ALL IMAGES: COMPUTER CLOTHING RESEARCH CENTRE/NOTTINGHAM TRENT UNIVERSITY

[1] On a computational catwalk within a virtual world designed at Nottingam Trent University, this idealized supermodel slinks through her routine. But very few people are supermodels, and no one is "ideal." The 3-D model can be a replicate of anyone's unique body shape, and fashion designers and their customers can see how clothes would fit at the click of a button.

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virtual reality

Virtual Fashion

It's *you!*
Be your own model
in a synthetic world
where everything
off the rack is custom fit

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Time and time again, the clothes-shopper goes through the same routine: no matter what size garment he or she selects, somewhere it pinches or hangs wrong. So the salesman casually adds: "We'll take it in a little"—but will it really fit? Or, even worse, the double-edged comment, "On you it looks good." This is the moment of truth—do we believe him?

Not that people have it any easier higher up in the industry food chain. Fashion is fickle, prone to constant change, a business in which survival depends on a sixth sense for shifts in style and on speedy adaptation. It is a world of big money, big egos, and big risk. Each step, from satisfying customers' whims to selecting fabrics, has its own logistical traps.

Strange as it may seem, computer graphics and virtual reality could allay much of the psychological tension in buying clothes, and even provide the kind of custom styling previously within reach only of the *habitués* of *haute couture*. Designers and manufacturers, too, will work hand in glove as never before to satisfy the expanding markets.

Putting it together

Broadly speaking, the principles of the fashion business have changed little in decades. A designer working with a manufacturer starts with a sketch and slowly fleshes it out into an illustration. With the help of clippings from magazines and journals, small swatches, and photographs of similar or rival designs from fashion shows, the manufacturer turns these concepts into a sample piece of apparel for the retailer. This garment is then assessed for quality, fit, feel, and aesthetics. The assessment is rigorous. In the United Kingdom, for instance, retail buyers reject more than seven out of 10 samples.

Production of most clothing is based on the use of two-dimensional patterns. Shapes are cut from flat cloth and sewn together on assembly lines. In contrast, design is often a three-dimensional process. Fabrics are draped over a mannequin, where they can be pinned together and tucked into pleasing designs. The "unwrapping" of these 3-D articles into 2-D form for manufacture takes a lot of time, and not surprisingly gives rise to many mistakes.

To tackle these problems, the Computer Clothing Research Group at England's Nottingham Trent University began the Virtuosi research program in 1993. Central to the program was developing a computer-aided design (CAD) package that would enable designers not only to manipulate 2-D pattern shapes, which had been done before in other systems, but to work these patterns into 3-D styles.

Many companies have grappled with the reverse problem of unwrapping 3-D shapes to create 2-D templates, but almost all have attacked it by creating a close-fitting garment-as-skin rather than by trying to drape an independently modeled garment over a figure. Some made a significant impact with their early 3-D work, but the clothing industry failed to capitalize on their initiative. Companies such as Cyberware Inc., in Monterey, Calif., and Hamamatsu Photonics KK, in Hamamatsu City, Japan, make 3-D data capture devices that have been seized upon as tools for made-to-measure goods, and this idea has been developed by Textile Clothing Technology Corp., known as $(TC)^2$, of Cary, N.C.

The Virtuosi system has defined its field of activity quite clearly so that its use and value can be quantified. The system is built for clothing design professionals, not the general public. Companies such as Levi's have not fared well with attempts to take "made-to-measure" to the mass market (In fact, Levi's no longer attempts to do so). Despite the attractiveness of the idea, many practical problems tripped up the projects.

The attempts miscarried because of psychological factors—"if I can't even buy a pair of blue jeans off the rack, maybe I shouldn't wear them at all"—and inadequate capture of true size and shape data. Military "fashion" designers, incidentally, have had much greater success—the air masks of fighter jet pilots, for example, are designed around digital models of each pilot—but of course in a different market.

The Virtuosi project differs from these in its use of virtual reality (VR) and having collaboration as a key component (as an extreme example of isolation, the technology of $(TC)^2$ is available only to U.S. companies). It has created a world of virtual mannequins, both as runway models and as replicated consumers, which work with pattern and material cloth databases in a virtual studio [Fig. 1]. The goal is for the studio to be shared over telephone lines: a designer in Milan, say, could work simultaneously with a retailer in New York. All this leads to a fast, dynamic, and creative response to fashion trends.

A particularly complex aspect of this research is cloth modeling. Obviously the modeling of cloth, especially in motion—known in computer graphics circles as "dynamic drape"—is crucial to the fashion industry. The fact that a garment may look great on the design sheet or on a static mannequin is no guarantee that it will look as good on a moving figure, whether in the real world or a virtual one.

Incorporated in the virtual studio is a multimedia database of materials and knitting yarns, as well as accessories, supplier listings, business forecasts, and the like. The database was developed by the Computer Clothing Research team in collaboration with British Telecom. Originally called Fashion Information Systems (FINS) and delivered on a CD ROM, it is now available on the Internet under the name Fashion Connect. With the database, a physical model and image of a material and pattern can be taken from its display—the virtual swatch—for transfer onto clothing patterns.

The need for fully networked VR (both local and wide area) influenced the team's choice and design of base software. At the heart of the system is dVise VR software, which runs on Unix and Windows NT platforms and is supplied by Division Ltd., Bristol, England. Because collaboration was a key component of the project, the developers needed to consider wide-area network configurations and performance. So the system is bandwidth independent and works successfully at rates as low as 128 kb/s. Latency is not considered to be a problem with this minimum standard.

Getting into VR

Fashion designers in VR, like their breathing counterparts, need mannequins: clothes horses over which garments will be draped. However, lifelike detail unrelated to body shape on each mannequin is immaterial, so the VR design team dispensed with facial features and hair.

Also, mannequins, like runway models, must be able to adopt pose after pose that will show off garments to their best effect. And as far as the clothes-shopper is concerned, they must show them in less-than-perfect settings—that is, not when shown off with just-so gestures by a supermodel, but worn by a more normally shaped person walking around normally.

Although most of the Virtuosi project centered on two VR models whose origins were entirely digital, deriving models from real people became an increasingly interesting line of development. The laser scanners from Hamamatsu and Cyberware construct full 3-D representations of the human form, but the resulting bodies are static. For the Virtuosi project, though, articulated models were required.

As for modeling the human body, the work undertaken in Switzerland by Nadia and Daniel Thalmann, at the universities of Geneva and Lausanne, respectively, was investigated during the early stages of the project, as were other products, including Mannequin from BCAM International Inc., Melville, N.Y., and Playmation (formerly known as Animation Master) from Hash Inc., Vancouver, Wash. Each approach had demonstrable benefits, but from the team's viewpoint, each also had limitations, most of which stemmed from our desire to work with case-by-case models of real people.

Real people come in a wild variety of shapes and sizes. As everyone knows, the "right" size on the label of one garment is no guarantee that a second, similarly labeled garment will fit. Adding to the customer's difficulties, no two retailers define size in the same way, and garments from different manufacturers may be sized differently to begin with. Factor in some people's psychological reservations about buying very large or small clothes, say, and the problems multiply.

Part of the Virtuosi program involves investigating the body sizes of various population groups. This research focuses on the general relationship of body size to body shape, data never before gathered in any systematic way. Over the last three years, for example, we have analyzed the shape of some 7500 women. Shape must be analyzed (derived) from far more detailed measurements than just the three in the familiar bust-waist-hips measurements. Our shape definitions—shoulder slouch, say—are based on over 50 measurements made on each person. As will become plain, the data was essential to preparing a database of body types for use by the VR software.

Our surveys revealed significant changes from the admittedly scattered earlier data available. The "ideal" bust-waist-hip measurements of English women during the late 1950s were 36–24–36 inches (91–61–91 cm). This "ideal" has, like many things in the fashion industry, strong psychological and economic components enmeshed in a feedback cycle.

This "ideal" is a subjective figure taken from interviews with women, who presumably find ideal what men find ideal. As for the economic component, this set of measures—which, it must be pointed out, reveal almost nothing about what an "ideal" *shape* might be—was the figure of the majority of design mannequins and the one most often designed for as a reference garment for manufacturers.

Now, in the late '90s, the *actual* woman is more likely to have a figure defined as 36–27–37 (91–69–94 cm)—yet the '50s' "ideal" by and large still reigns in the industry. Underwear, too, plays its part in these changes, as body-hugging garments made of flexible materials have replaced the rigid bras and corsets of 50 years ago.

For example, the studies show that the distance of women's nipples from the nape of their neck—a critical component in the specification of garment structure—is now nearly 5 cm lower than in 1950.

To accommodate our wonderful body diversity, the team has developed a measuring booth that digitally captures an individual's measurements and does so in a few minutes—much less time than the laser scanners mentioned above, and generating far less data extraneous to our needs. After all, a person armed with only a measuring tape cannot hope to carry out a survey on such a scale, and with such accuracy and consistency.

The body shape is captured by a digital camera, which photographs customers in their underwear. The figure captured is not the full 3-D point-by-point scan of systems like Cyberware's (which would entail prohibitive computer processing), but rather the frontal outline and side profile of the entire body. The relatively simple software used at this stage detects the front and side edges by looking for the sharpest distinction between contiguous bright and dark pixels in the digital camera [Fig. 2].

The process that follows is more complicated. A left side to match that implied by the right profile (or the reverse) must be made, as must a back view for the full-face view. These must then be stuffed, so to speak, with a representation of the appropriate body distances and mass. Here, the database of body shapes, optimized on the basis of the surveys mentioned above, comes into play. It is searched by expert system software designed by our team; this software, upon finding the closest match, fits the profiles to it.

The digital templates of the body in the database are 3-D, and once one of them is chosen, it is automatically reshaped to fit the digitally captured profile. The sculptural form of each client is not perfect, but the system captures enough shape data for an acceptable approximation of each measurement to be calculated.

The measurements and profiles are then used to construct a more accurate image of the customer than the (often lying!) mirrors in shops. This personal, customized mannequin is then input to the VR system, where it is dressed and moved about, giving the purchaser an objective view of the clothing's fit on his or her body. This unique form of self-observation is not trivial, as every salesman and shopper knows when in the stressful environment of a shop. Most people take along a trusted friend to comment on the clothing's look, and the objectivity of this system should alleviate some of the buyer's stress in choosing between his subjective appreciation of the clothes and the comments proffered by the sales staff.

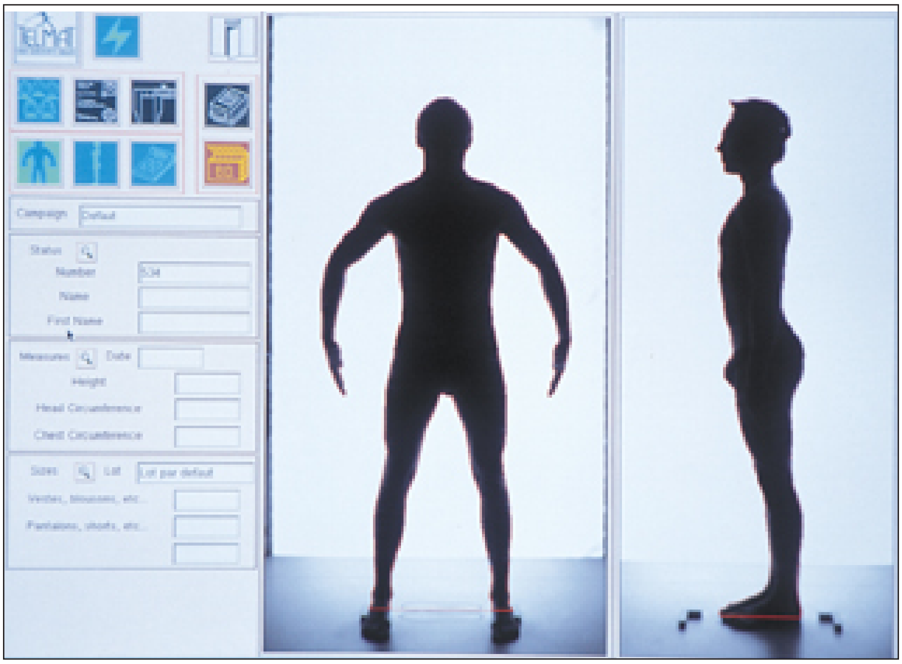
You've got the look

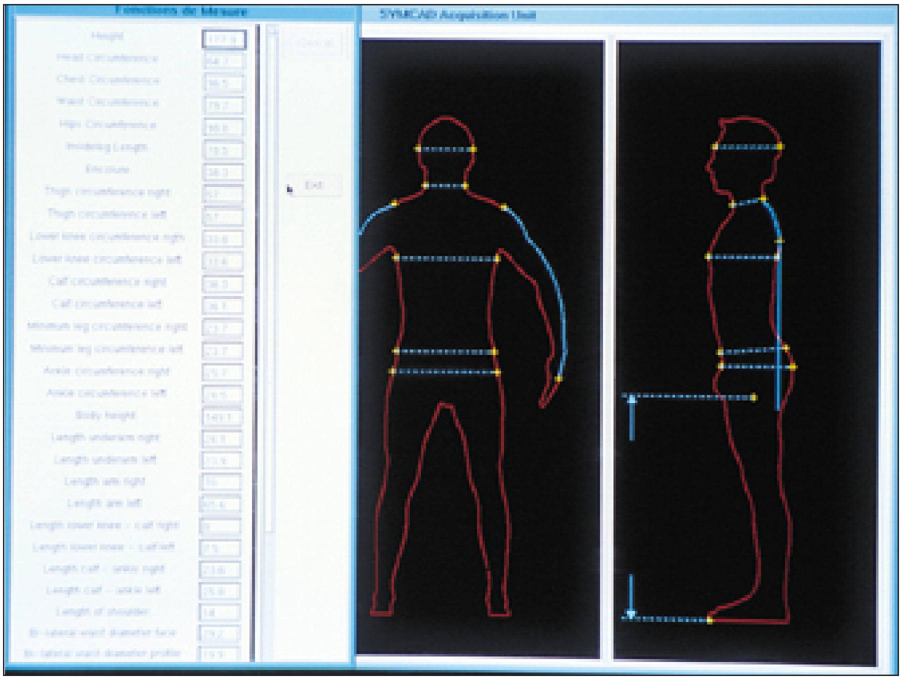
VR modeling has potential in areas a few steps removed from the retail level. The discussion so far has been about real people with non-ideal bodies, but a more select group of real people and body types does exist: professional models, whose top fees can reach $25 000 per day. In a virtual fashion show, mannequins can model new designs for far less money, and are more controllable to boot.

To get the mannequins up and walking, the Virtuosi team had to position joints inside the shell generated by the camera's scanning process. But as there was no direct relationship between the underlying pseudo-skeleton and the outer skin,

[2] To create a mannequin that exactly matches the customer's shape, he or she strips to underwear before being photographed in silhouette with a digital camera [below, top]. Over 50 measurements are automatically taken from the profiles—enough to quantify a shape.

After image capture [bottom], the most important measurements, some of which are shown by dotted lines, are identified in the list shown at left. To create 3-D digital mannequins, the front and side profiles are seamed together and the full shape is derived from the two closest matches in a huge database of body shapes.



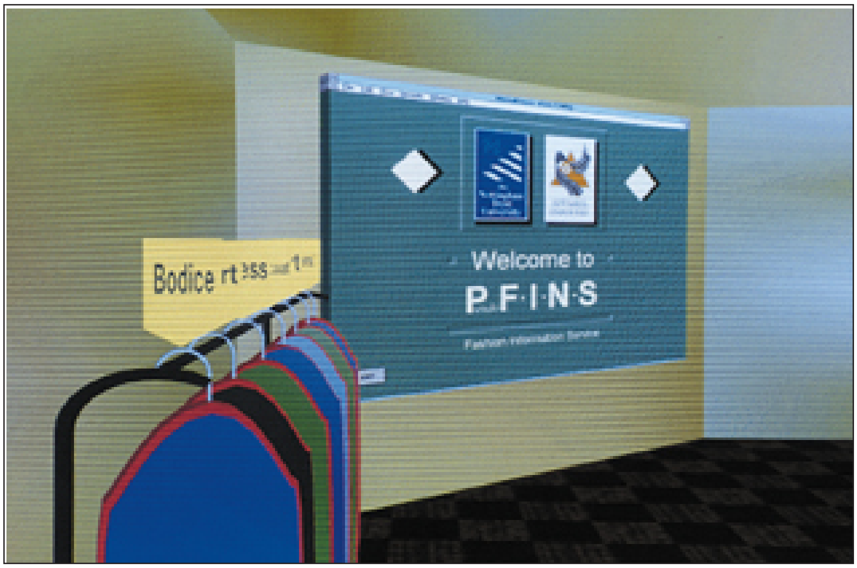


many problems arose. The team had to compromise by splitting the bodies into separate members (legs and arms, for instance) with joints that fitted into each other. The visual impression is one of continuous skin. Graphical articulation with simple software control is relatively easy, but movement could also be achieved on inexpensive hardware.

The VR models seldom require the realism of a store mannequin, let alone a design studio one, so even facial "details" such as hair and eyes have been omitted from all the demonstration systems. (Interestingly enough, the disengaged gazes of real models and the vague masks on their VR counterparts are not unalike.)

The articulation of a movement is vital to a virtual fashion show. In themselves, algorithms for human-like movement of a digital model are not a problem—a healthy amount of research has been done in this area already—but movement in a virtual fashion show calls for quite different qualities. Runway models do not move like normal people: certain gestures are exaggerated, and the Virtuosi team had to respect the movements and poses expected in fashion shows, and create software specifically for the task [Fig. 1, again].

[3] In the Virtuosi virtual design studio, objects give access to different computer functions: files contain customer information; the wall screen in the back, the design area proper, displays information from textile databases or is used for videoconferencing; and a mouse click on the computer terminal may call up a cost accounting program for a particular garment design.



[4] The labeled garment bags on the rack contain information on the design or manufacture of each garment. Customers could view swatches on the wall display (the displayed PFINS is the acronym for Pseudo Fashion Information System, a test swatch database).

Haute couture for all

The payoff in investigating body shape and the discrete numerical measurements required is clear: better information with which to select clothes, because the measurements are based on a greater knowledge of the human form, especially its posture and stance (round shoulders or hollow back, say). From the clothing manufacturer's point of view, therefore, the natural progression of the investigation is to create better-fitting blocks (cutout forms), either for individual clients or for the mass market, using real mannequins generated from virtual data.

The Virtuosi team is aiming to achieve this automatically, generating patterns and grade rules in three dimensions (grade rules are the method of basing a range of sizes on just one sample pattern). Many manufacturers are well able to cope with cutting cloth and sewing it, and need only the supply of correctly sized patterns to provide personalized service. This could be obtained from in-store measuring systems (such as ours), pattern-creation software, and a telephone link to the retail outlet.

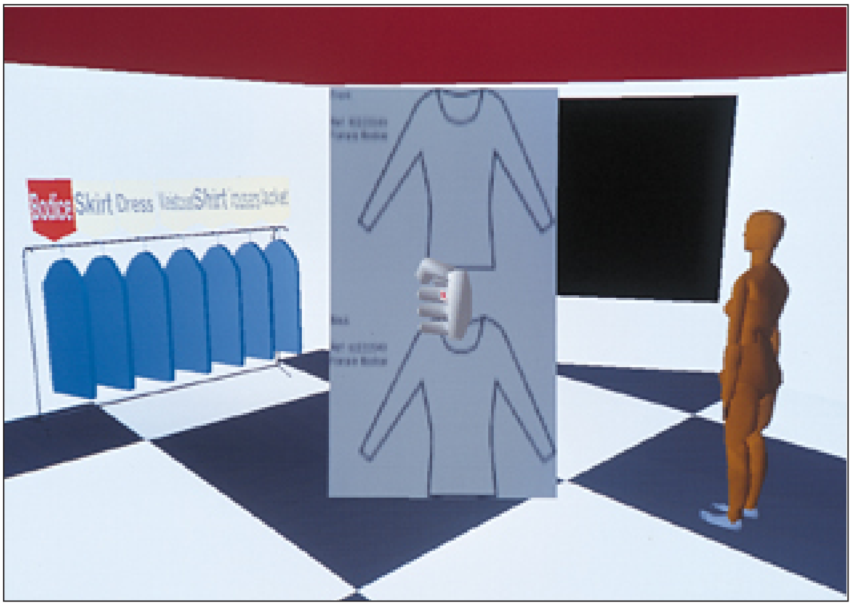
The team's multimedia database Fashion Connect contains extensive business information—guides, forecast trends, exhibition reviews and the like, together with specifics of fabric samples, trims, and accessories. The format of the database is geared to the industry: searches can be made on color, design, and weight or season (lightweight fabrics are most popular in summer). Manufacturers are listed for each sample, most of which are presented in graphical form with colors matched to international Pantone standards, the most widely accepted color reference guide.

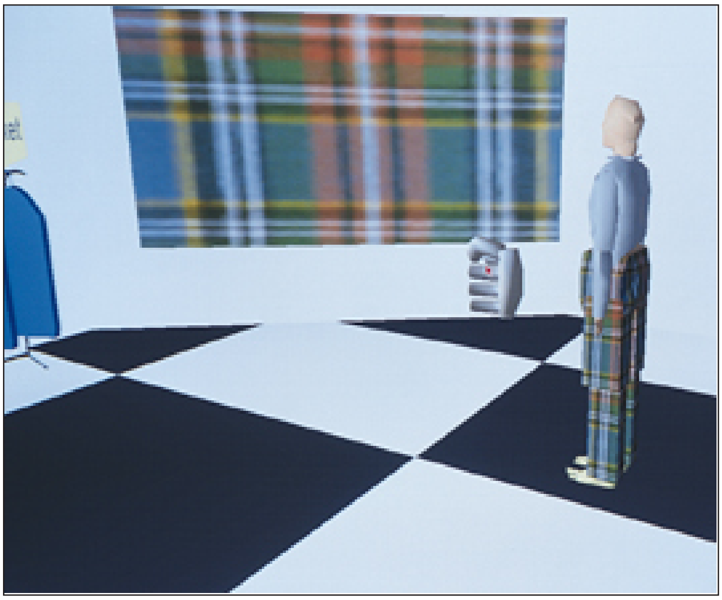
The virtual studio has a link to just one part of Fashion Connect, its fabric library, but relies on the same search criteria. The user may, for example, select stripes, floral designs, or children's prints as categories and the results will be projected on a wall *within* the virtual studio. These designs form part of a list that can then be scanned forward and backward until a suitable material is found. Full access to the Internet as a whole from within the virtual environment is in the works.

Needle and thread

The virtual design studio is much tidier than most of its real-world counterparts. It has familiar objects—among them, realistic-looking desks, telephones, computers, and filing cabinets [Fig. 3]. A click of the mouse on a telephone icon, for example, and the user can contact someone else over the normal telephone lines. A computer terminal icon opens up other applications, such as a costing program. The wall screens display swatches, multimedia displays, or videoconferences. Files contain product histories; and labels on clothing reveal complete specifications, along with 2-D patterns.

In general, the design studio is a place to select styles, to put them on mannequins, and choose fabrics. As shown in Fig. 4, work is concentrated in one area of the studio, where a clothes rail contains labeled garments, each with its own set of data.





[5] A woman has selected a bodice style, and its outlines are presented to her [top] (the large graphic of a hand is the pointer in the VR world). In another test, of the fabric database [bottom], a tartan swatch shown on a wall display within the VR studio has been automatically mapped into trousers. (The Charlie Chaplinesque look resulted because the test revolved mostly around the database and not garment styling.)

Folding clothes

The designer's toolbox looks a little like an aircraft control panel, and is overlaid on part of the screen. A study of the habits of clothing designers helped in the grouping of functions in the toolbox. The designer usually chooses color and fabric independently of fit and styling, so each group has its own entry in the toolbox and is displayed separately. Buttons for selecting cloth are separate from those for controlling garment length, and so on [Fig. 5]. All the commands in the toolbox may be activated by voice as well.

Besides being shown in 3-D on the mannequins, garments are specified as 2-D pattern shapes, as well as manufacturing drawings for showing details like seam construction and fastening options. Because this data, too, is integral to the garment models, they can be easily linked to other computer systems with CAD/computer-aided manufacturing (CAM) packages and other data manipulation packages, particularly costing and production planning systems.

The team's algorithms for computer-based specification are legion: for instance, those for "pin-and-tuck" (fitting joins together) must run side by side with those for "slice-and-slash" (making a skirt more flared, say). And the modeling of pins, scissors, and tape in a VR world has not been determined though it is no trivial matter, conceptually, to designers. As in other applications, a decision must be made whether functions in a VR world should mimic real-world ones or be forged with entirely new mental models allowed by the technology.

The most practical use of the output from the system is as input to CAD/CAM. Pattern output from the Virtuosi program is, for now, in planar geometrical form—namely, the block patterns used for cutting cloth for manufacture into clothing.

Figure 6 shows how certain key body landmarks [in red] are needed for individual classes of garment. These points are automatically identified when the user selects an item of clothing. Associated construction lines [yellow] serve as the key to the unwrapping process. When 3-D objects are cut along these lines, they can be laid flat in 2-D representations.

Years of tailoring experience have gone into the selection of these guide points and lines, and the Virtuosi project has embraced these proven methods. For example, the unfolded pattern for the bodice in Fig. 6 specifies the front and back joined together down the side seam. The key landmarks for the position of the bust, shoulder, armhole, and waist are used to compute the main points on the 2-D pattern block.

The representation of curves is a tricky matter in the unwrapping process. For instance, a sleeve will not fit well into the shoulder opening if the hole is not the correct shape. The two-way translation from 3-D to 2-D and back again allows designers to see the effect of changes in both made-up and flat form. For the larger sizes, this is particularly useful as many of the 3-D objects look "wrong" when unfolded into 2-D.

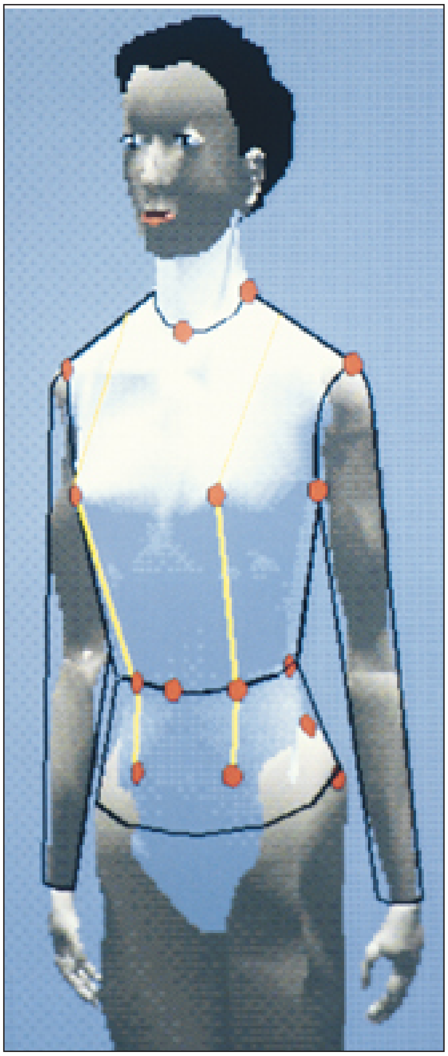
The computational catwalk

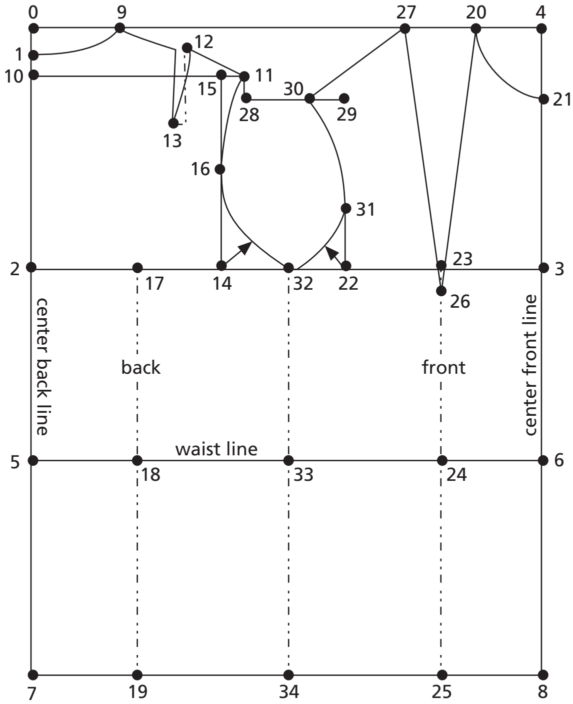
Once garments have been designed with our system, they can be shown off to other people, as would usually happen, in a second virtual environment. Mannequins can be transported instantly into the showroom, complete with chairs, tables, statues, and other objects, which can be used as landmarks for the mannequins' walks. In Virtuosi, these movements are voice-controlled.

Alternatively, their paths could be written in a pre-defined manner utilizing the Virtual Reality Modeling Language. This method allows 3-D viewing and manipulation over the World Wide Web.

One set of instructions enables users of the system to pose the mannequins as required to show off their clothes to good effect. Another group allows them to walk the figures around the room in a realistic manner. For atmosphere, music can be played in the background.

Perhaps the biggest challenge to the software writers was to devise tools that feel





[6] Body landmarks (such as those defining the position of the collarbone, bust, nape of the neck, and hips) are derived automatically from any individual's shape data. The Virtuosi team's algorithms were validated against detailed measurement of the shape of some 7500 women. Shown here are reference points [red] superimposed on a finished portion of a garment [left].

For the piece's manufacture, software "unwrapped" (laid flat) the 3-D garment and generated a 2-D pattern [below]: yellow lines show the cut lines and the numeric sequence for the path of the cuts; dotted lines are seam lines.

as natural as possible to the users. Hence the decision for voice control to instruct the mannequins to pose, or for the user to select clothes and choose fabrics. It was decided that designers would want to speak in complete sentences that used the same vocabulary adopted during real fitting sessions (direct speech, but, sadly, no "please" or "thank you").

The outcome was instructions that could be fitted into a 100-word vocabulary that the system learned to recognize from any one speaker in under 3 hours. This is not to say that the mannequins must mimic manual methods: the advantage of a VR environment is the ability to do things that cannot be performed in real life. For example, a costume designer for the next flying superhero movie might test his ideas on a flying mannequin.

Dynamic drape

The computer modeling of cloth drape has been discussed in a good many learned papers, and it has achieved a certain measure of success. In practice, the clothing designer needs high-quality images in order to make buying decisions. In effect, the aesthetic properties of the objects—for the present, only the visual ones—must be paramount.

Although many tests for measuring fabric characteristics have been developed, no commercial modeling system of fabric characteristics includes more than a basic few. Current systems, such as Clothreyes by Infográfica, Madrid, are used in small niche design trades, primarily relatively simple-to-model soft furnishings (tablecloths, curtains, and the like).

These modelers treat cloth as a 2-D texture (in the computer graphics sense, of a set type of imagery only), rather than a complex 3-D structure in its own right, with physical characteristics that must be modeled. Fabric properties such as rigidity, elasticity, yarn structure, and fiber content can all be measured but have yet to be combined in a single mathematical model for graphical representation. (Perhaps the best research on these problems is coming from the laboratory of Sueo Kawabata at the Shiga University in Shiga Prefecture, Japan).

Attempts to use finite-element analysis and high-level mathematical graphics techniques to model clothing demand vast computer power, yet still do not produce truly effective simulations of cloth in motion. Even surface design is usually rendered as a graphic overlay on the cloth model, instead of being integral to the structure.

When cloth is modeled as a physical object, even a single piece draped across a static object can be represented only with a huge amount of mathematical calculation [Fig. 7]. The scale of the problem increases tremendously when the object is moving. Not only must the properties of the cloth be taken into account, but every encounter of the fabric with the underlying object and with itself must be computed and then portrayed on screen in graphical form.

Another jump in scale occurs when the problem moves from modeling a single piece of cloth to modeling a complete garment, with all its seams, linings, fastenings, and shoulder pads. Joins must be modeled in their own right, as well as internal items such as collar stiffeners or linings. The Virtuosi project team has been trying to maintain the correct aesthetic appeal without modeling the complete mechanical assembly of each garment—a task that one day will have to be faced.

The calculation of the cloth's behavior in relation to the model's pose is complex

[7] To model the way cloth hangs, folds, and moves (known as dynamic drape) as well as how it contacts other objects, software must represent the cloth's physical properties such as rigidity, elasticity, and yarn structure. This task is much more difficult than modeling only its surface texture.

and necessarily constrained by the fixed elements of the garment. It is not yet possible to perform this type of calculation in real time, and therefore an animated fashion show with fully modeled cloth is not yet feasible.

Of course, sequences of static poses can be generated over time, recorded, and played back to make an animation. The business benefits, however, do not justify the time needed to generate these moving images. Nonetheless, the possibilities are limited only by computing power, not by the underlying mathematical model.

The business of fashion VR

The lack of easily available, fast, and broadband access to the Internet is well known. When this changes (and it surely must), the fashion industry is likely to be an important catalyst. All the main retailers now offer Internet catalogs, and some are earning significant revenues from them. Mail-order companies are in the forefront of electronic catalog shopping.

With its vast retail experience, the clothing industry is well aware of the need to pique shoppers' interest, and firms on the Internet are no exception. Indeed, a new mindset for shoppers must be cultivated. VR will lead the fashion revolution of the masses: we have nothing to lose but our off-kilter clothes.

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To probe further

Cyberware's external body scanners have played a key role in movies like *Robocop II*, *Terminator II*, and *Jurassic Park*. For more information, contact Cyberware Inc., 2110 Del Monte Ave., Monterey, CA 93940; or call 408 657-1450; fax, 408 657-1494. The company has a richly stocked Web site at http:// ghiberti.cyberware.com/.

The immense research on body scanning and anthropometry done by the U.S. Air Force is outlined at its Web site: http://fittshed.al.wpafb. af.mil/cardlab/.

The Web site for Fashion Connect, the multimedia database created by the Clothing Research Centre at Nottingham Trent University, is www.fashion-connect.com.

Daniel and Nadia Thalmann are prime movers among digital body modelers. Of their many publications, a good start is *Models and Techniques in Computer Animation* (Springer-Verlag, Tokyo, 1993).

Infográfica's Clothreyes is a cloth-modeling plug-in for Kinetix's animation package, 3-D Studio Max; the company is located at Plaza Santa Barbara, 10, 28004 Madrid, Spain; (34+1) 319 4155; fax. (34+1) 319 4174. Animations and more are at its Web site, http://www.infografica.com/cloth/cloth.html.

The research company in apparel manufacture, Textile Clothing Technology Corp., is at 211 Gregson Dr., Cary, NC 27511; 919 380-2156; 800 786-9889, http://www.tc2.com.

A search engine for technology in the textile and apparel industries can be found at http://www.tech exchange.com/tekguru/.

Data on women's measurements in the 1950s can be found in a publication of the United Kingdom Board of Trade, *Women's Measurements and Sizes*, Her Majesty's Stationery Office, London, 1957.

About the author

Stephen Gray heads the Computer Clothing Research Centre at Nottingham Trent University, United Kingdom. He is a board member of the Textile Institute and chairman of its events committee, and has been a member of the council and executive board of the Institution of Electrical Engineers. He is also a Chartered Engineer.