The Use of Prototyping and Simulation in the Development of Large-Scale Applications

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Prototyping can be an efficient and effective way of developing large-scale computer applications. In particular, it can realise the improved systems quality which results from users being able to evaluate design decisions before they have become fixed. This paper identifies the benefits that can be derived from the use of prototyping, and describes the steps that must be taken to ensure that prototyping is implemented correctly.

1. INTRODUCTION

This paper deals with the role of prototyping and simulation in large-scale application development. It identifies the benefits which can be derived from the use of prototyping. In particular, it emphasises the improved quality of systems which results when users can evaluate them directly before design decisions have become fixed. Working on a number of large-scale application projects has made it possible to develop procedures for the conduct of prototyping in this kind of environment. The paper aims to describe the steps that must be taken to ensure that prototyping and simulation is both effective and efficient.

2. THE CASE FOR PROTOTYPING

The development of computer application systems that successfully meet the needs of user organisations is heavily dependent upon the design of the interface between the user and the technology. This interface is not simply that represented by the hardware used or the layout of the screen and keyboard, but extends to the interface which supports the match with the tasks of the individual end user and the organisation. Thus a concern for good user interfaces extends deep into the structure of the data and the software and has significant implications for decisions about the nature of the technical system. In the development of large-scale applications, those involving large quantities of data, complex processing and many end users, the implications of creating a poor user interface are particularly serious. The scale of the development often makes it difficult to correct problems which derive from the fundamental decisions about the nature of the system and the numbers of people affected results in higher costs to run the system because of potential errors and lowered efficiency. At best the improvements which can be made are palliative and in some circumstances have to be meshed into the existing infrastructure. It is thus particularly important to ensure that all possible steps are taken during design to produce a user interface which does represent a good solution to user and organisational requirements.

There are a range of steps which can be taken to achieve user-centred design solutions. However, a central feature of those regarded as most likely to be successful is the involvement of users in the design process. The formal recognition of a user role is an increasingly common feature of structured design methodologies, e.g. SSADM.[2] What is less evident is that the recognition of the importance of user involvement needs to be accompanied by effective means of gaining access to user skills and knowledge to inform the design process. It is not surprising that users find the formal methods of representing proposed design solutions hard to understand and cannot relate them to their experience of the task.[3] On the other hand, the technical specialists find that verbal descriptions and written requirements lack the precision which they feel they need as a basis for design.

One solution to this problem of communication between designers and users it to provide more concrete representations of possible solutions, which the users can comment on directly. Such concrete representations may take the form of prototypes of technical solutions with their corresponding interface properties or they may be simulations of the interface and the internal information processing. A more complex version may incorporate prototypes but also be expanded to include other aspects of the socio-technical system, so that the effect of the technical development on the larger organisational unit may be evaluated. The distinction between a prototype and a simulation is really quite arbitrary, since for large applications it will probably be necessary to simulate some aspect of the use of any prototype in order to allow the user to comment effectively.

It is worthwhile to consider two other mechanisms for presenting users with concrete versions of technical systems with a view to eliciting feedback to design. It is common for potential customers for a system to be shown demonstrations. In large-scale applications this often means the opportunity to visit other sites and organisations with systems resembling those being considered. While this is useful for initial appraisal of possibilities, it is rarely considered as an opportunity for end users and is unlikely to yield specific guidance to the designer because of its lack of correspondence to the central concerns of the specific user organisation.

Another option is the development of pilot systems, which are used for the processing of a 'live' workload on a limited scale. The use of pilot systems can be shown to be highly effective as means for defining and developing systems for wider use,[4] but suffers from a number of disadvantages when considered as part of a large-scale development. The pilot system must be developed and evaluated before commitment to the main system is far

advanced, otherwise the outcome will only be of value for the cosmetic improvement of existing design decisions, or as a means of informing the implementation and user support processes. However, pre-specification piloting represents a time delay for projects which, because of their scale, are often viewed as needing as much development time as possible. Another factor is that while pilot systems prove to be most useful as part of an evolutionary strategy, in large-scale systems development it is common to find that the volume of activities which need to be computerised is so tightly interlinked that a requirement for them to be available simultaneously and in all locations is part of the specification. This militates against an evolutionary development strategy.

Prototypes and simulations bridge the gap between these two alternatives. They provide the environment within which users may be offered the opportunity to respond directly to design solutions at a stage when the decisions are still open to influence. In large-scale developments which take place over some considerable amount of time, it is probably true to say that all these mechanisms have a part to play. However, the practical impact on interface design decisions is most likely to arise from the activities of prototyping and simulation, given that pilot systems are not used as a precursor to the decision to commission the application development. This serves to emphasise the importance of ensuring that user requirements are fully and appropriately represented at the specification stage.

2.1 The relationship between prototyping and simulation and the design process

The assumption upon which this paper is based is that large-scale application developments are commissioned for use in an organisation with known tasks and user populations to be served, and that it will be possible to gain access to these people in order to involve them in the design process. This is to be contrasted with the problems of prototyping 'off-the-shelf' products for generic tasks and user populations, which are discussed elsewhere.[3] Large-scale developments must usually be divided into functional stages for the purpose of design. The stages of Initiation, Specification and Logical Design, Physical Design, Development, Installation and Operation are typical of such a division for a structured design methodology. If prototyping is to play a part in influencing the design of the user interface, the most important stages are the first two, where the specification of the system is decided. Of course the results of prototyping and simulation can also be applied to other aspects of system usage, such as the provision of support, training and implementation strategies, and the window of opportunity to use information relevant to these issues is greater than that for specification. However, unless the user issues are addressed in time to affect decisions about the system specification, these latter activities are likely to be dominated by the need to develop strategies which will cope with the technical system as given.

There is a general relationship between the type of user-related information which one might seek to establish through prototyping and simulation, and the time scale of development, and an example of the implications of this is shown in Fig. 1.
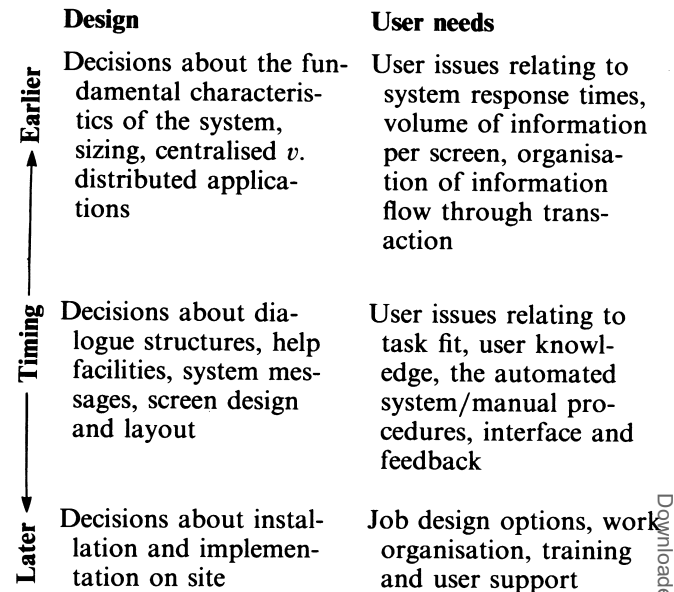
	Design	User needs
Earlier ↑ Timing ↓ **Later**	Decisions about the fundamental characteristics of the system, sizing, centralised v. distributed applications	User issues relating to system response times, volume of information per screen, organisation of information flow through transaction
	Decisions about dialogue structures, help facilities, system messages, screen design and layout	User issues relating to task fit, user knowledge, the automated system/manual procedures, interface and feedback
	Decisions about installation and implementation on site	Job design options, work organisation, training and user support

Figure 1. The relationship between design decisions relating to user needs and the timing of design.

For large-scale developments the decisions about the nature of the design become more detailed as time passes, and later decisions are constrained by those made earlier. Increased differentiation and functional specialisation make it difficult to institute changes because of the impact on the time and resources already invested. While iteration occurs to some extent in all design processes,[5] it is viewed as a problem if the pressure for change cannot be accommodated in a timely and economical fashion. It is therefore important, when considering the role of prototyping and simulation, to identify those aspects of the system impacting on the user, which will become fixed by decisions taken at given stages. This will provide an indication of the points at which testing should be carried out if the information generated is to be perceived to be of value to the designers.

Of course, all the issues might be studied in prototype or simulated form at the beginning of the process, but for complex systems this assumes that one has some way of creating a concrete version of the system without having gone through the process of technical development. In practice there is an interdependence between the availability of the technical system and the possibility of prototyping with users. One must adopt an incremental approach, in which the timely evaluation of design-critical issues is carefully planned. Having identified the stages at which one seeks to obtain feedback from the users on the basis of prototyping and simulation, it is necessary to consider how such feedback should be obtained.

3. REQUIREMENTS FOR THE EFFECTIVE USE OF PROTOTYPES AND SIMULATIONS

Whenever a prototype or simulation is created for evaluation and feedback from users, it will be necessary to ensure that the methods and procedures adopted comply with the requirements for generating valid and reliable data.

3.1 Adherence to design assumptions

As indicated above, the process of prototyping runs in parallel with the development of design solutions. Thus even in the stages of project initiation, a prototype will be based on some assumptions about the nature of the system for which technical support will be needed. It is very important that any prototype should be designed to incorporate user interface characteristics in the form which would be implied by the use of a particular technical solution. This is particularly important when the interface characteristics are predicted to be critical to user acceptability. Where the prototyping activity takes the form of a comparison between alternative solutions, the versions studied should be technically feasible. The particular risks arising in this connection stem from the possibility of creating small-scale and partial versions which are capable of being tailored to present an unduly favourable image of what is planned. A good example might be prototyping an interactive system on a microcomputer, when it is known that the final application will be mounted on a mainframe environment. The likelihood of increased response times in the latter situation should be reflected in the performance of the micro-based prototype.

A complication in producing systems which do adhere to design assumptions is that it may prove difficult to actually achieve the realistic representation of a number of different variables concurrently. It is therefore necessary, in the process of planning prototyping exercises, to identify the critical user-related issues and to ensure that these are represented. If this is not possible, it must be taken into account in the analysis of the data, and the implications of such limitations should be reported in the feedback to the designers. For example, it may be the long-term goal to integrate a number of other applications with the one under development, and while the results of prototyping may be positive with respect to the current application, the reactions of the users when faced with the task of moving from one application to another may be somewhat different. In these circumstances, human factors guidance should be offered concerning likely outcomes. In the situation described above, relevant information would relate to consistency and navigation. Source of information would include the evidence in the literature and experience of other systems elsewhere. However, in this situation it is inevitable that the lack of direct user feedback will make it more difficult to be confident about predictions for actual use.

3.2 The importance of 'hands-on' use

In order to provide users with the opportunity to gain a realistic feel for the characteristics of an interactive system it is important that they be offered direct 'hands-on' experience. It may be tempting to obtain views from users who have seen the system being demonstrated; it makes it easier to manage the prototype and a number of users can be consulted simultaneously. In practice, experience shows that users have difficulty in relating to the characteristics of a system when it is demonstrated, and fail to take account of the dynamic interaction properties. Working with the prototype as one would in the work situation provides a much better basis for judging its strengths and weaknesses. Users must input

information using the keyboard or other input device and move transactions forward in accordance with the information displayed as output. The output from the system should be responsive and appear to be the product of appropriate internal processing of the input data. Engaging in this activities ensures that the user gains a realistic sense of how the system will perform in relation to the task. The experience gained is fundamental to the process of providing meaningful feedback to the designers.

3.3 The creation of a realistic task scenario

Such hands-on use implies that the users must also be able to engage in appropriate task-related activities. They should be asked to carry out selected tasks using the appropriate sources of information, and the materials used should be as close to the real thing as possible. This means having paper records if these are used as a basis for input, and the data presented should be of the type and form which is common to that task. If the input task is carried out in conjunction with the use of other information sources, such as telephone enquiries or face-to-face interviews, the prototype task should allow for these to be incorporated or simulated in some way. Where computer-based activities form part of some larger sequence of activity, it is desirable to examine the interface between the computerised and non-computerised activities, in order to evaluate the way in which task functions have been allocated.

It is also important that in relation to the question of assessing the acceptability of the prototyped system for routine use, the users should be able to spend sufficient time working on the system, so that they are familiar with both the tasks and the general attributes of the application. This has implications both for sampling the projected user population, which will be discussed in the next section, and for the length of time which may be involved in prototyping. Some activities may last for a matter of hours, while others may require users to be involved over a period of weeks. The need to develop habitual aspects of usage through longer-term exposure means that a more complex prototype is required. This will need to support a sufficiently varied job and be sufficiently demanding to engage the participants' motivation. This implies the simulation of some parts of the system's operation, and the decision to engage in such long-term activities must be based on an assessment of the potential effect that problems may have on efficiency and acceptability in long-term use. However, if the decision is taken to establish the infrastructure of such a simulation it does make it possible to examine the widest possible range of issues, including usability, acceptability and aspects of organisational match.

3.4 Sampling the user population

Ideally one would recruit a sample of the user population which is statistically representative of the projected user population on all relevant dimensions. In practice this is likely to prove impossible, because of the size of the sample which would be required. It is therefore important to ensure that the sample is as representative as possible on critical dimensions. Particular attention should be

paid to recruiting volunteers who are representative in terms of age, sex and grade of employment. It must be realised that the evaluation of prototypes and simulations is dependent upon the willing co-operation of users. Thus any attempt to draft users, because they are 'representative', is likely to result in resistance and bring a generally negative attitude to what is being tested. It is also important to try and ensure that the sample is not biased towards people who have particularly positive or negative attitudes to computers. Since the sample must be based on volunteers, it is likely that larger numbers with a special interest may come forward, and it may be necessary to take additional action to encourage more disinterested parties to agree to participate. These issues have significant implications for the management of prototyping activities and mechanisms which are established for communication with the user population about the developments in Information Technology applications which are under way.

Other characteristics of the organisation may affect sampling. If the installation is to be spread across the whole country, there may be regional trends in the characteristics of the employees which must be taken into account. In some areas there may be high labour turnover, with the result that staff tend to have a much shorter period of experience than is typical of other parts of the country. This issue may be particularly critical to the trade-off between 'ease of use' and 'ease of learning',[6] since in one case the speed and efficiency with which the system can be taken in is highly significant for its overall effectiveness in the long term, while in the other case a longer period of learning may be compensated for by the greater ease and efficiency and sense of satisfaction with which it is used by experienced staff.

A further issue which affects sampling from a range of locations is the decision about the form in which the prototype or simulation will be mounted. If the prototype can be mounted as a stand-alone system it may be possible to move it from one location to another for testing. This undoubtedly has advantages as far as recruiting a representative sample is concerned, since it removes a number of the barriers which may discourage certain categories of user from travelling to a remote location to evaluate a prototype, e.g. women staff with dependent children. However, it must be recognised that it is likely to be impossible to mount a complex system simulation which will support whole jobs or groups of workers as a mobile unit, and the disadvantages of bringing people away from their normal work locations must be accommodated in some way. One possible development for the future might arise from the availability of existing applications. Where an interactive system network has been established, this might be used to provide the infrastructure for testing of prototypes of new interactive applications at a variety of locations. However, this would have implications for the provision of capacity and facilities and would require careful management.

3.5 Data collection

The process of gathering information about the users' responses to the prototypes may take a variety of forms, utilising both direct measurement of performance, accuracy, speed, errors and requests for help, and the collection of subjective views, opinions and attitudes. The methods are those which are fundamental to the disciplines of ergonomics and applied psychology. The most important consideration is to identify, from the wide range of techniques which might be used, those which will yield information which will be informative with respect to the key questions arising in relation to the future use of the proposed system. At the same time the chosen methods must be compatible with the circumstances in which the prototype will be mounted. For example, direct measurements of speed and accuracy may be precluded by a variety of factors, the nature of management/staff agreements, the absence of monitoring equipment or a shortage of staff able to record and analyse such information. The process of deciding what methods to adopt is therefore complex, and requires careful planning in conjunction with the planning of other aspects of the prototype.

It is worth noting that careful selection of methods for data collection is particularly important in relation to the capacity to analyse the data which result. Developers are continually surprised by the volume of information which can be generated by a prototyping exercise. While it may appear tempting to develop systems which will automate data collection down to the level of individual keystrokes, there should be a policy that data collection is organised in accordance with a hierarchy, which will allow issues to be examined at the highest level consistent with the nature of the area being considered. Only if there is evidence that problems have their origins at a lower level of detail should the corresponding analysis of the detailed data be pursued.

4. THE PLANNING OF PROTOTYPING EXERCISES

User involvement in prototyping is a demanding process, and in order to make it fully effective it is necessary to plan the activities in a systematic and carefully structured way. In view of the importance of the earliest possible use of prototyping and the significant interdependence which it has with the design cycle, it will be evident that the timing of the design decisions will be a major influence on the allocation of priorities. Having identified the timescale within which decisions must be made, the aim must be to select the topics which should be given priority in terms of investigation at a given stage of the design cycle. The guidelines for assigning such priorities can be broken down into three categories.

4.1 Frequent usage

Any use which represents a significant proportion of overall activity should be included. For example, it would be essential to cover the processes associated with gaining access to the relevant applications. There may also be dialogues which are used for a majority of all transactions, and this heavy use would lead to significant costs if the match to user needs was sub-optimal.

4.2 High-risk activities

Other areas which should be given priority are those dialogues and exchanges where the consequence of failure carries a high penalty, for example if errors are

likely to be perpetuated in other parts of the system or the cost of retrieving mistakes is high.

4.3 Uncertainty

The third cause for assigning priority would be in any area where uncertainty exists about the adequacy of standard recommendations in relation to the particular tasks and user groups, or where the proposed design solution does not conform to generally accepted practice for such tasks and users. In these cases the issues which arise should be explored in a prototype or simulation before a final decision is made.

Having decided what is to be tested in the prototype, there are a number of activities which need to take place in parallel.
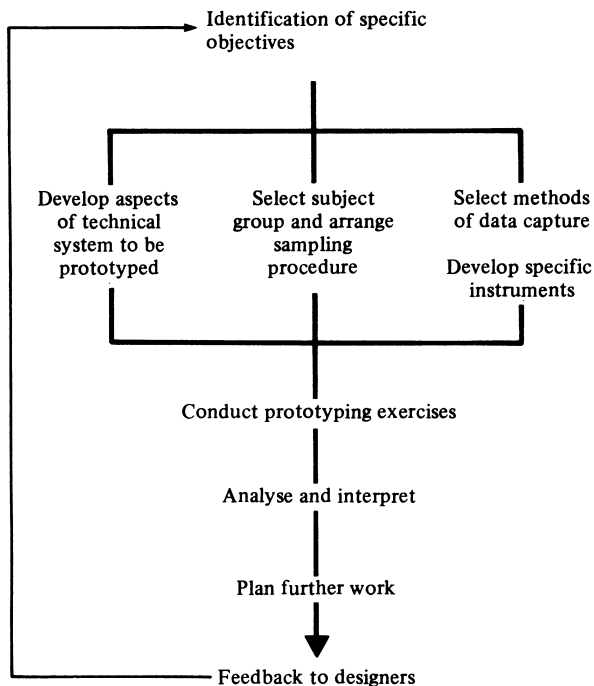
Figure 2. Stages in the planning and conduct of prototyping exercises.

With a knowledge of which objectives are to be addressed by any particular exercise or set of exercises, three things need to be addressed. The first is the development of the necessary technical support for the interface issues to be prototyped, including the tasks and supporting materials. The second is the issue of identifying the subject population and recruiting a sample. The third is the development or tailoring of suitable data-collection methods. Decisions made about these issues will be conditioned by the objectives of the exercise, and trade-offs will depend on the course of action which will best meet the goals.

A simple illustration of how the particular goals of an exercise may influence decisions at this stage is illustrated in Fig. 3.

Depending upon the nature of the issue which is to be examined, one may vary some aspect of the exercise. In this example, the choice of the subject sample will be very different if the aim is to evaluate the adequacy of the

Example of planning required to ensure specific objectives are met

Selection of user subjects

Objective	
Test dialogue suitability for habitual use	Identify parts of dialogue which need extra training and support

Subject sample	
Long-term users of prototype	User sample never previously exposed to prototype

Figure 3. An example of how different objectives may affect the selection of subjects

interface for long-term usage by experienced operators, as opposed to the sample of users that would be required to take part in an evaluation of the prototype training programme for the interface.

The conduct of prototyping exercises and the analysis and interpretation of the data collected are specialised subjects in themselves, and will not be discussed here. The only point which it seems appropriate to make relates to the involvement of users in the evaluation process. In the type of application development which is being discussed here, the people who become involved in the evaluation process are, or should be, the future users of the system. They should be well briefed about the stage and status of the design to which the prototype relates and they have the right to know, in general terms, what the results of their participation have been. This feedback is important to them as individuals, and also provides the opportunity to communicate information about proposed developments to the wider user group.

Of course the most important aspect of feedback is that which is provided for the design process. The whole object of prototyping and simulation is to give the designers information which they can incorporate into their decision making. It is not possible to be dogmatic about how this feedback is achieved. In some cases the designers will play a significant role in the prototyping exercises themselves, while in other cases these activities may be assigned to a specialist group who transmit the results to the designers. In each case, however, it will be necessary to review the results and classify them in terms of their impact on the design. There will be indications that in some cases the design itself needs change, while in other cases the results may indicate a requirement for special attention to training for certain groups of users. Where action is needed there should be a forum for agreeing the priority to be assigned to the different issues, together with the opportunity to agree a course of action for the issues that are raised.

In some cases the nature of the results may require more detailed investigation or analysis, or the prototyping may move forward to the issues relevant to the next stage of the design cycle. One point which it is important to remember is that where prototyping leads to changes in design, these should be verified in a subsequent prototyping exercise. If prototyping is to be effective it must be used as part of an iterative process in which the need to re-test revised designs is recognised and allowed for in the planning of design activities.

5. IMPLICATIONS FOR THE MANAGEMENT OF THE DESIGN PROCESS

As the above section will have indicated, the systematic use of prototyping in order to achieve designs which better match user needs is likely to have considerable implications for the management of the design process. While prototyping the user interface in the early stages of design is a cost-effective means of avoiding the expense of putting things right at the end, or running a system that is sub-optimal in terms of efficiency, there is a requirement to allow for both time and resources to be devoted to the prototyping activities in the earlier stages. It will be necessary to identify the points in the design process where prototyping is to be used and to agree a strategy for allocating time and technical effort to achieving the desired result. In particular it should be noted that in structured design methodologies, which are very popular in the United Kingdom for large-scale applications, there is to some extent an inbuilt resistance to the use of any technique which will require iteration in the design. Some of these barriers are reduced by the recognition of the advantages of prototyping and the advent of rapid prototyping tools, but it must be pointed out that while it may be easier to develop the technical interface with new technology, the need for systematic and thorough attention to the other requirements for effective prototyping of user interfaces is not lessened. It should also be noted that for large-scale applications the role of rapid prototyping tools is constrained, because at the present time they are not capable of adequately representing, from the users' point of view, the complexity and scale of the applications being developed.

Despite these constraints it is possible to develop effective prototyping strategies and to put them into effect. The stages involved must be formally recognised in the design life cycle, and roles and responsibilities assigned to relevant people. In applications where the users are given a significant role in the development process, they may be the best people to take responsibility for the management of prototyping. This is particularly useful if they have the formal role of approving the specifications and design solutions, since the prototyping activities will provide them with direct evidence upon which to arrive at their decisions. It is important to maintain a close relationship between the various parties. Inevitably the scale of activities tends to lead to the division of responsibility, and it is important to ensure that both groups know what is happening in the other one. For example, it is easy for proposed design solutions to move on, without the new elements being incorporated into a prototype, or the designers may develop a particular form of solution without being aware of some difficulties which have emerged in the prototyping exercise. This close communication has to be achieved without either group becoming a hostage to the other group's immediate priorities. Looked at from the perspective of user-centred design, it has to be said that the tendency has been to allow the technology to drive decision making, particularly when there is a great deal of time pressure. One of the features to emerge from prototyping is a much clearer sense of the user's priorities, which enables them to separate issues which are highly significant in their impact from those issues which tend to dominate popular discussion while having no significant long-term implication.

6. CONCLUSIONS

Prototyping and simulation are powerful tools for ensuring that users can contribute to the design of systems. If they are to be used to full advantage they require systematic attention to the circumstances in which they are applied and particular consideration must be given to their role within the design process.

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