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SIMULATION ON MICROCOMPUTERS
THE DEVELOPMENT OF A VISUAL INTERACTIVE MODELLING PHILOSOPHY

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Abstract

This paper describes the development of a visual interactive modelling philosophy in Ford of Europe. The challenges of developing large visual interactive simulations on microcomputers are discussed together with the methods adopted by the authors for overcoming them. The benefits of modelling in this manner are also discussed and two case studies are presented.

Background

The Operational Research department of Ford of Europe did not begin to use simulation modelling techniques in earnest until 1977. This date coincides with the planning of a new Engine Plant at Bridgend in South Wales. Simulation models of the proposed cylinder head and cylinder block machining lines were developed. These early models were so successful that requests were received to model a number of existing facilities in order that a better understanding of their operation could be gained.

All modelling up to January 1982 was done using either FORTRAN or GPSS (mainly GPSS) in a batch environment on large IBM mainframes. Since that date, with an ever expanding workload and conscious of the need to develop models more quickly, a different modelling approach has been adopted.

This approach has been based on the use of simulation models which are both visual and interactive and run on micro computers. By adopting this method it has become possible to take the models directly to the project sponsor (or User). In the comfort of his own office he can see the models working and he can interact with them directly changing many variables easily and quickly. Because of this involvement his commitment to simulation is far greater; he more readily accepts results generated by the models and in some cases he is starting to develop his own models.

Simulation modelling projects now cover the whole spectrum of Ford's manufacturing operations in Europe. Models are being used to assist in the planning of Flexible Manufacturing Systems (FMS) as well as the more traditional automation normally associated with the motor industry. Where changes are being planned to existing facilities or where problems with existing facilities are being experienced then simulation models are providing valuable information. With the advent of monitoring systems on the shop floor the opportunity for the development of simulation models for crisis management is also being investigated. Because of the complexity of the majority of the models which are now being built and the limitations of memory and speed on microcomputers it has been necessary to develop methods which will help overcome some of these problems. The use of these methods, described in more detail later, are now an accepted part of building visual interactive models in Ford of Europe.

Introduction to Visual Interactive Modelling

The essence of visual interactive modelling is firstly the ability to display on a colour screen a mimic diagram which the model User can relate to and receive as a moving picture of the dynamic system under study. Secondly, the User can stop the model at any stage to check, in detail, its workings and modify any element of the model. Thus, decisions are made by the User who is helped in making his choice by looking at the current status of the problem area displayed on the screen.

There are many advantages in using the visual interactive approach to simulation and some of these follow directly from the two concepts defined above. Using a moving colour picture as output ensures that everyone involved in the study completely understands the rules used and the assumptions made by the model. The model is easier to validate and this must increase the confidence in the model of both the User and the analyst. Also, by presenting an overall and structured view of the study area counter-intuitive patterns of behaviour can be seen and this new information can lead to better solutions to problems. The extensive interactive facilities within these models allow the user far greater control over the model. The User can change, interactively, the layout on the screen, or the control rules embedded in the model, at any time. Alternatively, the model can be programmed to stop when certain conditions are met and prompt the user to make a decision.

A full discussion of visual interactive modelling and further references can be found in the papers of R D Hurrion(1), E Fiddy(2), and B W Hollocks(3).

Implementation Strategy

At the same time as these advances were being made in visual interactive modelling rapid changes were also occurring in the technology of car manufacture. New types of machines were becoming available and new ideas on how to operate them were being developed. Ford of Europe were committed to using the new technology and required methods of evaluating proposals in this increasingly complex world. Simulation had proved itself an effective method in the past and it was anticipated that visual interactive modelling would be an even more powerful tool. Thus, the new modelling software matched a real business need in the company and it was decided to promote the use of simulation within Ford of Europe.

The Operational Research' department was asked to develop a strategy for implementing visual interactive models within the company. Two key decisions were quickly made. For the first part, Operational Research would take charge of coordinating the implemention of visual interactive modelling software. Secondly, every attempt would be made to involve the User in the simulation process with the ultimate aim that they would become model builders as well as model Users.

To begin with models were developed by Operational Research that were simple to operate, easy to understand and could be changed without reprogramming. The project sponsor was encouraged to take responsibility for the model by borrowing a microcomputer and using the model at his own desk. For the first time within Ford of Europe the user could validate and experiment on a model. This policy proved very successful and demand for the loan microcomputer quickly became so great that individual departments bought their own systems. Currently, thirteen User areas have visual interactive modelling systems installed.

Effect of this strategy on Users

The use of visual interactive simulation models on micro computers located in the Users' own work area has led to a number of significant changes in both the way simulation models are used now compared to before and also in the time spent on associated activities.

It has been found necessary, in order to obtain the full benefit that a model has to offer, to train Industrial Engineers in the practicalities of setting up and running a completed model and the use of the host simulation software on its associated micro equipment. To this end internal training courses and refresher courses have been developed and attended by the major Users of visual interactive models in Ford of Europe.

It is essential that the model developers themselves are familiar with simulation techniques. Also, those members of the Operational Research department whose background has not covered simulation have attended courses on simulation as well as software familiarisation. Likewise any potential model developer in a User area has been recommended strongly to attend simulation, programming and software courses rather than rely on second hand information and trial and error.

However, in order to benefit from the model development experience being built up in many areas outside the Operational Research department, study groups have been set up to exchange information. Here, for the first time, people from very different functions within the company have been able to meet and discuss common simulation problems. This has been a unique development directly resulting from the implementation of visual interactive modelling in the User area and is considered to be a major benefit to all involved.

It has been possible at such study group meetings to set up sensible modelling standards by example and keep a record of work in progress to avoid duplication of effort. The meetings are hosted by different areas in turn and may be preceded by a workshop or gathering where models under development are brought along and run on local equipment, viewed and discussed. Sub-committees covering an aspect of simulation common to more than one area have been set up and report regularly to the study group. Conveyor modelling and machine breakdowns are just two examples of such common areas of interest.

Study group meetings are attended by both Users and model developers and by Industrial Engineers who may be both. In general however 'complex' simulations are developed by Operational Research and only 'simpler' models by Industrial Engineers alone.

But with the introduction of more generic models where Users can run models that are flexible enough to build significantly different simulations, many Industrial Engineers can contribute sophisticated skills in model use to such meetings.

The success of visual interactive simulation in User areas can be measured by the number of people Ford of Europe has trained in model use. Ford now has thirteen working visual interactive modelling installations on microcomputers in Europe. The Operational Research department has three to four people working full time on visual modelling and about ten Industrial Engineers outside Operational Research spend a significant amount of their time developing their own models as well as using ones built by Operational Research. The simulation study group meeetings are attended regularly by twenty five people who take a full day out of a busy area of the company to contribute and exchange information. These figures are considerably higher than the maximum number of people ever involved in simulation using batch orientated software.

The Model Building Process

Analysis An initial conventional systems study is undertaken to ensure that visual interactive modelling is an appropriate tool for investigating the system. At the end of this study the analyst should be able to state the objectives of the investigation.

A detailed report is then prepared describing the rules that govern the system and the data that are available. The report is usually written by the User under the guidance of the model builder.

It is often the case that data is readily available but very little understanding of the control rules exists. Interactive models give the inexperienced User the ability to change data easily, therefore less time need be spent collecting data during analysis and the model builder can concentrate on exploring the logic of the system under study. It is interesting to note that a simple visual model may be developed at this early stage, as it has been found that even a static display on a colour monitor can help communication between model builder and User.

The final stage of analysis is to structure the model. A variety of formal techniques is used within the department and these include entity life cycle diagrams, activity cycle diagrams, and state-event diagrams. All of the methods require the analyst to draw on paper the logic of the problem area using a simple set of symbols as building blocks. The diagrams are then presented to the User who checks that they correctly describe the system.

Structure The first releases of visual modelling software that were bought by Ford of Europe ran on a Cromemco Z80A based 8 bit micro. 192K bytes of RAM were available but when the operating system and host simulation software were loaded only 34K bytes of RAM were available for model logic. The storage of the "simulation data array" (entity, set, timeseries, histogram etc. information) was an overhead on memory occupied by the host simulation software.

It soon became apparent, with the level of detail being modelled and the size of the problem under study, that the 34K bytes of RAM were going to be a severe limitation.

All models that are developed have to go through a definition phase which initialises the "simulation data array". This definition phase is only executed once but its code continues to occupy part of the 34K bytes of RAM during the rest of the simulation run. With large models this could be in excess of 20K bytes.

To overcome this restriction large models were split in two. A "define" model and an "execute" model were developed separately. The interface between the two models is the defined model's simulation data array. This is stored externally from the model but controlled internally by using the interaction facilities provided by the host simulation software. (In fact this feature of the host software is used extensively to "save" states of the execute model after various experiments and at different simulation times.)

Figure 1 illustrates the concept of a two stage model. The figure also shows data "packets" entering and leaving the execute model. Data "packets" are a feature of very large model developments when even the two stage model approach does not yield sufficient memory. Data "packets" evolved from the idea of using a number of micro models and a macro model to describe fully the plant or process being modelled.

Initially data "packets" consisted only of the absolute clock time that entities left the micro model. The list of times then provided an arrival sequence for the next micro model in the sequence. This approach proved to be unsatisfactory when entity type information was also called for in the successive micro model. The data "packets" now contain coded information relating to entity type and associated attributes as well as absolute clock time.

At the macro level arrival times may be taken directly from the data "packets" or they are combined to produce arrival distributions which are then sampled from on a random basis. Also at the macro level data "packets" are produced which can be used by lower level micro models.

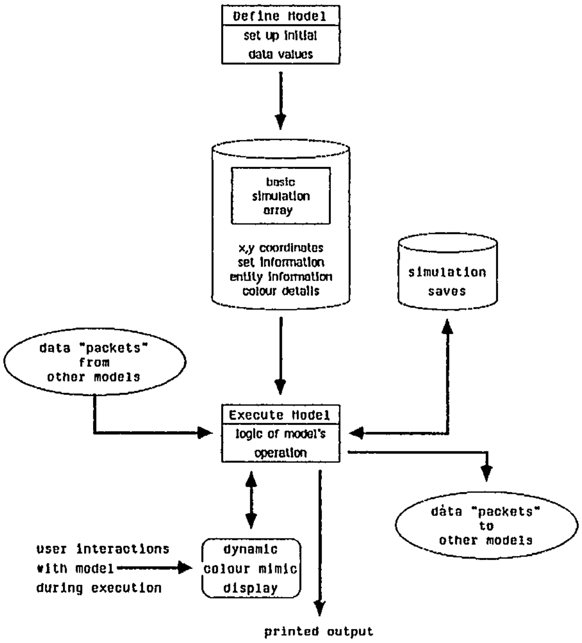

Figure 1: Two Stage Model

Use of micro and macro models in this way obviously does generate a number of difficulties. While it is possible to model forward interference accurately it is not easy to model backward interference successfully. To overcome this problem the User is provided with sufficient information to enable him to test the preceding models in the cycle. Improved methods of linking models are under investigation.

An example of the use of micro and macro models can be seen in Figure 2. The Bridgend Engine Plant is again featured in the example but this time the engine assembly lines are being modelled. Modelling to this degree represents an investment of approximately 7,000 lines of executable FORTRAN code without taking into account the host simulation software overhead.

Since the beginning of 1984 development of visual interactive simulation models has been done using 16 bit microcomputers. The Cromemco micros were field upgraded to 16 bit mode and 512K bytes of RAM were added to each machine. The 16 bit processor (68000 based) and additional memory did to some extent solve the model size and speed limitations.

During the conversion process of existing models it soon became obvious, however, that the previous philosophy of two stage micro and macro modelling still had a major role to play in the enhanced computing environment. In particular the example given above was still too large to be modelled as a single model. Even if memory size had been increased to accommodate it as a single model it is likely that the speed of execution would have been too slow to allow useful exploitation.

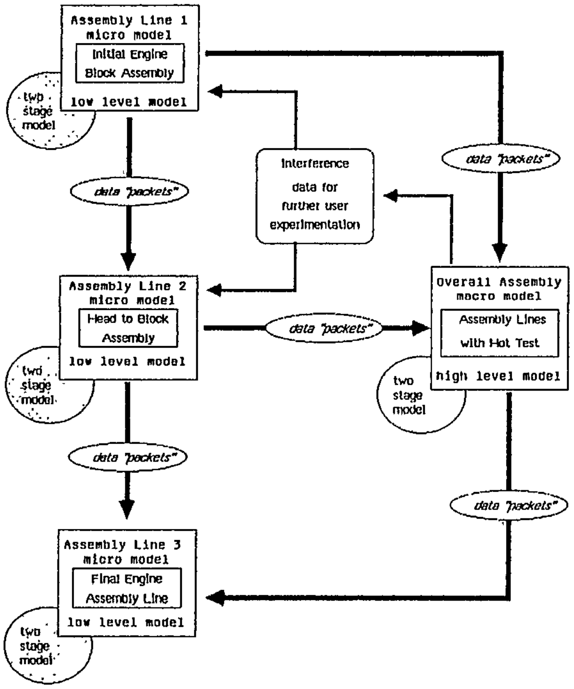

Figure 2: CVH Engine Assembly
Bridgend Engine Plant
South Wales

Design Inevitably the use of visual interactive software which offers a wide range of screen output facilities has led to more time being spent on the screen design of a model. The power of a pictorial representation of a study area has encouraged the model developer to design screens that clearly outline the situation. Shape, colour and movement are used to highlight critical situations as they develop as well as to highlight the statistical output of a model.

Large detailed models which contain too much information to fit on one screen have been split onto more than one screen. Typically a schematic Macro screen and a number of more detailed Micro screens, which may overlap, have been used for one model. This idea of 'paging', where the screen can be cleared and a completely different area of the model displayed in detail, while the model is running, is considered to have great potential for further development. An infinite number of screen layouts is ultimately possible for one model. Also, having a number of different screens representing the activity in a particularly critical area of a simulation eg. a machine, or a conveyor section or a buffer store, can greatly improve the understanding of the activity. This can be done using the 'paging' concept and redefining screen coordinates. Alternatively some software on the market offers the facility of 'windowing' across an almost infinite picture of information where more than one representation of the activity may exist. It is usually possible to display more than one of such windows next to each other on the same screen if desired.

The visual interactive models currently being built in Ford of Europe are more decision orientated than previous batch simulations. They have incorporated in them interactive routines to input and change the variable data of the model. This is usually done using a 'paging' facility where the screen is completely cleared and the current data values displayed. The cursor is then used to overwrite the old values with the new values and the interaction validates the new values as they are put in.

Other interactive routines are usually incorporated to allow preprogrammed 'what if' options to be taken up and assessed at any point in the simulation run. Likewise any other graphical screen, or 'paging' utility or printed report may be requested at any time.

Because of the interactive nature of the simulation, control can be returned to the User at any critical point to highlight a problem that has arisen but has not been catered for in the existing logic of the model. Even at this point standard software routines may possibly be used to effect a decision that would have to be taken in reality and the simulation can then be allowed to continue.

In general the interactive sequence of User decisions may be represented as in Figure 3.

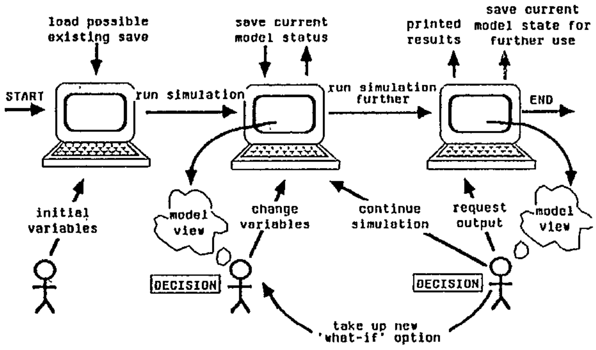

Figure 3: Interaction Sequence

The incorporation of more and more alternatives at decision points in a simulation will inevitably increase the amount of checking and snuffling of information that occurs as the model is running. This may slow down execution time. A number of run time improvement techniques have been used successfully in large models written by Operational Research, including Fibonacci searches of sequential stores and binary heap sorting methods. Also the conversion of real numbers into integer equivalents before storing and sorting and then reconversion to real only on output has been found to be worthwhile. These techniques are transparent to the User beyond their associated improved run times

A more apparent effect on the final simulation model design from the use of visual interactive techniques has been the virtual replacement of a 'Final Report' on the area under study with a 'User Guide' produced by the model builder. This

User Guide contains complete instructions on how to use the model, what facilities are included in the model, what assumptions have been made and what interactions are available. It may include some recommendations for experiments to be performed but usually it contains no detailed analysis of any operating strategies for the area being studied. This is now done entirely by the trained Industrial Engineer in the User area.

Other benefits of visual interactive models

Personalising the model Standard interactions are available to change the display position and colour of items that appear on the screen. The User can modify the screen to his own personal taste and this allows him to make a contribution to the design of the model. Consequently, the User feels that the model belongs to him and greater enthusiasm is generated for the model.

Models as catalysts Visual interactive modelling quickly showed it could act as a powerful stimulus to the Users' imagination. Furthermore, groups of Users with conflicting interests used the models to understand each others' views and to help resolve their differences. Thus a visual interactive model promotes new and original ideas, and can act as a catalyst for discussion between groups.

Models as training aids Visual interactive models have been used to introduce line foremen to new facilities and working methods. The model provides a cheap and safe method of giving foremen experience of running their plant. It is the industrial equivalent of a flight simulator.

Productivity

As the use of visual interactive simulation modelling has increased within Ford of Europe, demand for the development of further models of the company's manufacturing facilities has increased. With more people than ever before developing models it could reasonably have been assumed that the overall demand would fall; this has not been the case and the backlog is increasing.

To help alleviate the backlog, effort has been put into the development of User controlled generic models. To date two such models have been developed and their impact has been impressive. With one such model (described briefly later) the time to construct a 30 station machining transfer line model has reduced from approximately two and a half months to three days.

The need to cut down the amount of time spent programming has led to generic model construction which is data driven directly from the keyboard. This is now being supplemented by the use of structured data files which are read into the model during the definition and execution phases. Both these approaches feature dynamic screen layout redesign during normal running.

Another approach also being adopted is to review the simulation software market place on a regular basis. This ensures that any products which do become available can be evaluated quickly and all current simulation software suppliers to Ford of Europe kept aware of how they should be developing their product. In addition, should alternative simulation software become available, which offers significant productivity gains whilst retaining interaction and screen design flexibility, then a change of host simulation software would become inevitable.

Case Studies

V6 Crankshaft Machining Line - Cologne

Crankshafts for the V6 engine, installed in cars built in Europe and light trucks built in North America, are produced by the machining line in Cologne, West Germany. The demand for V6 engines is high. On occasions the demand exceeds the rate of manufacture and the crankshaft machining line is seen as a major bottleneck in the supply of parts to the V6 engine assembly lines. In order to improve this supply of crankshafts a major investment in the automation of the V6 machining line was made recently. The increase in output that such automation was designed to provide did not, however, fully materialise and a visual interactive simulation of the current line including automation was requested.

Ideally the effect of introducing automation to parts of an existing machining or assembly line would be understood before implementation. The availability of visual interactive simulation, however, was not known until after the automation was introduced. The model that was requested was to be able to simulate the exact manufacturing process currently in operation and also to cater for new crankshafts known to be needed in the near future. The automation between machines was to be modelled in detail to investigate its full effect.

Investigation of the existing machine line revealed that over fifty machines were used on the line along with a number of dedicated mechanical loaders. Also seven automatic loaders were loading more than one machine. These automatic loaders have the ability to distinguish between machine types. The transfer between machines was automated for nearly the complete length of the line with some sections using plattens or another type of carrier along the conveyor. The line itself was not in fact linear but included a number of junctions where the route taken by a crankshaft depended on derivative type and prevailing store sizes at that point. The model included on and off loading of parts between machines and machine breakdowns and tool changes. Some of the code relating to these aspects of the model was taken from other existing models in the Operational Research department. This particular model concentrated on the logic prevailing at junction points and the shared automatic loaders to ensure the model accurately reflected the existing line.

The detail of the model necessitated the use of more than one screen. Four 'pages' were used, three at a micro level, on overlapping sections of the line, and one macro screen that did not show off line stores or standby operations but gave an overall view of the condition of the line. A full screen was used for machine data changes and also for machine statistics. An initial full screen was used to set up batching requirements and the availability of manual on and off loaders and maintenance. Figure 4 shows an outline of the screens the full model offered.

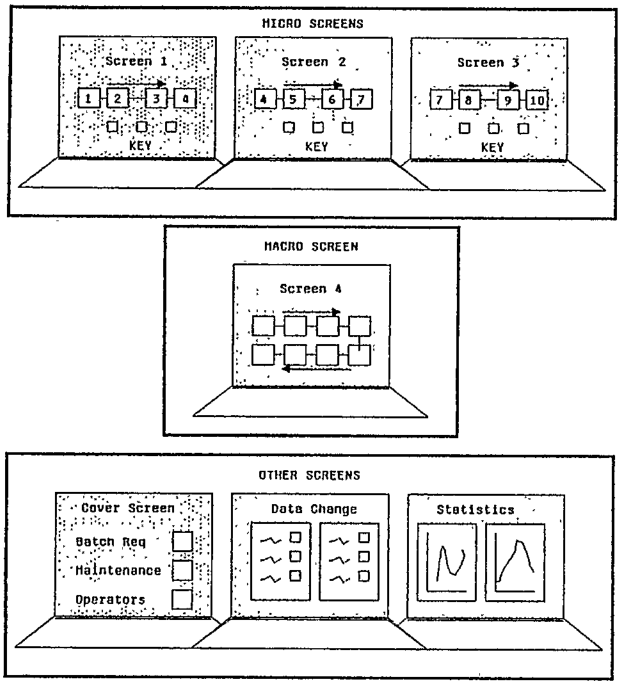

Figure 4: V6 Crankshaft Line Model - Cologne Screens Available

Generalised Transfer Line Model Machine transfer lines are a common class of facilities found in the automotive industry. These are serial lines of machines connected by automation which acts as a buffer store between machines. This is called on-line storage. Floor space is also available next to the machines and this off-line storage is used as a buffer when the on-line store cannot cope with machine stoppages.

The Operational Research department has developed a generalised transfer line model known as VICTOR. The VICTOR software allows inexperienced Users to build and experiment with visual interactive models of transfer line facilities.

VICTOR models are developed in two stages.

The User first defines the model using interactions to specify the logic of the transfer line, the picture on the screen, and the model data. All interactions are controlled from menus that are written in a clear and consistent way. Particular attention was paid to the screen definition phase because this interaction had to be flexible enough to represent a complex layout but still be easy to use. The balance between these two aims was achieved by presenting output from the model in four different ways. The four types of screen represent a summary of statistics of all machines; timeseries of hourly production by machine; a detailed display of the changing status of machines; and a more general display of the changing line status. The screens are allocated to nine pages and the User can switch from page to page during a model run. Consequently, the User can look at the model at different levels of detail and he can also define the form of the model output for the last three types of screen. When the User has finished defining the model the status of the simulation is saved.

The second stage of a VICTOR study uses the defined model save as a starting point for carrying out a model run. A series of controlled experiments is then carried out. The User has the ability to change all of the model data at any time during a model run and can also request printed reports of the model statistics. VICTOR models have been used to examine ways of making more effective use of man power, reducing stock levels, and quantifying the effects of different tool-change strategies.

There have been many benefits from developing the VICTOR modelling system. The most important of these are that visual interactive models of transfer lines can now be built within days rather than months; inexperienced Users can develop models without the need to learn a programming language; and code from VICTOR has been incorporated into other more complex models.

Operational Research plan to develop a more extensive modelling tool based on the philosophy that proved so successful in the design of VICTOR. The aim is to provide an interactive framework for developing any visual interactive model. The software will be used at two levels. Firstly, it will be used as an aid to Users who want to develop small to medium size models of a wide variety of areas. Secondly, it will be used as a productivity tool for experienced analysts who want to prototype large and complex models. Standard interfaces will allow the analyst to combine any unique code with the prototype model. If the code has a wide range of applications it will be added to the modelling environment and become available to future model builders.

Summary

This paper presented a brief look at the development of a visual interactive simulation philosophy in Ford of Europe. The work described represents just a small part of the total effort expended in this area over the last two and a half years. All involved in the work are enthusiastic and well motivated.

Visual modelling has opened up a new dimension in the communication process not only between model developers and Users but between Users and their own management. This communication process has also extended downwards to such an extent that line workers are being given the opportunity to view and interact with the models.

Visual interactive modelling is still in its infancy. Over the next few years there is likely to be an accelerating development; during this period Ford of Europe will maintain its leading position.

References

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