Evolving individualised consumer products

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Evolving individualised consumer products

Abstract

The origins of this project began in 2002 with experimentation into the application of computer generated random form to 3D product design. Advances in the Rapid Prototyping industry were offering the possibility of mss-produced one-off consumer products. Computer based 3D solid models were created that would randomly mutate within parameter envelopes set by the designer. At any given point the mutation could be halted and a real-world product generated via digital manufacture (Rapid Prototyping). This first stage of the work has already been reported on (Atkinson and Dean, 2003).

The next phase of the program has been to introduce evolutionary development so that, via the computer generated random mutation, the model develops generation by generation in a desired direction (though not necessarily to a predictable outcome). This requires an element of selection. There are several examples of computer based evolutionary design experiments that use human by-eye selection methods, notably Richard Dawkins' 'Biomorph' system (Dawkins 1993). The aim of this project is an automated system that selects on some measure of desirability and rejects outright any functional failures.

Each FutureFactories product form is define by a parametric CAD (Computer-Aided-Design) model. When evolution is initiated, a series of mutant designs are generated each with a single parameter, selected at random, adjusted by a small pre-determined step. The step may by be positive or negative, this again is determined at random. The resulting set of mutant progeny is then assessed for their visual 'success' using a quotient. The quotient aims to access the level of visual interest in a form. As the application is 3D products, there are physical parameters to consider, for instance 'hard points' generated by the envelopes of internal components which may not be intruded upon. If any of the offspring do not meet the necessary physical criteria they are rejected. Animation is employed to extrapolate between iteration present the evolution as a smooth metamorphosis. Product forms and associated development criteria have been created capable of evolutionary development over many generations. The resulting designs are both surprising and unpredictable.

Introduction

Future Factories is a digital design and manufacturing concept for the mass-individualisation of products. The project began as a one year Design Residency in School of Art and Design at the University of Huddersfield. The project has now been expanded into a practice-based PhD study. Instead of creating a single discreet design solution (or indeed a finite range of options), the designer creates a template. This template defines not only the functional requirements of the form but also embodies the character of the design. Through the design template, the designer establishes a series of rules and relationships which maintain a desired aesthetic over a potentially infinite range of outcomes. The design becomes a 'living' entity, continuously morphing within its template envelope (Atkinson and Dean, 2003). In a development of the project we have looked at coupling random mutation with selection and the introduction of evolutionary pressure. This application of computer based evolutionary design is the subject of this paper.

Technological context

Computer generated artwork has become commonplace, the creation of three dimensional artifacts from this artwork imposes considerable limitations and is consequently rare. Advances in digital technologies have made the creation of one-off products from computer generated models, a realistic, affordable possibility. There are three principle technologies exploited in the FutureFactories model (fig. 1).
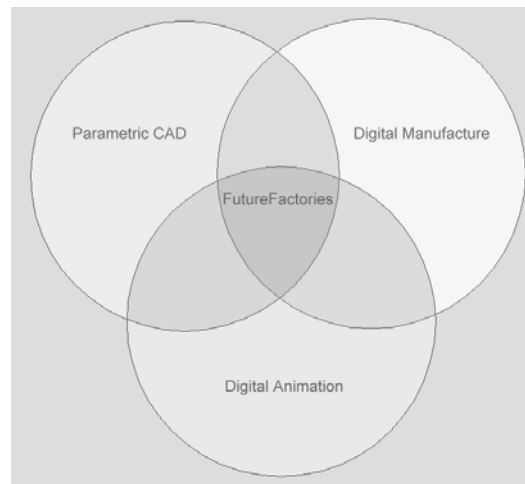

figure 1
Three core digital technologies exploited by FutureFactories

Parametric computer aided design

Parametric computer aided design (CAD) enables the designer to define relationships that form the character of a design rather than a single, discrete, design solution. Parametric design considers the relationships between degrees of freedom rather than the degrees of freedom themselves. When a variable is changed the whole model will

up-date to maintain specified proportional relationships. Individual variables in the computer based 3D model can be modified and the whole form will up-date to maintain specified relationships.

Digital Manufacture (Rapid Manufacture, Direct Manufacture)

Now that Rapid Prototyping (RP) is well established – the new frontier for the digital manufacturing industry is Direct Manufacture. Direct or Rapid Manufacture is essentially the adaptation of RP technologies to the manufacture of end-use products. "A number of compelling examples of RM suggest that it will span across many industries in the future. Among these are hearing instruments, dentistry, medicine, aerospace, military, oil exploration, motor-sports, and consumer products" (Wohlers 2003). Rapid Prototyping (RP) is a catch-all term that applies to the digital manufacture of prototypes directly from CAD data. Essentially RP allows on-screen models to 'printed out' in 3D. Most of the recently developed processes are layer additive. Software 'slices' the CAD model into thin layers (down to 0.05mm). The model then 'grows' one thin layer at a time as each data 'slice' is replicated in 3D from the bottom up. The layers are built on a moving platform, each built on its predecessor as the platform steps down in layer thicknesses. There is no tooling or cutting away of material. This allows unlimited geometry. Forms may be produced that would be almost impossible to mould or machine. The relatively slow layer-by-layer building means that digital manufacturing is unlikely to ever match production capacity of die casting and injection moulding. Manufacturing parts without the need for moulds or dies does however makes the volume production of individualised forms an economic possibility.

Graphics

In FutureFactories the product forms are not fixed. The designs exist in a constant state of metamorphosis. To appreciate this, customers should be able to see the designs continuously 'morphing' in real time. The concept lends itself to some form of 'virtual' web-based merchandising (Unver, Dean and Atkinson, 2003). A system is envisaged in which the consumer is presented with a 3D animated model via a website. The consumer may access the website directly or via a sales outlet within, for example, a gallery or a department store. Advances in the graphics capabilities of home PC's and the speed of internet connections allow the display of rendered forms mutating in real time on the customer's home computer. Memory hungry three-dimensional rendering now exploits graphics processors on the video cards instead of consuming valuable CPU resources when drawing 3D images. These advances in video cards and the software that manage them, driven hard by the video game industry, enable the smooth real time display of animated forms complete with realistic scene lighting and material finishes.

The introduction of selection into the FutureFactories model

In the original FutureFactories concept it was necessary to define a complete envelope of parameters. The envelope defined 'solution space' covering every possible mutation of the form. Each individual parameter required specified ranges that considered both the effects of that parameter alone and its effects in combination with others. It is clear to see that if there are more than a handful of parameters and their effects interrelate to any significant degree then the task of specifying such an envelope becomes extremely long and complex. An aim of FutureFactories is to

develop generic systems of commercial potential. For commercial viability it should be possible to introduce new designs with reasonable ease. Ideally one would be able to apply mutation rules to a conventional 3D model via an intuitive on-screen process (the system is seen as a plug-in addition to high-end parametric CAD systems). The complexity of specifying a parameter envelope could be reduced by severe restriction of the permissible parameter ranges and by isolating their effects where possible. But this would lead to uninspiring, predictable, movement in the form, repeated oscillations for example. A way of simplifying the rules for mutation had to be found. Evolutionary design principles offered a potential solution. Genetic algorithms permit virtual entities to be created without requiring an understanding of the procedures or parameters used to generate them. Instead of incorporating expert systems of technical knowledge into the programming, evolutionary design systems rely on utilitarian assessments of feasibility and functionality (Sims 1999, Funes and Pollack 1997). Our parameter envelope was designed to perform two functions; to ensure that manufacturability be maintained and that the mutated form retains the 'designers intent'. If these factors can be assessed and scored then mutation, coupled with selection, can be used to drive and control changes in form.

A model for mutation and selection

In the FutureFactories model, mutation takes place in a series of generations. The original model had a single parent producing a single, randomly mutated, child per generation. In this development of the system each generation has a single parent (the starting point) and ten offspring. In each generation, ten randomly mutated iterations are generated from the parent model. Each iteration has a single parameter, chosen at random, modified by a set small amount. The mutant offspring are ranked for 'fitness' and the most successful selected as the parent of the next generation. The scoring for fitness is based on the 'desirability' of the last transformation with reference to the designer's intent. Before becoming the parent of the next generation the selected iteration is tested against functional failure criteria. This ensures that after mutation the design is no less manufacturable. If the parent fails this assessment the next best offspring is selected. Only selected offspring are tested against the failure criteria to reduce computation. Animation is employed to provide a flowing transition between one generation and the next. The generations are a fixed number of animation frames apart with the software extrapolating to fill in the missing frames (fig 2). This is known as key frame animation.
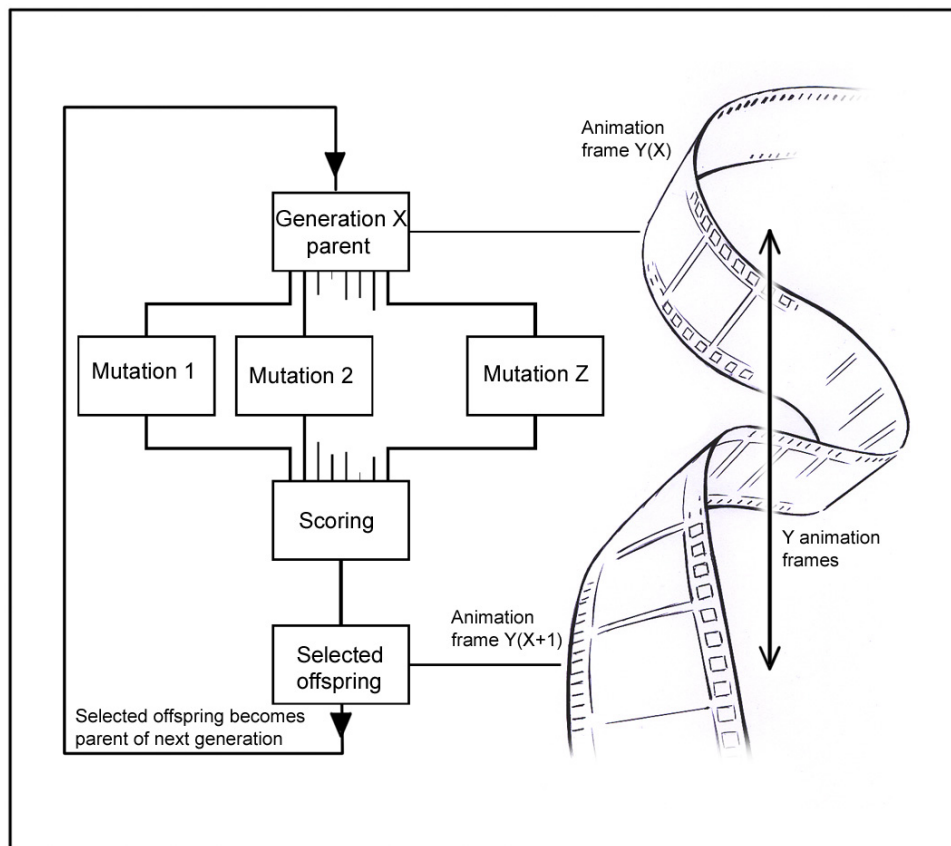
figure 2
The mutation, selection and animation process

The introduction of an evolutionary pressure
Given the use of random mutation and selection, the introduction of an evolutionary pressure was a logical step. Indeed it would be hard to avoid creating such pressure by virtue of the 'fitness' scoring. Public reaction to the early stages of the project also pointed to the inclusion of an evolutionary element.

Public reaction
As part of the Residency program at the University of Huddersfield, a touring exhibition was arranged to communicate the project to a wider public. The exhibition toured three regional venues, before going on to London and Milan. At each venue interactive displays were set up. Visitors were invited to 'try out' the system by selecting their own one-off designs from a computer rendered image of the design as it mutated randomly in real-time. Users received a 2D printed image of their individual design, which mimicked the production proposal, in which a 3D model would be digitally built. This gave the opportunity to assess levels of consumer interest and expectation.

The mutating image proved initially extremely seductive, with visitors drawn to the image and captivated by it. The selection process proved less of an attraction; users were often just as happy for the choice to be made for them. To some extent this is understandable, as no actual purchases were being made and no 3D objects would be generated. But it was nevertheless apparent that as the mutation was completely random there was little intrigue in 'what happens next'. Creating this type of intrigue is obviously important from a marketing point of view. A level of evolutionary development is seen as a way of stimulating this type of interest. The idea is that designs would be available and evolve for a limited period. Different periods of the evolution process may achieve different levels of desirability. The value of an artifact would vary according to its position in the evolution. There may be 'good' and 'bad' generations as there are good and bad vine harvests.

Aesthetic Evolutionary Design
The aim is not the functional optimisation of the designs through evolutionary computation. The suitability and functionality of the design are present in the initial seeded product form. Functionality is then maintained by the selection process, rather than improved upon. The aim is the evolution of aesthetic designs in what is described by Bentley as Aesthetic Evolutionary Design (Bentley 1999), an area that borrows from both Evolutionary Design Optimisation and Evolutionary Art (fig. 4).
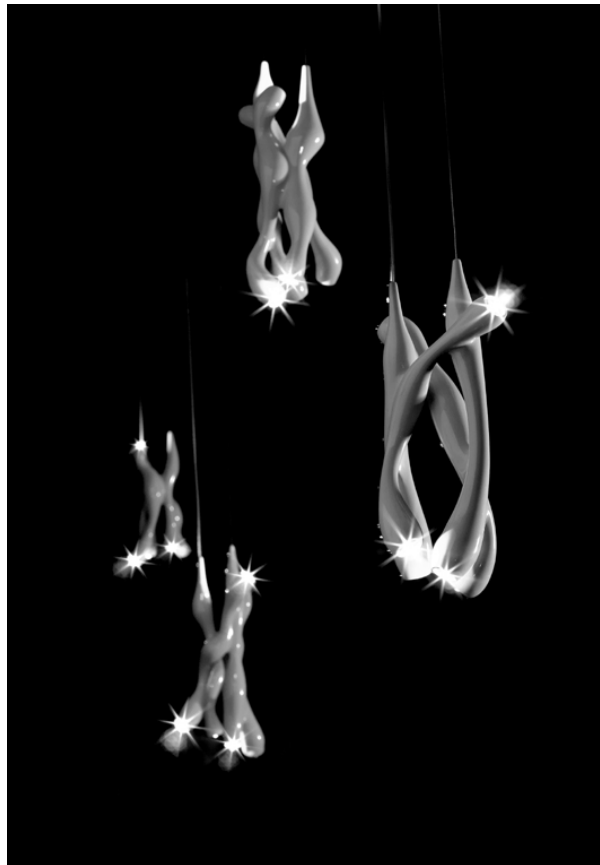
figure 4
'Tuber' pendant lamp produced by 3D printing

Failure criteria - feasibility, functionality and manufacturability

Assessing the mutant designs for feasibility, functionality, and manufacturability is relatively straight forward. The validity of the surfaces created can be assessed through the ability to export a suitable digital file for manufacture. Problems, such as overlapping surfaces, either prevent successful export, or are flagged up by error messages. The manufacturing limitations of the intended digital manufacture process can be imposed, minimum material section thickness and the machine build envelope for example. FutureFactories has experienced problems with clearing fine internal passageways of unused build material, this can be mitigated against with a limiting bore diameter/length ratio. Functionality may consider issues such as stability, checked via the position of the center of gravity, and the appropriate housing of internal components. These practical assessments are used to impose absolute limits rather than for relative scoring. The aim of FutureFactories is not technical refinement. It is not the intention to select the quickest to manufacture or the most stable; merely to assure that each generation conforms to a minimum functional standard.

Scoring the aesthetic

Maintaining the designer's intent requires a more relativist approach. Selecting designs based on a scoring of 'fitness' allows the designer to express general ideas for the design rather than absolute limits. For example the notion, "some rotation is fine but not too much," might translate to an exponential decrease in the probability of further rotation being selected as the angle increases. This less rigid form of definition simplifies the set up of the model and also allows the possibility of new unexpected forms (although the possibility of surprising turns has to be balanced against maintaining a coherent, identifiable design). The effects of the rules are 'softened' by the use of probability: a high fitness score can be allocated a higher probability of selection rather than assured selection. This again broadens the possibilities allowing from time to time the success of a less fit parent.

Step size – micro-mutation, macro-mutation and the balance between different transformations

Evolution is the result of accumulated small change. If the geometry of the model were to be re-arranged at random there would be infinitely more ways of creating a failure than a success. As Dawkins points out of the natural world, "Even a small random jump in genetic space is likely to end in death. But the smaller the jump the less likely death is, and the more likely is it that the jump will be in improvement……………The chance of improvement resulting from a transformation tends to zero with increasing step size and to 50% as it decreases" (Dawkins 1986). Also the more transformations that are occurring simultaneously, the lower the probability that they will all be successful. For this reason each offspring 'bred' from the parent form has only one parameter adjusted at random +/- one 'small' step. The step size is an absolute value arrived at through experimentation. A step size is set for rotation, transformation and scaling. The values of these different steps must be balanced so that they each achieve a comparable degree of change to the form. If particular transformations have disproportionate effects, they will inevitably exclude milder transformations from the evolutionary process. A diagnostics screen has been incorporated into the system to guide the setting up process. Amongst other information this screen is shows the percentage breakdown between the three transformation types that have acted on the model up to the current point in the evolution. It is possible to see the balance between the operation types as the evolution progresses.

Evolution – what are the aims?

The designer creates both the initial form of the design and the evolutionary pressure that will govern changes in that form over its evolutionary lifespan. The aim is to evolve increasingly visually interesting designs along the path set by the designer. The use of digital manufacturing favours more complex forms. If the forms are simple or regular, then the options increase for manufacture via faster, cheaper, conventional methods. So whilst simplicity may have elegance, FutureFactories evolutions will necessarily tend toward the more complex.

We have considered surface area divided by volume as a measure of complexity. Dividing by volume prevents simple expansion. When applied repeatedly to a simple

model, the resulting forms, after 200 generations, are clearly related, more intricate, and yet still manufacturable (machine build area is used as a failure criteria).
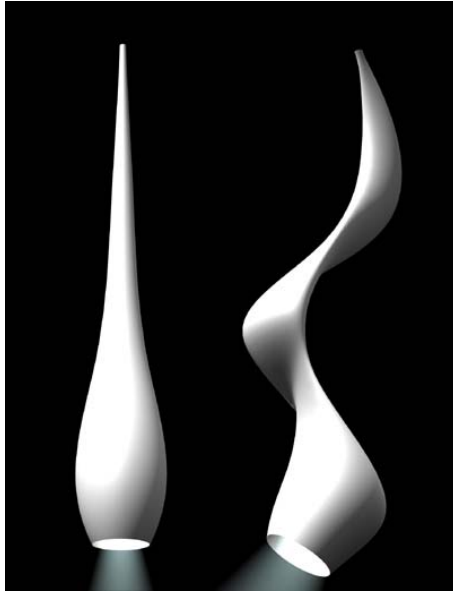

figure 5, the initial form and the form after 200 generations

Detail, grouped, and structural changes

The product forms of the FutureFactories models are made up of surfaces defined by control curves. It is these control curves that are manipulated during the evolutionary process. Each 3D iteration (in evolutionary terminology phenotype), is defined by a list of parameter values (the genotype). Parametric CAD generates the 3D form from this list or genotype. The evolutionary algorithm modifies the list generating mutated genotypes which in turn, via CAD, create mutated 3D objects (fig6).
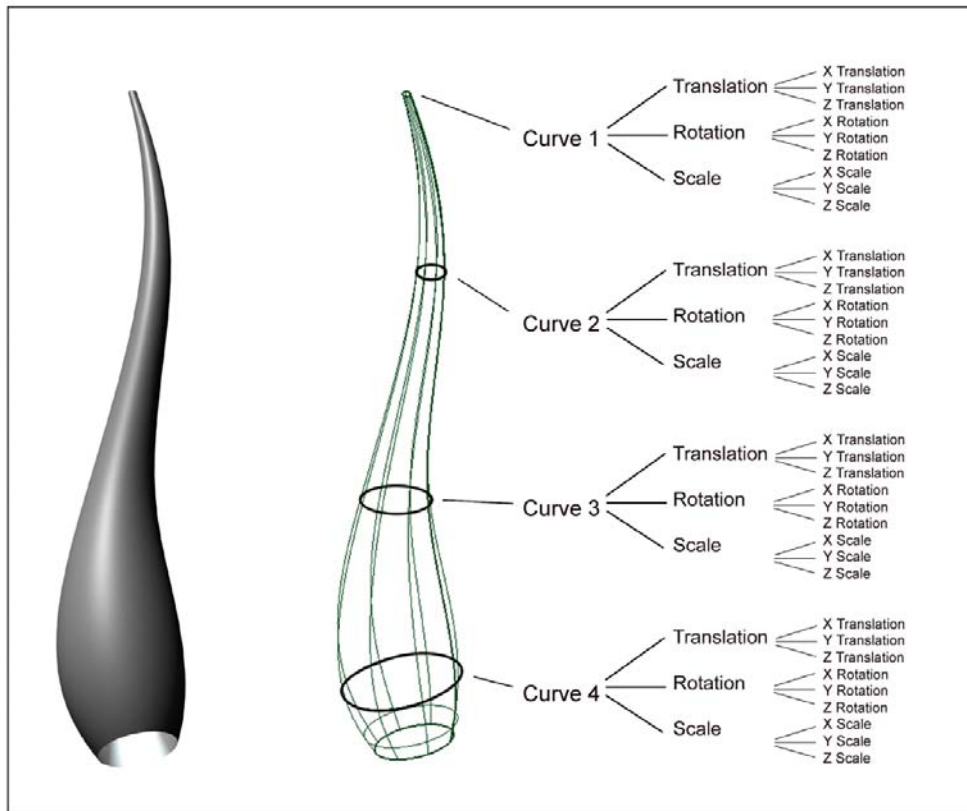
figure 6
The CAD model phenotype and its Parameter genotype

Manipulating individual parameters results in what could be considered as, local, detail changes. As well as detail changes it is often desirable to manipulate larger areas of the form with the same transformation. In a legged structure for example, it may be desirable to apply transformations to legs as a whole rather than specific areas of individual legs. For this reason FutureFactories allows the grouping of parameters at the set up stage, for example, a leg group. The grouped parameters are treated in the same way as the individual ones with a certain probability of random mutation. A transformation may be applied to the grouped parameters, or to individual parameters within the group: the percentage probability of each being dictated by the set-up rules. The particular transformation may be therefore applied to a small area as a detail change or may be spread over a particular feature (fig 7).

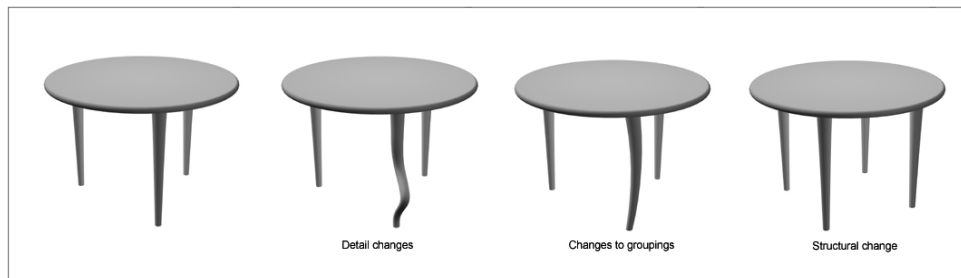Detail changes   Changes to groupings   Structural change

figure 7
Mutation sphere of influence

Structural change involves an alteration of the geometrical make up of the model, rather than adjustment of it. This could be the addition or removal of features, for example, an additional leg on a legged structure. This type of change is very difficult to accommodate in the FutureFactories due to the surface based geometry of the current models and the requirement that each iteration produces a potentially viable product. The system does not allow for the evolution of new features from functionally compromised beginnings. Complex natural systems, such as the human eye, have evolved from much cruder beginnings, like perhaps the light sensitive spots processed by some single celled animals (Dawkins 1986). One can imagine the parallel in the Tuber lamp (fig. 8). A new limb might evolve beginning as a small protuberance on the surface. This would elongate and develop a slight glow to the tip. The glow then intensifies, until it becomes the intense focused beam of the LED. This unfortunately belongs to the virtual world. FutureFactories is able to individualise product forms, but standard, interchangeable functional components are still required. An LED has a fixed size and specification. It is either there, or it is not.
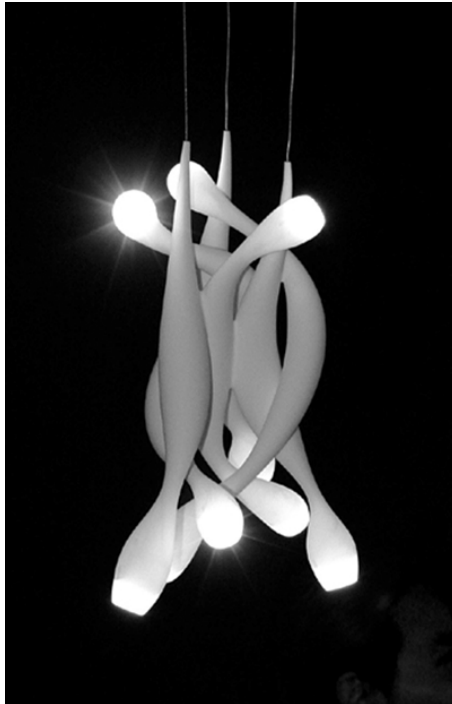
Figure 8
Tuber9 produced in Laser sintered nylon

A degree of structural evolution is desirable, if not essential. FutureFactories achieves
this by breaking the design down into an assembly of separate models. Tuber consists
of limbs that intersect. These are separate solid models joined by a Boolean
operation. The requirement is that all four limbs remain linked by enough material to
achieve a structural joint. The format of the assembly can change during the
evolution as long as all four limbs remain linked. A link can pass from one limb to
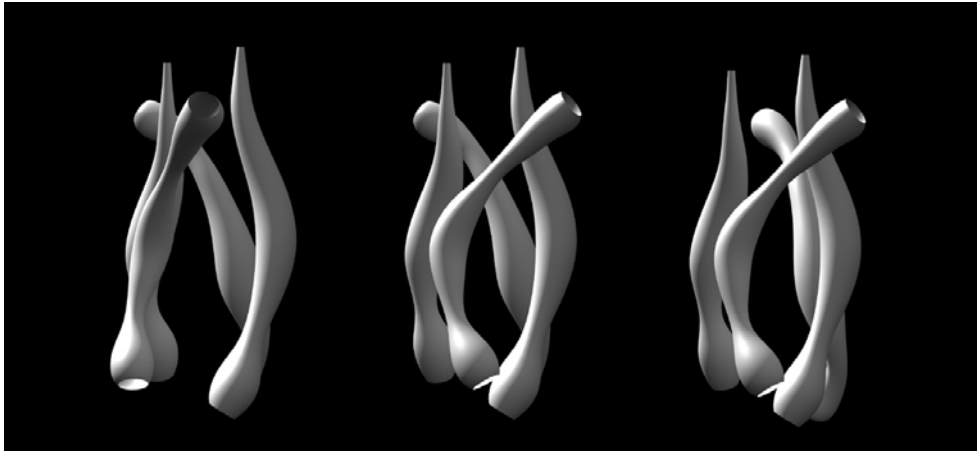another in the manner of a baton being passed in a relay race (fig. 9).

figure 9
changes in model structure

FutureFactories vs. Evolutionary art

FutureFactories employs many of the principles seen in evolutionary art. There are also major differences. Evolutionary art and FutureFactories are similar in that they have no fixed target solution. The design is not homing in on an ideal generation by generation (Although in evolutionary art, with manual selection a user might focus on his/her preference). What is important, is the level of development: this usually means complexity. The number of generations "progress" from the start point. The importance is the distance from the starting point in solution space rather than a particular region of it.

Organic art often starts with simple geometric primitives; effectively a blank canvas. FutureFactories starts with well developed, non random, seeded solutions, a viable design that must be maintained throughout the evolutionary process.

Evolutionary art exists in a virtual world. The constraints of the physical world, gravity for instance, need not exist. In evolutionary art anything is possible and the images are usually scaled as required to fit a convenient screen area. "The scale of forms generated from the same structure can vary by huge amounts as the parameters change: a single family can easily include both whales and insects" (Todd and Latham, 1999). Functional products must adhere to physical rules. In commercial manufacture, certain products would be destined for production in certain machines. The machines have build envelopes, into which parts must fit (although it is possible to subdivide a form into smaller components that are subsequently assembled into a larger structures using built in fastenings). There must be an element of repeatability in the production process if volume production is to be economically viable. Iterations of the same design, in spite of differences in form, should be produced in the same machine and use the same packaging (elements of protective packaging can be incorporated into the build process). Dimensions in FutureFactories are absolute, with limits imposed to ensure manufacturability.

Evolutionary art often allows a user, or 'artist', to guide the evolution. The FutureFactories selection process is automated: there is no human input during the evolutionary process.

One of the 'drawbacks' for Evolutionary art is that the images generated often have very distinct styles. "Often the style of the form generated using a particular representation is more identifiable than the style of the artist used to guide the evolution" (Bentley, 1999). The representations used are often limited to particular types of structure and generate forms with common, readily identifiable elements. In FutureFactories this is an aim - to produce designs that remain identifiable in spite of mutation.

The nature of the FutureFactories designs

From the project's inception, communication of the FutureFactories concept was an important factor. The example designs created had a strong flavour of organic growth in the aesthetic. The name Tuber and Tuber's colour – vivid green, were seen as factors in selling the concept. A frequent question raised is, given that the designs to date have such a strong organic flavor – could the system be applied to other aesthetics, to something more geometric?

Beyond the 'marketing' of the concept, there are other reasons for the preference of organic forms. Firstly, the example products produced to date are the work of one designer; inevitably the work reflects his tastes and ideas. Secondly, the virtual models are literally growing: natural organic forms are the result of growth and so the connection is hardly surprising. Thirdly, one of the transformation types employed is a twisting motion. Twisting a form is almost certain to result in the generation of curves. Where surfaces are formed between control curves, they are geometrically constrained to flow smoothly one curve to the next.

Geometric aesthetics are not being overlooked however. One of the areas for future work is an evolution that favors the creation of flat surfaces, straight edges, and angular relationships between faces. The evolution would start from a simple organic base and evolve into something geometric and faceted.

Conclusions

The use of simple fitness scoring and failure criteria has been used to replace the 'parameter envelope' of the original work. Using this evolutionary algorithm, selection based approach, represents a huge reduction in complexity. Consider the simple limb used in the earlier examples (fig 6). Instead of setting ranges for its 36 parameters, some of which interrelate and cannot be considered in isolation, a scoring system is used. Surface area/volume and machine build envelope limits control the model's evolutionary mutation. Running the evolutionary algorithm for 200 generations results in closely related, but at the same time, distinct solutions. The design progresses along slightly different pathways to the same region in 'solution space'. If we are confident that after a given number of generations the forms, whilst different, will conform to a broad design concept, we can allow the evolution to run repeatedly. On top of the initial design, the designer needs to specify selection criteria that will focus the evolutionary development on a solution space region, as broad or as

narrow, as required. This gives the possibility of running the evolution on the customer's home computer, rather than on the host server. Computationally, this is a much more attractive solution than the customer accessing an evolution on a host server: however, conceptually the main benefit is in the flexibility. Running the evolution on the customer's home computer means that the evolution can be started on-demand. The customer can run the evolution at will, stopping, starting and resetting as desired.

FutureFactories focuses on a single mutating solution. Evolutionary algorithms are usually much more sophisticated. They often feature populations of solutions, and two parents, both of whom contribute to the offspring's 'genetic' make up. This 'crossover' contributes to the evolution as well as mutation.   So far FutureFactories has been very broad in its aims for evolution. As the complexity of the models, and the degree of evolutionary control required increase, it is likely that the models will become susceptible to 'noise' and 'local optima' (solutions that score high on 'fitness' but are not ultimately the 'target').

The scope of the evolution possible within FutureFactories is restricted. It is limited by the use of standard components, by the geometry of the model, and by the requirement that the iterations remain recognisable designs, true to the designer's intent. Trials have shown us that customer demand is for significant change in the forms. It is also seen as desirable that, whilst conforming to a design idea, the evolved form contains some unexpected twists.

The potential for evolution is restricted by the internal components in the sense that, whist in principle the skin of the design might be allowed to mutate, significant areas of the form will be dictated by standard functional components. Ideally the entire product should be allowed to evolve including any functional components. It is possible that such components could be built digitally along with the body. This already happens with some simple mechanical devices for example, springs, bearings, clips and hinges. There are also machines capable of building in more than one material simultaneously. There are research machines capable of 'growing' circuitry on electronic substrates (de Garis 1999). It is safe to assume that technology will make components ever smaller and easier to package. New materials and possibilities for digital manufacturing are emerging all the time, with ever increasing performance. It will become possible to achieve more and more functionality from digital builds.

Simplicity in the model has been sought to facilitate the creation of generic systems rather than a discrete examples. We have sought to maintain simplicity whilst allowing a degree of structural change through a model made up of multiple bodies. This could be taken further towards the building block approach common amongst evolutionary systems in which geometric primitives are added, subtracted, and modified to achieve a desired form.   These methodologies however do not in themselves produce viable products. Further operations are required to translate the primitive blocks into the functional components. The evolution takes place on a simplified model. Each time a real product is required a set of mapping operations are performed, for example, primitive blocks are united into a single volume; this would then be smoothed and hollowed out. The FutureFactories customer sees the evolution occurring in real time. Either the customer is presented with the simplified model or

the mapping operations must be computed for each generation. The latter approach is impractical, requiring too much computation. Presenting the customer with a simplified version is open to misinterpretation. If the mapping operation makes significant changes to the model, then too much is left to the imagination. In the FutureFactories multiple body model, the animated evolution shows the separate bodies simply intersecting. Outputting a 3D model gives the intersection between the forms a fillet radius. An integrated form is made from overlaid separate entities. Visually the product becomes more realistic and 'believable' after this 'mapping' (fig 10): however, a reasonable impression can be gained from the simplified animation model. From a computational point of view leaving complex modelling operations to a mapping stage, completed only if a 3D outcome is required is highly desirable. But visually the animation needs to be close to the final outcome. A square block representation of a soft sculptural form, for example, would not be acceptable.
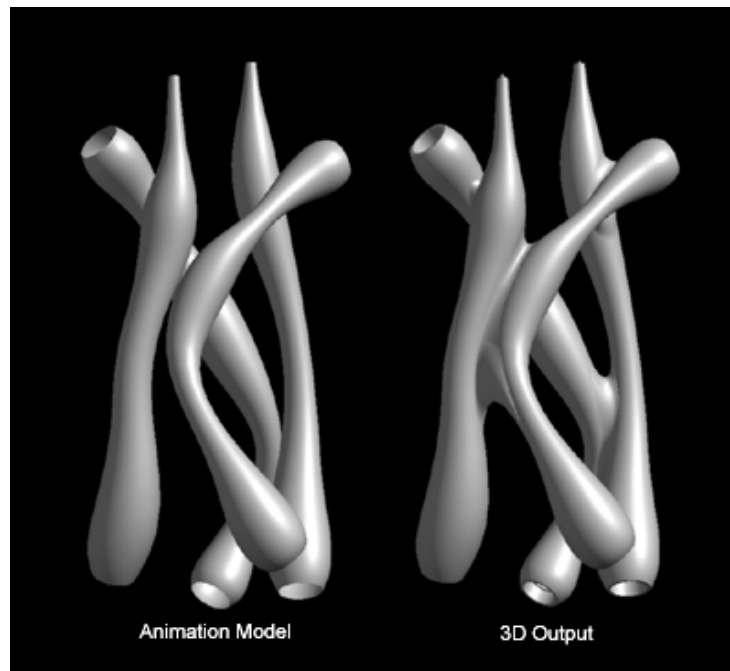

figure 10
Animation model vs. 3D output

Scoring surface area/volume represents a crude beginning. Other assessment methodologies are under consideration. Consideration is also being given to the number of polygons required to idealise a surface, average surface curvature, and the spread of surface-normals as fitness criteria: the results to-date are promising.

The potential impact of 'Future Factories' have been noted and described since the first stage of this work as mentioned (Atkinson & Dean 2003) and are still considered to be significant. As the project has developed, additional elements have been recognised with respect to the system's impact on issues of authorship and accepted notions or

definitions of design practice (Atkinson & Hales 2004).

Clearly 'Future Factories' is an example of emerging and converging technologies and new practices which are forming a new position for the maker and author as the creative source of finished pieces. In fact, the designer may not even be aware of products selected and produced in his or her name. The combination of mathematical algorithmic processes and autonomous production potentially act to isolate the author of the work from the outcome, and raises questions of responsibility and ownership.

Finally, the use of software processes and real-time networks as generative tools questions existing, transient boundaries of practice, and also exposes the relevance or irrelevance of conventional definitions and accepted nature of the roles, practices, techniques and processes involved. It is clear that the outcomes of such a new model of creative production cannot be thought of as traditionally conceived pieces. They are, without question, art. Outside of that, existing definitions convey little of the reality of their production, as they lie in some new, as yet unspecified arena of production.

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Lionel Theodore Dean – Biography

Lionel is a graduate mechanical engineer and has a Master's Degree in Automotive Design from the Royal College of Art. He worked as an automotive designer, for Pininfarina in Italy before setting up his own design consultancy business in 1990. Initially focusing, on small cars and motorcycles Lionel's work spread from the mid-nineties into interior products in particular lighting. Lionel's products are very much design led: through his work he seeks to explore the boundaries between Art and Design. Lionel was appointed Designer in Residence in the school of Art and Design, University of Huddersfield for the academic year 2002/2003 when he began the development of FutureFactories. The project proved extremely successful and has now been expanded into a practice based PhD study supported by the school. Lionel collaborates with Huddersfield academic staff on cultural and technical aspects of the project (one of the aims of the Residency program). FutureFactories was exhibited in London and Milan 2004 and in New York in 2005. Tuber9 (pendant lamp in laser sintered nylon) was acquired by MoMA The Museum of Modern Art, New York, 2005.

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Paul Atkinson – Biography

Paul Atkinson is the Head of Professional Development and the Subject Leader for 3D Design for the School of Art & Design at the University of Huddersfield. He qualified initially as a mechanical engineer, and then as an industrial designer before

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On moving into education as a career, Paul led Product Design and Industrial Design degrees before undertaking an MA in Design History and becoming a Principal Lecturer and the Coordinator for Historical and Contextual Studies. He is now responsible for organising and planning all staff research activity within the School. Paul has had an active role in the Design History Society for a number of years, acting as Editor of the Society's Newsletter for three years before taking up a position on the Editorial Board of the Journal of Design History. He has spoken at a number of conferences around the world, and published articles on the design history, visual culture and material culture of the computer.

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