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TOWARDS COMPUTER ASSISTED DISTRIBUTED DESIGN

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1 Background

It is rarely in industry that designers meet an entirely new design task. Mainly their work is based upon previous concepts or products. Usually the outline for the overall design is well established before the detailed aspects are commenced. The designer is then often faced with considering variants, the improvement of sub-parts within that overall framework. As this must fit in and integrate with existing designs it is necessary to follow the existing practices and processes of the design office. Here greater use can be made of previous work if a parametric designing approach is applied [1] which is supported by most modern CAD systems. From the parametric description of a single form of a component, a whole family can be derived. Whilst these take longer to prepare than single one-off designs they similarly provide great benefits when parts are generated from previously prepared features and assembly models are required [2]. However this approach needs to be closely controlled as considerable time can be wasted in a large distributed project in searching for suitable parametric features and in adapting them to the particular design need.

When the design activities are widely distributed, possibly across large distances, between experts with different skills, and time zones, the problems of communications, accessing information and project control becomes more difficult to handle. This can become even more of a problem when different teams of designers operate across a range of modelling and representational tools (including standard engineering drawings), implement different analysis tools and employ a range of different manufacturing facilities. A major part of the role of the design management team is to control these activities, from design concept through to manufacturing processes without stifling creativity, without minimising design improvements or taking excessive time to complete the task. Such problems are generic and caused by a lack of full understand within the team which is not restricted to simply geographic location.

1.1 Multi-disciplinary designs

The problems expressed above are further repeated in the creation of products that require the input of a number of multi-disciplinary teams. Whilst these may not be widely distributed globally (so that may have the opportunity to meet regularly), they may not have a common understanding or appreciation of the requirements and difficulties being handled by the other teams. Changes that may be insignificant to one team may be a disaster to another and force them to completely restart their design.

The design research group within the University of Bath has been involved in the issues of handling these complex problem interactions for over ten years through the process of working with a wide variety of industries [3]. They studies do not relate to the normal issues of cooperative working, where the main issues to be addressed are those of technologies to support communication and organisation at a distance. The problems addressed all arose from the fact that different areas of responsibilities existed within the single company, so that no one person held a complete view of all of the problems that were simultaneously being addressed. This has led to the creation of a number of approaches to the handling of distributed problems based upon constraint processes.

2 Network design approach

Within a design environment, problems are naturally divided up between the team and are in this sense 'distributed'. Some are partitioned due to the different requirements of the sequential steps of the processes, whilst others are separated into sub-problems on the basis of the specialist skills that are required in their solution. This partitioning results in approaches or solutions to parts, which then have to be integrated into an overall solution.

Such an approach requires a close working arrangement to allow both the interaction between groups to be understood and their integration into a unified design. Historically and traditionally control has been exercised through a linear management structure where the authority is passed through stage-gates as the design advances from initial concept through to a manufactured item. This linear process has however been modified over the years as more and more specialised activities are included to detail and optimise designs and processes within each of the major design stages.

3 Constraint-net methodology

Much of the research of the design group at Bath has been centred on the creation and refinement of constraint modelling processes [4][5]. Here the relationship and objectives specified for the design are converted into constraint rules. Each requirement is constructed into a rule that can be tested to determine its truth as defined within symbolic logic. These rules can then be assembled as a set of conjunctions to determine the overall truth of the defined problem. The solution is then sought through a direct search approach (shown in figure 1) in which the initial set of variable values is tested against the truth of the constraint rules. If the solution is not 'true' the search procedure manipulates the declared variables until a set of values is found that makes the rule set true (or it is determined that no true state exists or is achievable in a set search period).

Within the constraint modelling environment these rules can be generated to allow geometry, mathematical relations and logical conditions to be all tested within a single design environment. The approach has been used to solve many machine and device designs through the construction of internal routines. These, in their simplest form, extend from the formation a set of individual rules that are applied sequentially to the building of parametric models that satisfy given design requirements. At the other extreme optimisation procedures have been created to allow machine systems to be modified to meet new performance requirements [6][7].

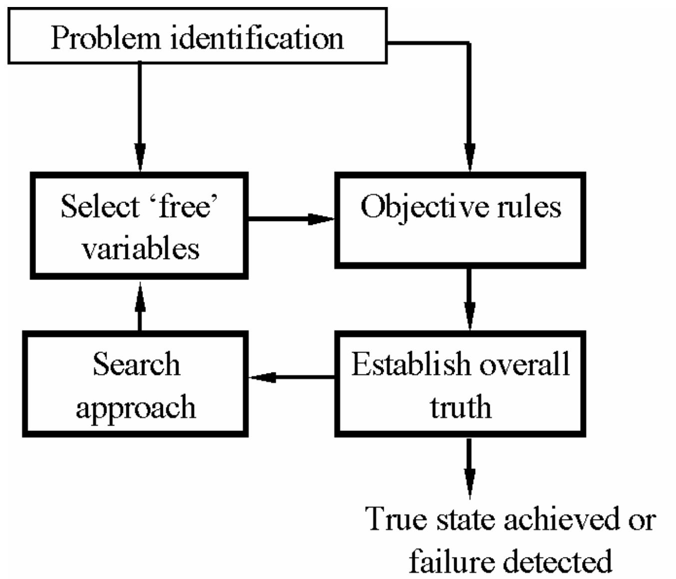

Figure 1. Structure of constraint resolution approach

This approach has allowed the constraint rules to be formed into nested loops to provide means of creating resolution processes that can maintain the integrity or operation of a machine whilst allowing, at the same time, the ability to select and manipulate a set of 'free' design variables that can be used in the search for a new or improved solution. The flexibility of this approach has allowed other new forms of solution processes to be considered.

Whilst investigating the design processes occurring in designs where distributed skills occur, a net form of the method was considered. Here the constraint rules were broken down into sub-problems that were assembled into a network structure. These sub-problems could be assembled to represent different aspects of the design approach and represent a single aspect within a distributed problem. They could contain all the rules relating to a single component or assembly or equally well contain all of the rules that fell under a particular discipline or skill.

The design sub-problem has to be firstly considered in isolation and then its interaction or dependency on other sub-problems must be established and their interactions resolved to form the network. Each sub-problem can be resolved on its own using the internal variables but some problem variables will be shared with other sub-problems that will ultimately need to be agreed with the 'owner' of the other problem.

Solutions are thus not simply and automatically found by a global search through all of the freed variables but by individuals addressing their sub-problems and then either allowing the shared variable values to be implanted in connecting sub-problems or through the generation of separate sub-solution and then discussing and resolving any conflicts that arise. In solving an individual rule set, as shown as Rules1 in Figure 2, all variables of the problem (shown as connected dots a to f) need to be manipulated in the search for a solution. The interconnecting variable d however influences Rules3 whilst e and f both influence Rules2 and must thus be resolved by acceptance from the previous rule or resolved by negotiation.

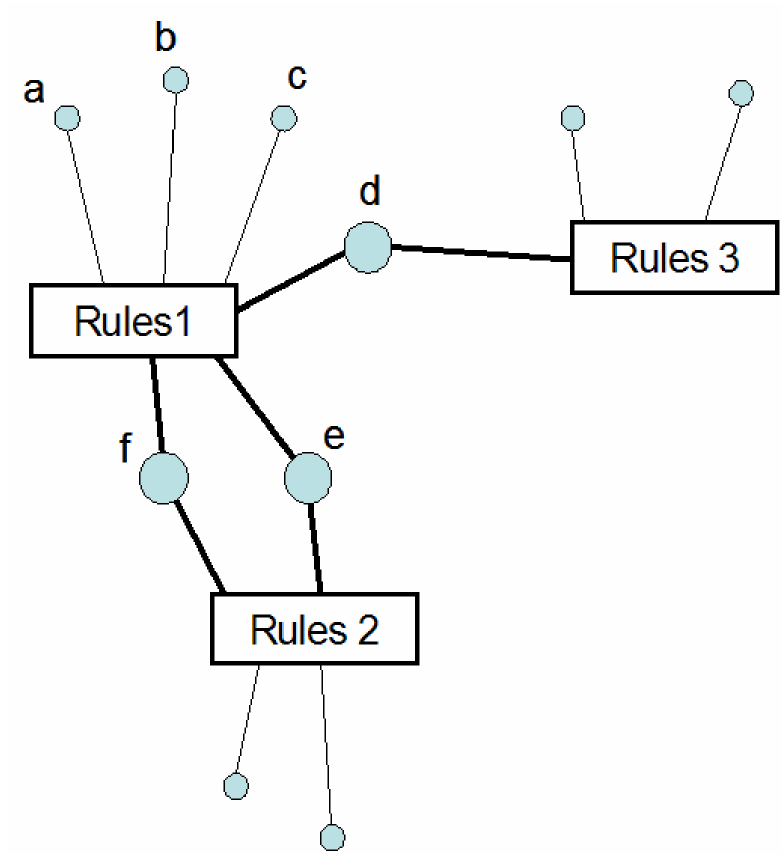

Figure 2. Constraint-net for three interrelated sets of rules

Within this approach the individual rule sets can be assigned to different teams which can work independently as long as there is agreement on how they should handle the issues arising from the shared interface variables. The rules often naturally group together and thus readily decompose into sub-problems or components.

It is within these groups that the design team is able to assemble its own design knowledge into rules that will enhance their design considerations. These may include both the explicit ones such as relating to strength, assembly, function, as well as the implicit ones that can extend from limits to size, appearance, to ease of interaction and use.

4 Design applications

The constraint-net approach is currently be evaluated through its application within two different areas of design: the first relates to the optimisation of machine design whilst the other addresses the problem of designing within a multi-disciplinary team.

4.1 Machine improvement

Within this investigation the motion of a mechanism within a toffee wrapping machine was investigated. This part of the pull-off mechanism is composed of three separate mechanism chains; the first two taking their inputs from separate drive cams whilst the third is connected the original two together to form the desired output motion.

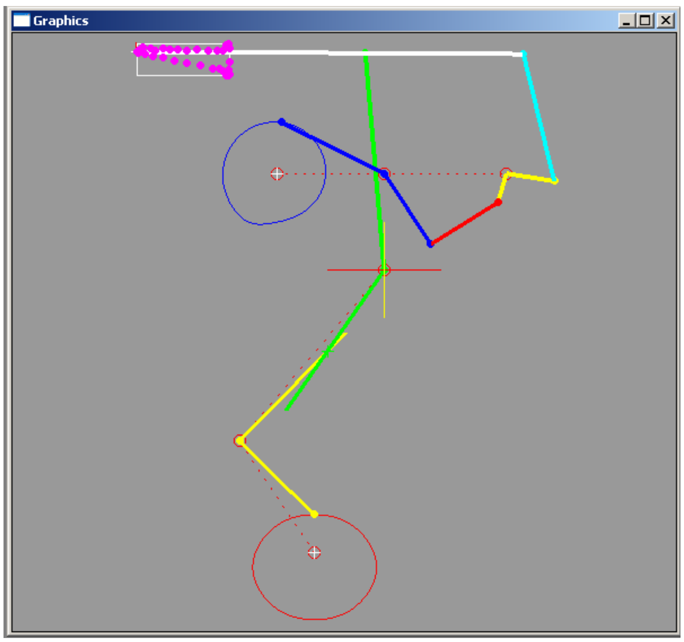

Figure 3. Mechanism layout

The design investigation was directed at establishing the possibility of changing the position and envelope of the output motion. Whilst this could be achieved by the replacement of both driving cams, such an approach would be costly and very time consuming, if the cams needed to be frequently changed.

It was decides to address this problem not by the integration of all aspects into a large analysis program, but by breaking it into a network where different aspects could be investigated and resolved. Different requirements were thus distributed between nodes in the net. In this manner a network was formed for each of these machine elements together with both the internal and interconnecting variables.

Figure 4 shows the stroke mechanism for the pull-off device together with its constraint-net drawn alongside. This net shows that twenty variables are included, or influence, the solution of all of the rules contained in this sub-problem. The effect of each upon this sub-problem, and all others, can then be investigated through sensitivity. This then, together with the other sub-problem constraint-nets, leads to the selection of the variables to be employed in the optimisation search.

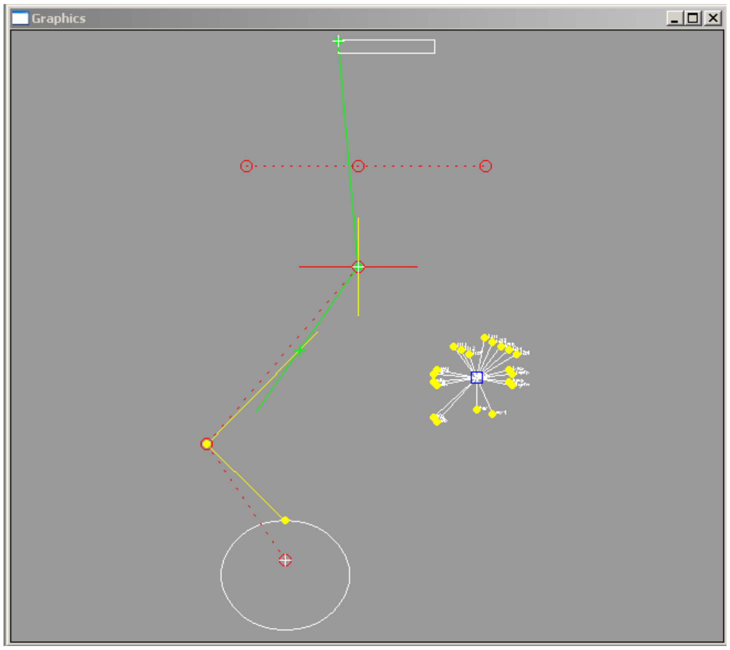

Figure 4. Stroke drive mechanism with constraint-net drawn alongside

From a consideration of the influence of each of these variables, a number were selected for use within an optimisation programme. Each of the interconnecting variables was considered but freeing this in both sub-problems requires the agreement of both design sub-teams. These were in the main the most critical and so were eliminated from the optimisation activity.

There was a greater opportunity to use the internal variables within the search but an elimination approach was used based upon a number of criteria. These were as follows:

- Having no influence upon the objective outcome
- Having a low sensitivity in the outcome
- Having great influence on the topology of the assembly

When all variables had been considered, and many eliminated a small group of variables remained from which seven were selected for the search. This resulted in a new configuration that, in this case, provided a successful outcome. Often the problem is over-constrained or the variables inappropriate for the form of the search. This however provides a greater insight into the problem and allows other (more appropriate) variables to be selected, agreed and applied to the solution.

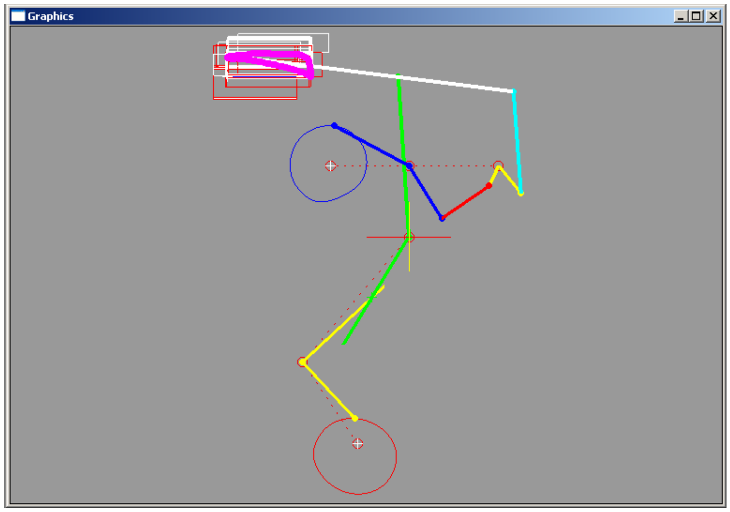

Figure 5. An optimisation search to provide a new position and envelop for the output motion

Here the use of constraint-nets allowed the different aspects of the mechanism to be divided up and represented independently as a set of distributed problems, together with the interconnections. It was then easier to select the variables for the optimisation search and for them to be agreed. The influence of each variable upon a particular part (or multiple parts) could be easily seen. The discussion on selection was then made on more rational decisions based primarily on influence and sensitivity. These could then be recorded, together with their effect, to increase the knowledge of the design. This can then be reused if further changes are required to meet yet more changes in the design specification.

4.2 Medical device study

In the machine improvement study the nets were used to allow the overall design to be decomposed in order that the most independent variables could be selected in the optimisation activity. This medical device study approached the design issues from the opposite direction. Here it was required to design a simple device that met a range of medical requirements that drew upon a wide range of skills extending from medical practice through to optics and image recognition. The design team was thus built around a set of individual with a broad base of diverse skills. To complicate the problems further, the experts, comprising three main teams, were located at different sites (throughout the United Kingdom) with the medical experts and users on a further three (one being abroad).

The project commenced with an extensive study of what was required in performing the required blood sample analysis and the complete audit/patient reporting route. This led immediately to a redefinition of the brief as the initial proposal did not address many of the major issues and the technology being applied (that of slide preparation) was under consideration to be replaced by a ‘wet’ approach. The decision of the team to direct its efforts into this new direction has since been vindicated as this is now recommended as the preferred approach.

The initial studies into the requirement indicated that the blood sampling should take place automatically within a small disposable device. This would allow the tests to be performed outside of a sterile environment without risk to patient or medical staff. The proposed means of analysis was to be by the attachment of selective antibodies with florescent markers so that filtered images could be used to identify a number of different types. The final design thus depended upon an understanding of the flow of the fluid down a diverging channel, its spread as a monolayer upon a porous membrane, the attachment of the antibodies, the imaging of the sample region and the generation of appropriate image processing software, to identify, place, combine and count the number and type of cells present. Whilst the final device (shown in Figure 6) was a simple assembled set of mouldings its form had to ensure that the individual aspects had to be met which included:

- An adequate number of cells were laid down to provide an acceptable test (the number of regions and lines scanned)
- The loaded membrane was sufficiently flat to remain in focus throughout the scanned region
- The required amount of sample could be stored in the device
- The region of analysis was optically transparent
- The device could be mounted on a standard microscope (in order to allow verification outside of the specialist instrumentation also being designed)

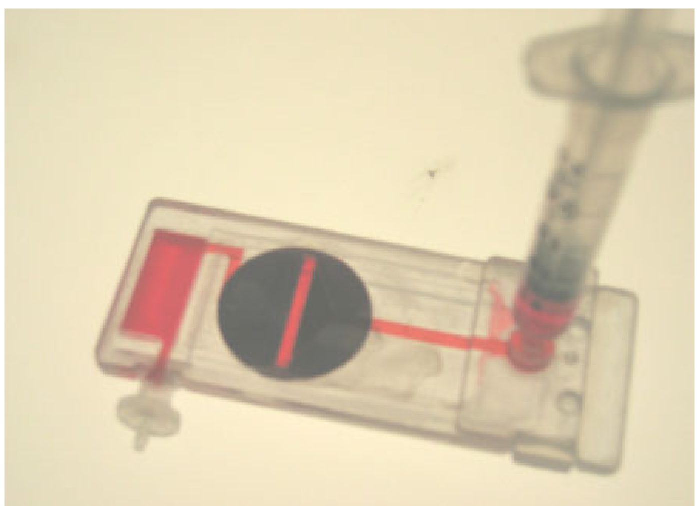

Figure 6 Early test model of device used in flow evaluation

A parametric model was constructed to allow the major features to be analysed and tested (Figure 7). Sizes of the necessary channels, diverging region, weir, analysis region and sample reservoir were all explored. The flow through the device and its spreading were analysed using a CFD programme and constraint rules generated to specify the relationships between features and the resulting overall size. The position and area of the membrane were also specified by rules that depended upon the microscope depth of field and field of view, together with the expected number of cells to be found in the analysis. The image processing was to be undertaken by the recording of an array of image tiles. The size of possible readable image thus related to the number of tiles to be recorded which would relate to the maximum line of images possible across the device. The requirement to have multiple lines of images recorded would greatly increase the analysis instrument (through the requirement for a transverse indexing platform as well as the longitudinal one needed for the line of images). All of these interactions added complexity to the device and greatly influenced the final cost of the device and instrumentation.

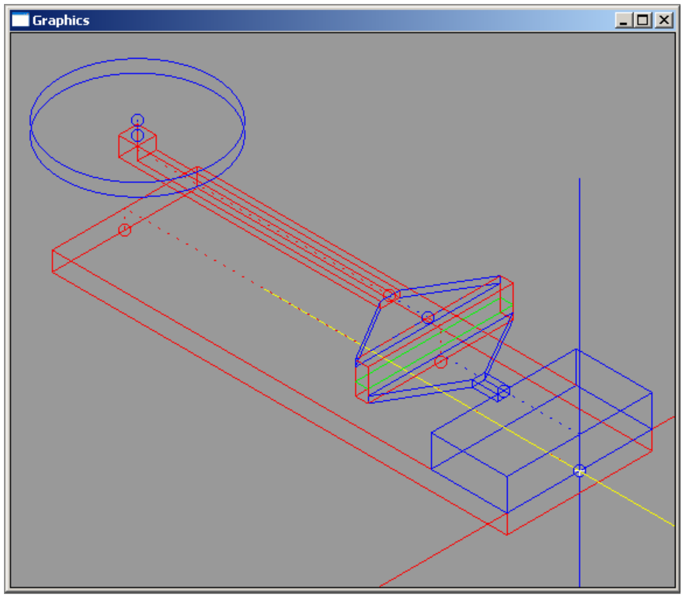

Figure 7. Parametric model of chambers in the device

A constraint network was generated from this collected information and initially all variables of the design were assumed to influence all the constraint rules (Figure 8). Here nodes were set up in which the constraint rule for each part of the distributed problem. This recognised the expertise of the individual design groups and was based upon their responsibilities rather than their location.

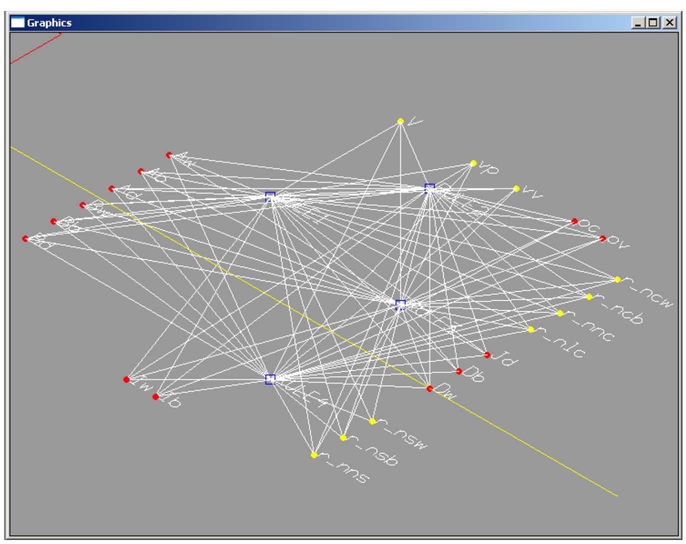

Figure 8. Constraint-net showing assumed total interdependency of rule sets and variables

By re-clustering the rules in the individual groups to represent different technology or knowledge sets, it was possible to greatly simplify the form of the network (Figure 9). Here one set contained all of the rules related to the number of cells to be present in the analysis if an acceptable test was to be achieved. Another contained all the information about the membrane size, hole density etc, whilst yet another contained all of the information relating to the optics and image sizes. These, whilst relating to one another, also related, through the volume of fluid contained in the sample, to the size of device and the possibility of holding all of the fluid in the reservoir.
Such divisions of the constraint-net were chosen to closely follow the areas of responsibilities of the individual distributed teams. Within the net it was possible to see how changes to resolve individual problems in of one team would influence the work of other teams. For example the membrane stiffness, and hence flatness, could be increased by a reduction in the hole density. This however would require either an increase in analysis area or an acceptance of a lower number of cells in the final analysis sample.

The team approach (or management strategy) was that the teams could advance as long as they did not make the problems worse for other teams. When these points of conflict occurred the teams met and the problems were addressed and agreed before they returned to work on the new set of relationships.

The computer model of the network proved useful in identifying areas of potential problems and was shown to give good correlation to experimental data recorded during a series of development and evaluation trials. It also has provided an understanding of the capabilities of the device and the form of the parametric values (and hence size) if other medical, or non-medical, applications are to be accommodated.

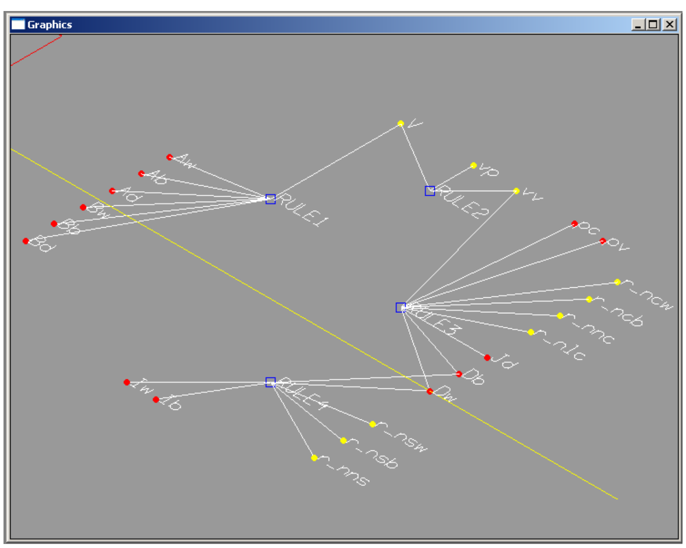

Figure 9. ‘Untangled’ constraint-net with grouped relationships

5 Conclusions

An approach to distributed problem design has been attempted using a constraint network structure. Two case studies have been handled successfully with quite different objectives; one to refine and simplify an existing design whilst the other draw widely different skills together in the creation of a new design. Here the responsibilities for different aspects of the design (both in terms of component design and specialised knowledge) have been distributed as sub-problems. The resolution of conflicts arising from these sub-problems was resolved through the connecting net.

This approach encourages the sub-teams to take responsibility for their individual problems and, at the same time, to be aware of the overall goals in order that they are achieved and a successful solution emerges. It encourages a greater awareness throughout the team as rule creation, checking and proposed solutions occur through open, collaboration and awareness.

Such a design methodology was suitable for many smaller companies (such as in the packaging industry) as it draws together the design knowledge of the various teams whilst remaining essentially based upon the designer's skills to manipulate the outcome of the network. It is thus possible to draw upon the wide range of knowledge residing within the different and distributed teams.

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