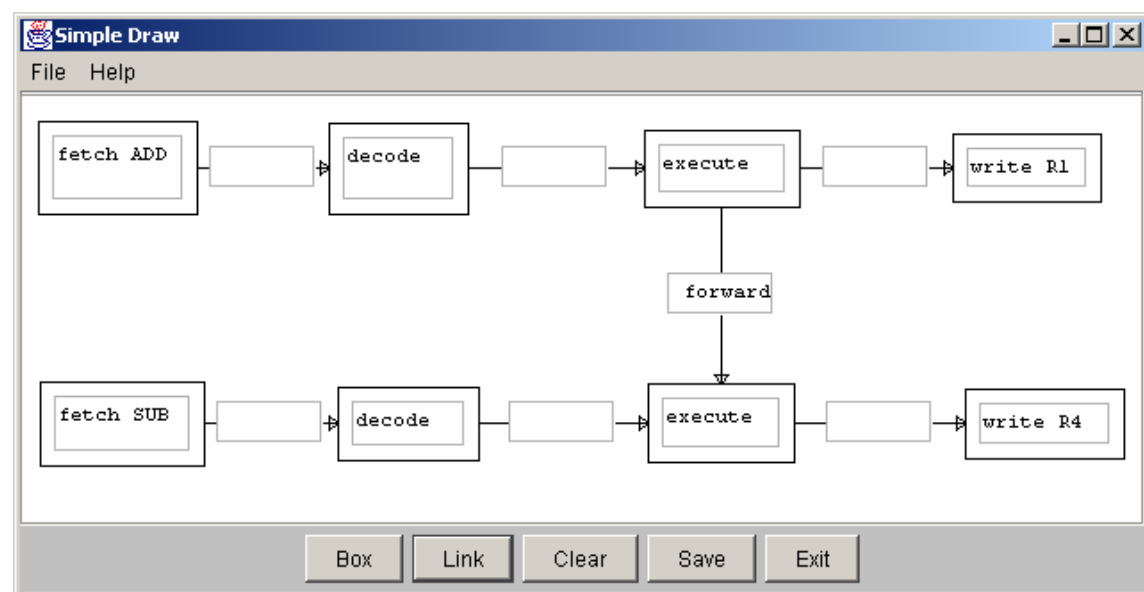


**Figure 1. The drawing tool interface.**

The drawing represents a specimen solution to the examination question given in Figure 2 that was posed in the online examination.

Use the drawing tool to draw a diagram that illustrates how the data hazard inherent in the execution of the pair of instructions:

ADD R2, R3, R1;  SUB R1, R5, R4

by a 4-stage pipeline, can be overcome.

**Figure 2. The examination question.**

The drawing tool was easily accessed through a single click on a button on the electronic examination paper. Once the student had completed their drawing it could be saved to their local disk by clicking on another button. A simple textual encoding of the diagram including spatial co-ordinates, text and associations between drawing elements was stored. This encoding was

sufficient for the diagram to be re-displayed whenever the student wished to amend a previously saved diagram.

We so arranged the tool that it would write to a specific file on disk that was automatically uploaded to the server once the student submitted the exam as a whole. The simplicity of the tool meant that there was very little overhead in deploying it and in saving the diagram.

## Student Feedback

Two trials of the system have been undertaken to date. The first trial we wanted basic student reactions to a prototype tool and to its use in an examination. Students could try out the tool in advance of the examination but few took advantage of this opportunity. In the examination, the use of the tool was not mandatory so only a few students used it. Those who did not answer the diagramming question thought that it would take up too much time in the examination although they had not practiced with it before the exam. Some minor changes were made to the tool as a result of this feedback.

In the second trial, 15 students submitted the examination 12 of whom attempted the drawing question specified in Figure 2. This was part of a compulsory question and was worth 4% of the marks on the whole paper. Nine students answered the question successfully, 3 students tried to draw a diagram but gave up without submitting it, and 3 did not attempt the question. Figure 3 summarises student opinions of the drawing tool (14 students provided feedback).
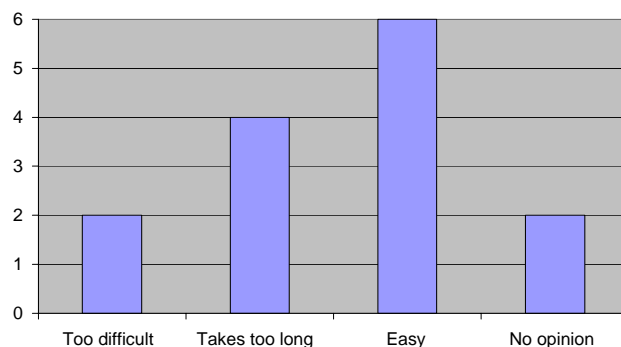


**Figure 3. Opinions of the Drawing Tool.**

The main problems experienced by students were a perceived lack of space to type in the boxes and a dislike of scrolling. The following are typical comments.

"The scroll bars in the boxes I found offputting, I started off drawing boxes that were too small - I nearly didn't do this question because of that."

"Text boxes needed to be bigger so could see whole answer at once without scrolling"

"The text boxes could be a bit bigger – at least big enough to contain the expected answers. It was a bit disconcerting trying to scroll up and down the boxes."

There is no limit imposed by the tool on the amount of text that could be entered into a box. The boxes could be expanded by dragging, and scroll bars are available on all elements. This was explained in the help menu but it is doubtful whether students referred to it given the time constraints they were under.

Despite these problems, 6 students felt that the drawing tool was easy to use.

"Very easy once I got the hang of it"

No-one cited their difficulties in using the drawing tool as a drawback to their overall experience of the online examination when compared to a conventional closed book examination (see Figure 4).
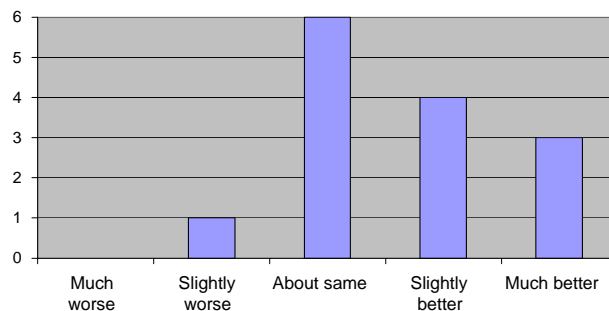


**Figure 4. Opinions of the Online Examination.**

The specimen solution given in Figure 1 illustrates the expectation that students would draw explicit relationships between boxes (shown by arrowed 'links'). However, students represented the temporal associations between the stages of the pipelines using spatial associations as shown in the typical student diagram in Figure 5.

This figure also illustrates how the size difficulty, particularly with the links, was often overcome – with an additional 'comment' box, positioned in this example at the bottom of the diagram.
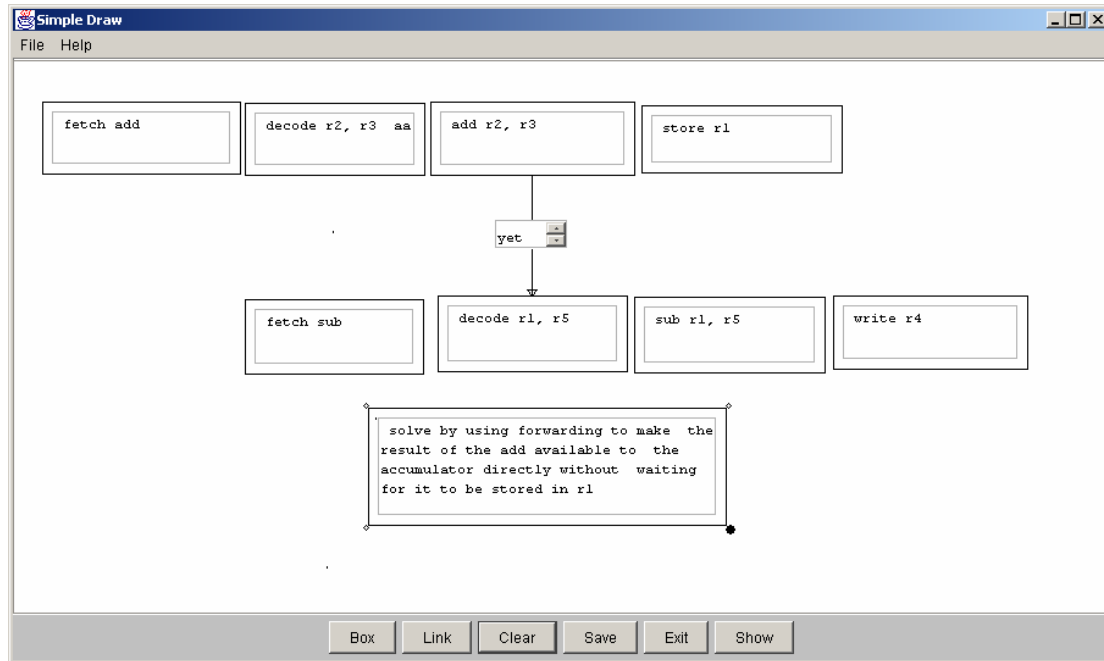
**Figure 5. A typical student drawing.**

## Discussion

Unsurprisingly, there is a definite reluctance on the part of some students to attempt to use a software tool under examination conditions, primarily due to the anticipated length of time it would take to complete a drawing (a good example of a barrier to learning [6,11]). In these trials, students were faced with a using a tool that the majority of them had not seen prior to the exam, which could only exacerbate the situation. In addition, the question, whilst in the compulsory part of the paper, was of a 'low stakes' variety being worth only 4% of the total mark for the examination. We might assume therefore, that students would avoid such a question without too much concern. However, only 3 out of 15 students did not attempt the question (but this could be because they did not know the answer). This suggests that despite natural reluctance, students will generally attempt to use the tool. No doubt, if the students had had experience of the tool prior to the examination, this hesitancy would have been reduced. However, placing students in the position of not knowing a tool and having to learn it under examination conditions is unlikely to be a common situation. One would normally expect students to be exposed to the tool during their normal studies. We were pleased therefore to see how well the majority of students coped with the situation.

It is clear, however, that whatever tool is used, it must have certain qualities, not the least of which are ease of use and good affordance. In these trials we minimized the functionality of the tool but students still had to determine how to use it within a very short period of time. From the comments received, the tool was easy to use once the student had become familiar with it but there was a degree of initial difficulty to be overcome. At least one student felt bewildered by what they were initially faced with. We conclude that a redesign

of the interface would be necessary to improve the affordance. It was also the case that students did not investigate all the features of the tool (such as moving and resizing the boxes) which reinforces the conclusion that prior exposure to the tool is essential.

The minimal set of drawing features provided by the tool did not seem to be an issue. The students were able to convey their thoughts adequately enough (albeit not in the expected way) and did not mention this limitation as a drawback in their post-examination comments. The most irritating feature was the apparent lack of space in the text fields and the appearance of scroll bars. Students often got around this problem by drawing additional boxes to act as comments. In this particular question, there is no standardized syntax for diagrams and free-form diagrams were acceptable. In more formal situations (as with E-R or UML diagrams) additional features would undoubtedly be necessary and a different approach taken to capturing large amounts of textual information (see Figure 6).

**Diagram Understanding**

The approach we have taken to the understanding of diagrams [14] is in five stages which we have named segmentation, assimilation, identification, aggregation and integration. The first two stages translate a raster-based image into a set of diagrammatic primitives such as boxes, lines and text. The output from a drawing tool, such as the one described above, is effectively a set of diagrammatic primitive objects each with its own set of attributes, including special co-ordinates. The use of a tool reduces the complexity the first two stages.

The identification stage uses domain knowledge to identify what we have called minimal meaningful units (MMUs). Thus, an arrow between two boxes is taken to represent a transition, in time, between two actions in the domain of processor architectures. Therefore, an association between two boxes denoted by an arrow is an MMU. The identification stage identifies all MMUs contained within the set of diagrammatic primitives.

The aggregation stage combines MMUs into higher level, abstract features, For example, the diagram shown in Figure 1 consists of two pipelines and an association between them. A pipeline consists of three associations (MMUs).

The final stage, interpretation, looks for meaning in a diagram. In our current application, meaning is ascribed to a student generated diagram through comparison with a specimen solution (another diagram represented as a set of abstract features) for which a grade, based on the degree of similarity, is generated.

In general, a student generated diagram is *imprecise* in the sense that it can be incomplete, contain extraneous material, or be malformed (in the sense that it does not conform to standard rules for drawing specific features in the given domain). A good example is shown in Figure 5 where the expected use of arrows is missing. In this case, associations can be inferred from special

considerations. While it would be possible to design a drawing tool to enforce the rules (and one might wish to do so in a teaching context), we felt that, for assessment purposes, there should be some latitude in what the tool would accept.

In our identification stage, we used the idea of proximity to infer the presence of an assumed association in a student's diagram. Any inferred associations that did not match with associations in the specimen solution (assumed to be a *precise* diagram) were ignored.

## Automatic Marking

As with all our work on the automatic grading of examination papers, we asked a number of independent graders to mark the students' answers. In the case of the drawing question, three graders were used who awarded a modal mark of 3 out of 4 (the average was 2.8 with a standard deviation of 1.05) indicating that students were able to produce meaningful diagrams under examination conditions. Further details of the approach taken to marking diagrams can be found in [5,14].

## Future Work

In this paper we have concentrated on only one feature of the general problem of automating the examination process. To enable students to communicate through diagrams electronically requires a number of issues to be resolved. More recently we have redesigned the drawing tool to cope with Entity-Relationship diagrams as illustrated in Figure 6, taking into account the lessons learned in the trials reported here. The tool is closer to being a CAD tool than a drawing package. We have a new trial underway in which students are using a revised tool in answering assessment questions which will provide a larger corpus of drawings to analyse and mark (the course has around 1200 students on it!). We then intend to apply the results to an online examination later in the year.

To-date our work on diagram understanding, and grading diagrams in particular, has produced good results for small diagrams [14,18]. The representation of diagrams that we have used has proven to be adequate for both capturing the basic data from the drawing tool and for interpreting the diagrams. We are currently examining the use of constraint multiset grammars [7] as a way of formalizing our ideas to enable us to look at alternative representations.
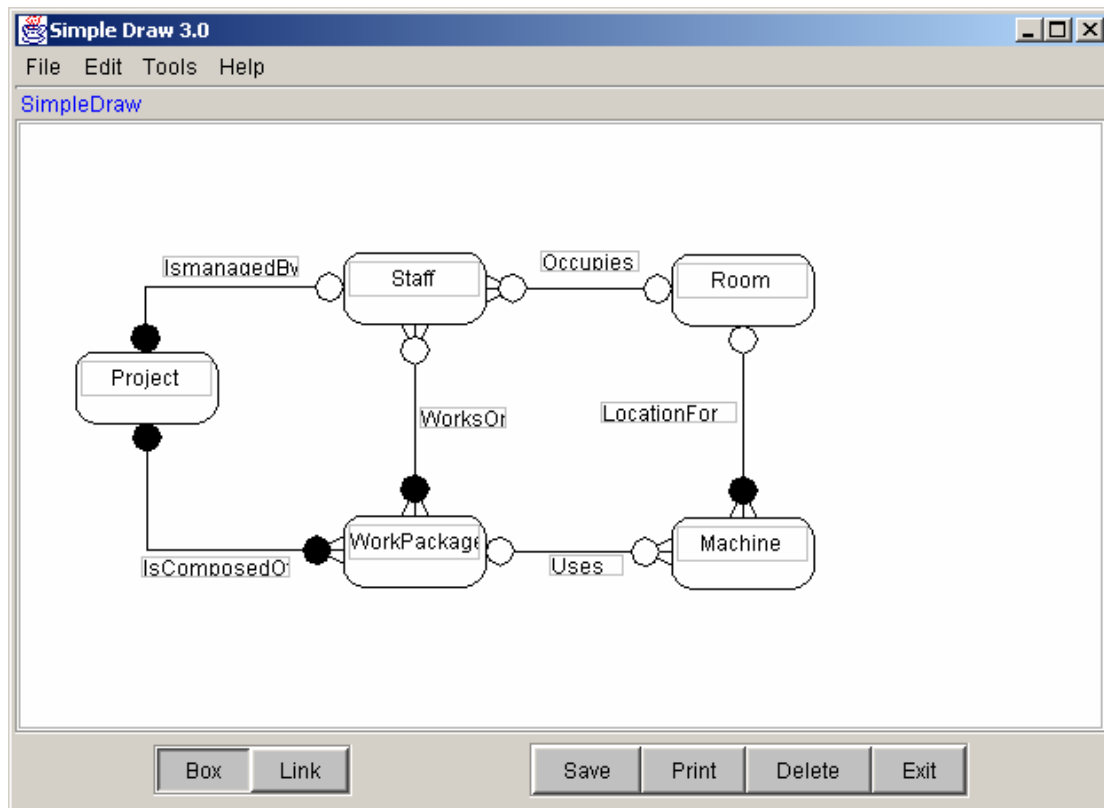
**Figure 6. The revised tool for E-R diagrams.**

The most challenging question, however, is how to provide useful feedback to students on their performance in the examination. In the present system, communication between a student and the marking tool is entirely textual. Students' answers, including diagrams, are text-based, and the feedback is in the form of a textual commentary on their answers. Feedback on the diagram question is simply a brief textual description of the specimen solution. We feel that the feedback should be diagrammatic, so we shall be investigating how to provide such a feature which is likely to require further development of the drawing tool to display the additional information. Whilst we shall continue the practice of enabling the tool to be launched from the examination paper, a stand-alone application will be required for viewing the automatically produced feedback.

## Conclusions

Many questions in computer science examinations are most naturally answered with a diagram, which indicates that diagram drawing and marking components should be included in electronic examination systems. Our initial efforts to provide such a feature have been successful, with diagrammatic answers being created, submitted, and marked.

Asking students to use an unknown software tool under examination conditions would not normally be recommended. However, most of the students in our trials were able to use a simple drawing tool to construct meaningful diagrams in response to an examination question.

Despite the small number of examples of student drawings obtained in the trials and the clear difficulties that some students faced, we feel encouraged to continue the development of the tool and to undertake further trials.

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