Implementation and evaluation of an IEC-based 3D modeling system

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Implementation and Evaluation of an IEC-Based 3D Modeling System

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Abstract

We show how IEC (interactive evolutionary computation) make the 3D shape design an easy and intuitive task through subjective tests. We assume two different design aspects such as a real object reproduction and a new shape creation, and conduct the tests with twenty subjects. Some qualitative observations and discussions are presented from a viewpoint of the effectiveness of the proposed modeling method.

Keywords

3D modeling, interactive evolutionary computation, computer graphics, subjective test.

1. Introduction

Although computer graphics became a readily accessible technology for everyone, the production of appealing 3D models remains a challenging problem to attack. We elaborate enhanced functions and evaluation of the formerly proposed IEC-based 3D modeling system [1] to easily creating aesthetically pleasing shapes as a solution to the problem.

The proposed system uses IEC as a framework to augment designers' ability for inventing and inspiring new shapes. It allows the designers or even beginners to create novel and realistic 3D shapes by simulating natural evolution of the 3D geometric models. The system evolves the 3D shapes by applying the genetic algorithm (GA) operations such as crossover, mutation, and selection to them. The users' role is to subjectively specify the degree of "likes or dislikes" for the evolved shapes by rating and request the system to generate better shapes through the evolution based on the given rates. This "rating-evolution" process is iterated until the system converges on a satisfactory result.

IEC has been applied to various fields such as art, engineering, education, and entertainment for the last ten years [2]. One of major application fields is the creative artistic design. Dawkins has demonstrated the power of computer-simulated evolution by implementing the "boimorphs," a 2D line drawing system of complex structures [3]. Following his pioneering work, the two representative graphics applications were developed by Sims [4] and Unemi [5]. They established a concept, the so-called simulated breeding, to generate aesthetic graphics images based on artificial selection rather than natural selection. Although their approach was quite successful to create innovative results, the target shapes are limited to highly abstract artwork. Other artistic applications are: interactive EC-based drawing lines, such as morphological lines of insects, plant lines based on the L-system, and face drawing: interactive EC-based CG, such as for creating, 3D CG rendering of artificial life art [6], and animal and plants CG [7]: 3D CG lighting design support [8]: industrial designs. See the reference [2] for further detail survey.
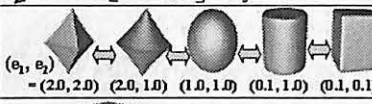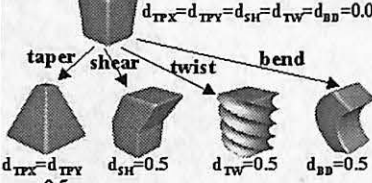
A common problem of these applications is the lack of qualitative evaluations. While many attractive pictures and images are presented in the literatures, few persuasive data and discussions are given to show how effectively IEC support creative tasks. We present the qualitative observations and discussions through subjective tests in addition to the concept and mechanisms to make the 3D modeling a simpler task. The tests consider two different design aspects, the realistic examination to reproduce the real shape as closely as possible and the creative examination to invent new shapes. The tests assign a modeling task with and without IEC interface to the subjects, investigating the effectiveness of IEC on both examinations.

2. IEC Modeling System
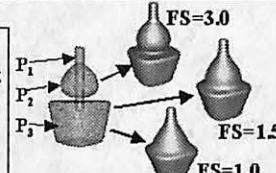
2.1 3D Modeler Function

The developed 3D modeler employs the implicit surface method [9]. It allows the users to easily rough out their ideas and imagination in 3D by iterating the primitive blending and the shape deformation [10]. A primitive shape is represented by a superquadric function [11]. Each primitive shape has six kinds of functional parameters as described in figure 1(a). These parameters define scale, position and orientation in a global coordinate system, geometric pattern, and deformation strength of the primitive shape. Changing the parameter values dynamically modify the primitive geometries as those illustrated in the figure [12].

Blending multiple primitives can represent further complex shapes. Figure 1(b) exemplifies a

Parameter	Roles and functions
type *primitive type in int*	super ellipsoid supertoroid
(r_x, r_y, r_z, r_a^*) *scale in float*	scale position (x_0, y_0, z_0)
(x_0, y_0, z_0) *position in float*	orientation
R (4x4 rotation matrix in float) *orientation*	$R = \begin{bmatrix} m & m & m & 0 \\ m & m & m & 0 \\ m & m & m & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ global coordinate system
(e_1, e_2) *shape in float*	(e_1, e_2) = (2.0, 2.0) (2.0, 1.0) (1.0, 1.0) (0.1, 1.0) (0.1, 0.1)
d_{TPX}, d_{TPY} : tapering d_{SH}: shearing d_{TW}: twisting d_{BD}: bending *deformation in float*	$d_{TPX} = d_{TPY} = d_{SH} = d_{TW} = d_{BD} = 0.0$ taper shear twist bend $d_{TPX} = d_{TPY} = 0.5$ $d_{SH} = 0.5$ $d_{TW} = 0.5$ $d_{BD} = 0.5$

$^*r_a$: torus radius for supertoroid primitive

(a) Functional parameters to define a primitive shape.

Parameter	Roles and functions
FS: *field strength in int*	FS=3.0
d_{TPX}, d_{TPY}: tapering d_{SH}: shearing; d_{TW}: twisting d_{BD}: bending *deformation in float (Same role with primitive deformation)*	P_1 P_2 P_3 FS=1.5 FS=1.0

(b) Functional parameters to define blending.
Figure 1: Functional parameters to define 3D models.

bottle shape made by blending three primitives P_1, P_2 and P_3. Additional parameters as described in the figure control the global deformation and the blending operation. The figure shows the effect of the field strength parameter.

2.2 GA Coding of 3D Model

We adopt GA as one of the EC technologies to evolve 3D models in the system. A 3D model is encoded for the simulated evolution as illustrated in figure 2. It shows the PTYPE and the GTYPE of a green pepper shape a subject used in the experiment described in the next section. The PTYPE consists of six primitive (P_1, P_2,..., P_6) and one blending (**B**) parameters, and the corresponding GTYPE composes a bit string of all parameters held in the PTYPE. A subset of parameters can be selected for the evolution by using the selection flag. For example, eight parameters including scale (r_x, r_y, r_z), shape (e_1, e_2), tapering (d_{TPX}, d_{TPY}), and bending (d_{BD}) parameters
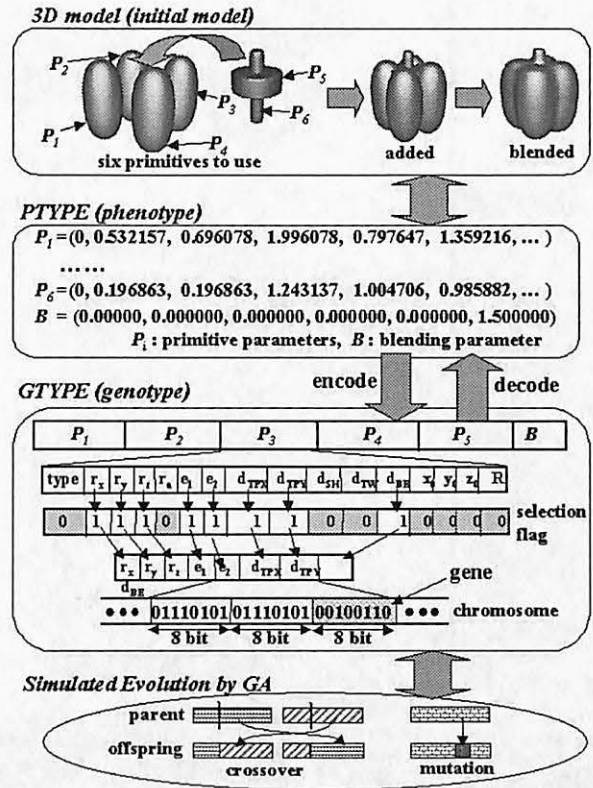

Figure 2: GA coding of 3D shape.

are chosen for the evolution of the green pepper shape in the experiment.

Each parameter is encoded as an 8-bit string, the so-called *gene*, using the following equation:

$$G = [(2^8 - 1) / (P_{max} - P_{min}) \times (P - P_{min})] \quad (1)$$

where P is a parameter value; G is an encoded 8-bit gene; P_{max} and P_{min} are the parameter's maximum and minimum values; [ ] is Gauss' symbol. A collection of genes in one GTYPE is referred as a *chromosome*. The bit length of the chromosome is given as **p x n + b**, where p is the number of primitive parameters; n is the number of primitives; b is the number of blending parameters. Therefore, the length of the chromosome of the green pepper shape in figure 2 is 54 bytes (8x6+6).

2.3 IEC Modeling Algorithm

Figure 3 summarises the IEC modeling algorithm. First of all, an initial shape should be defined. In the case of the green pepper example, it is made by using six primitives as shown in figure 2. Secondly, some conditional variables such as the selection flag, P_{max} and P_{min} in the equation 1 for each selected parameter, and GA control variables like crossover and mutation rates need to be set. Then, an initial generation of models is randomly created until the user finds some shapes containing appropriate geometric features to
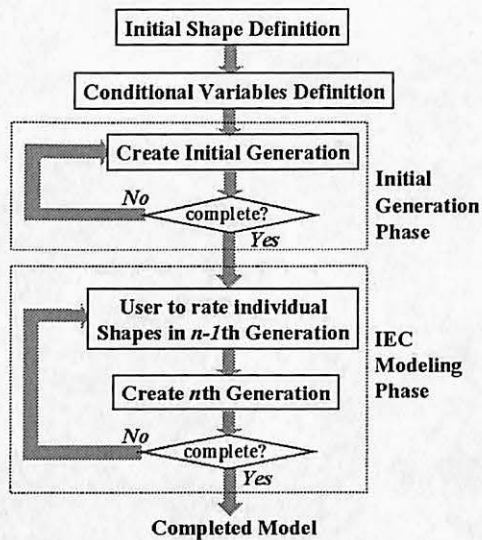
Figure 3: IEC modeling algorithm.

emphasize in the IEC modeling phase. Finally, the initial generation of GTYPEs are decoded to PTYPEs for rendering corresponding 3D models. The user rates the *fitness value* for each rendered model according to his/her subjective preference. Then, a new set of GTYPEs (offsprings) is reproduced from existing GTYPEs (parents) by applying crossover and mutation as shown in figure 2. Highly rated GTYPEs have high probability to survive, being selected as parents to generate new offsprings. Top 5% of such highly rated individuals survive in the new generation if the crossover rate is 95%. This "evaluation and reproduction" process is iterated until an acceptable model shape is produced.

2.4 System Interface

The IEC-based modeling depends on the users' rating to get successful results from the simulated evolution. Therefore, the interface to allow the users to easily find their preferred shapes and properly set the fitness values is a crucial element to realize. Additionally, a mechanism to manually modify the model geometries with finer control also is required. Consequently, we implemented two different modelers as shown in figures 4 and 5. The 3D models generated through the IEC process are simultaneously displayed in a list format as depicted in figure 4. The users can observe up to twenty generated models at the same time, comparing one another, and assessing whether the shape is good or bad. The manual 3D modeler as shown in figure 5 is provided to define an initial shape used for the IEC modeling and elaborate the model shapes by directly changing the parameter values.
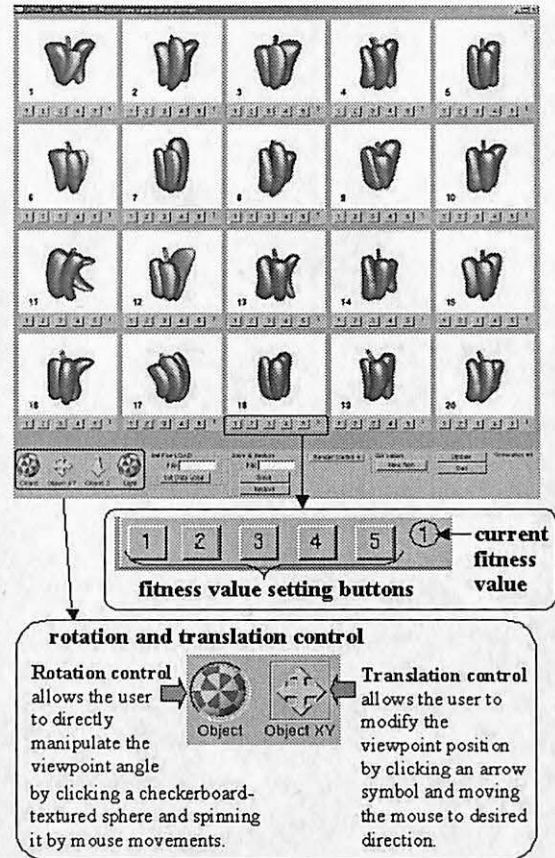

Figure 4: IEC moleder.

Because a mechanism to freely observe the models from various angles is a mandatory function for the 3D modeling task, both modelers provide the rotation and translation controls to modify the viewpoints. The fitness value can be set by pushing a button laid in each model's subwindow as shown in figure 4. The parameter values can be modified by using the slider controls in the manual modeler as described in figure 5. All these operations can be handled only by a mouse device to make the users be concentrating on the modeling tasks.

Both modelers are written by C, C++, and OpenGL, running on Windows PCs and SGI Unix workstations. The GUI interfaces are implemented by using GLUI toolkit [13].

3. Subjective Tests

3.1 Design Motifs

We conducted subjective tests to evaluate the effectiveness of the proposed IEC-based 3D modeling. To verify the system's ability to support creative design task, the green pepper is chosen as the
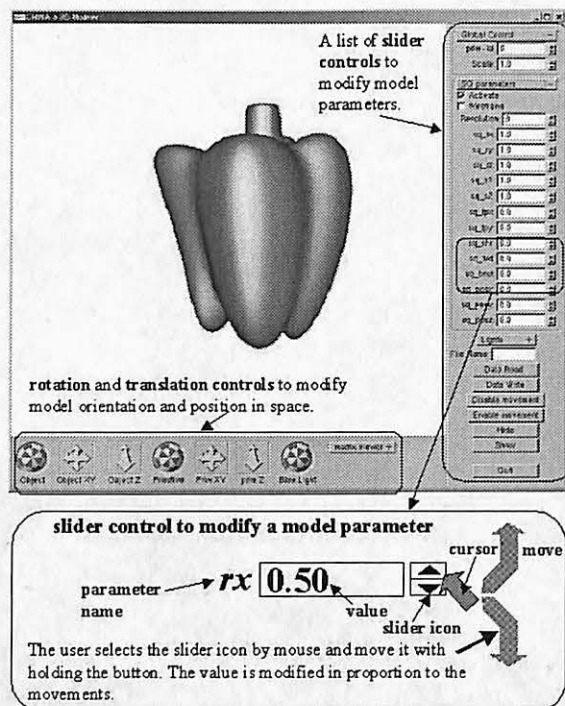
Figure 5: Manual 3D modeler.

Figure 6: A real green pepper used in RE.

target shape in the experiment because of the following reasons:
- Everyone easily imagines its shape without depending on his/her knowledge and experience,
- It is an inartificial shape which is difficult to design by using the traditional CAD tools, and
- Its shape has enough variations to encourage the subjects' flexible thinking and imagination.

Twenty students are employed as subjects, ten from art major and the rest from engineering major. Two motifs are given to all subjects including (1) the *realistic examination (RE)* to show them a photo of a real green paper and let them reproduce its shape as closely as possible, a photo used for this examination is shown in figure 6, and (2) the *creative examination (CE)* to invent a new shape from an abstract motif, a "ferocious green pepper," and instruct the subjects to draw its CG image.

3.2 Experimental Procedure

All subjects are requested to make the green pepper shapes by using both manual and IEC modeling methods for each examination. After they complete both examinations, they are inquired about the following two questions to grade each modeling method according to five ranks:
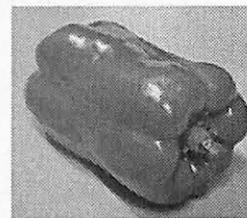(1) *Quality* of the models to indicate how realistic to the photo or close to their imagery they can produce,

(2) *Operability* to specify which method is better and easier to make the models.

All subjects complete the whole experimental procedure according to either A or B plan shown in table 1. In the A plan, they make the RE with the IEC method followed by the manual method, and then make the CE in the same manner after that. They try the same procedure with the reversed order of the modeling methods (the manual first then the IEC) a week later. The B plan replaces the order of the modeling methods as shown in table 1.

All examinations are performed under the following conditions:
- six primitives are used,
- scale (r_x, r_y, r_z), shape (e_1, e_2), tapering (d_{TPX}, d_{TPY}), and bending (d_{BND}) parameters are selected for adjustments,
- the population of individuals is 20,
- the crossover rate is 95%,
- the mutation rate is 1%, and
- the fitness value is a rate on a scale of 1 to 5 (the worst to the best correspond to 1 to 5).

While 19 offsprings (95%) out of 20 are generated by the crossover operation in every generation, the only 1 individual (5%) is treated as a highly rated elite parent to survive.

We used a pair of Windows2000 PCs for all examinations as illustrated in figure 7. Because the blending operation is too slow to keep interactive responses, it is separated from the modelers and executed on a dedicated PC. The subjects need to request the blender to update the image using the latest model geometries.

Table 1: Test Procedure and Schedule.

	RE	CE		RE	CE
A	iec-mn	iec-mn	1 week	mn-iec	mn-iec
B	mn-iec	mn-iec	1 week	iec-mn	iec-mn

RE: Realistic Examination, CE: Creative Examination
mn: manual method, iec: IEC method

3.3 Results

All subjects performed each examination twice and their answers are classified into the following four categories:
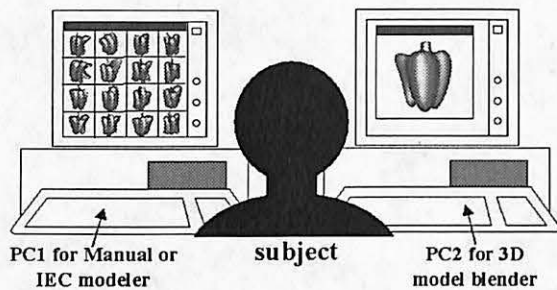(a) Manual (or IEC) is better for both examinations,

Figure 7: Experimental environment.

(b) Manual (or IEC) is better for one examination but no difference for the other,
(c) No difference for both, and
(d) Manual for one and IEC for the other.

Because the categories (c) and (d) are meaningless answers, they are excluded from the data for statistical evaluation.

Table 2 collects the answers of the category (a) and table 3 adds up both (a) and (b). While 7/2[1] subjects express the manual method is better for the quality question in the RE, only 0/1 subject votes on the IEC method. Therefore the manual method is considered to be a better solution for the RE, because of a significant difference with 5% of risk observed in a paired comparison. For the operability question, 8/1 subjects vote on the manual, whereas 3/0 vote on the IEC. Although there is no statistical evidence, the subjects tend to prefer the manual interface in the RE.

In the case of the CE, 4/3 (manual) versus 4/1 (IEC) for the quality question and 4/1 versus 7/1 for the operability question. As a result, there is no significant differences observed between the manual and the IEC methods.

Table 2: Test result from category (a).

	RE	CE
	mn : iec	mn : iec
Quality	7 : 0*	4 : 4
Operability	8 : 3	4 : 7

*(p<0.05) **(p<0.01)

Table 3: Test result from categories (a) and (b).

	RE	CE
	mn : iec	mn : iec
Quality	9 : 1*	7 : 5
Operability	9 : 3	5 : 8

*(p<0.05) **(p<0.01)

4. Discussions

Because the manual method allows the subjects more detailed control to modify and improve the

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[1] 7/2 means seven subjects' answers are classified into the category (a) and two answers into the (b).

shape in comparison with the IEC method, it seems to be preferable when they have a clear goal. The result of the quality question in the RE explicitly proves this tendency. A few subjects cite that the IEC method prevented them from producing satisfactory results due to the lack of fine control. On the contrary, the IEC dominates the operability question over the manual in the CE. Finding a set of appropriate parameter values to externalize the abstract motif is very difficult in the CE. The IEC seems to have an advantage over the manual in this situation.
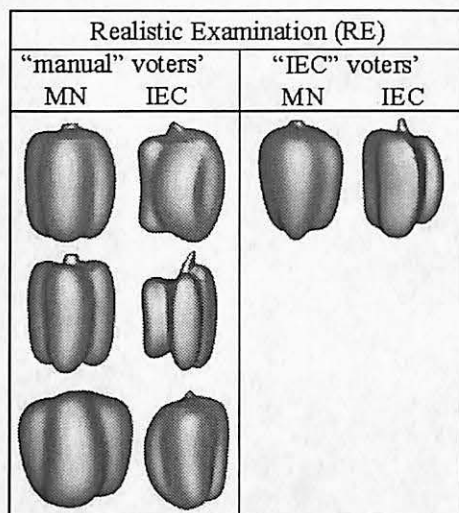
Although no significant difference was observed between both methods in the CE, which method is better may depend on each subject's capability to invent the new shape in case of the creative modeling. The subjects who can draw a firm image in their mind seem to like the manual more than the IEC. On the other hand, the subjects who have only some vague images or no idea tend to prefer the IEC. The latter subjects state the IEC successfully presented a set of interesting candidate shapes, widening the possibility to create more attractive shapes than the manually produced models.

The subjects who vote on the manual method express the IEC's difficulties to elaborate the model shapes especially in the final stage. Therefore, a synergetic use of both methods can be considered as a better solution. An example is to mainly use the IEC interface in the initial stage of the modeling task to discover some fresh and original shapes, and then switching to the manual mode to finalize the selected shapes by the IEC. Both methods should be integrated into a single interface to realize this requirement.
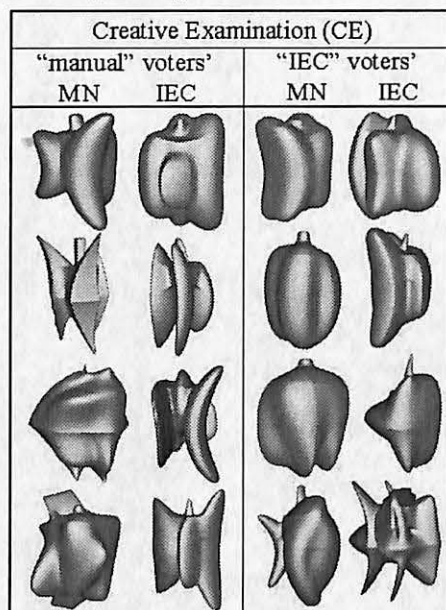
Figure 8(a) and 8(b) show some example shapes made in the RE and the CE, respectively. Each figure includes two categories such as the models made by the manual and the IEC voters. Because a subject only votes on the IEC in the RE, a pair of shapes is presented in the IEC column in figure 8(a). Because the target shape is not far from the initial shape in the RE, the acquired shapes seem not so difficult to manually produce. On the other hand, the subjects who cannot make drastic shape modifications tend to prefer the IEC method in the CE. Therefore, the IEC's ability to effectively support beginners and inexperienced users appears in the results in figure 8(b).

Giving the subjects a fun is another reason to decide a preferred method. A few subjects indicate the manual editing is like a clay modeling and the fun to use it. On the other hand, some difficulties to control the IEC's GUI components especially the rotation tool are pointed out. Accordingly, providing more intuitive and fun-to-use interface for spatial

Realistic Examination (RE)			
"manual" voters'		"IEC" voters'	
MN	IEC	MN	IEC

(a) Example models from RE.

Creative Examination (CE)			
"manual" voters'		"IEC" voters'	
MN	IEC	MN	IEC

(b) Example models from CE.
MN: models made by the manual method
IEC: models made by the IEC method

Figure 8: Example models made in experiments.

operations is a critical requirement to make the IEC method be attractive for everyone.

5. Conclusions and Future Work

We described an approach to implement an intuitive 3D model design framework using IEC and subjective tests to evaluate its effectiveness. The results of the experiments suggest the proposed IEC method is more useful for the creation of totally unprecedented shapes than the reproduction of realistic objects. While this tendency cannot be proved by significance test in this experiment, it is anticipated to become a noticeable difference if the target shape is more complex one. Therefore, additional tests using more complicated motifs should be an important future work.

We have an enhancement plan to make the system be accessible via the Internet, applying to the problems such as remote training and education, collaborative design, and 3D data sharing and distribution.

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