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Education system using interactive 3D computer graphics (3D-CG) animation and scenario language for teaching materials

Hiroshi Matsuda* and Yoshiaki Shindo
Nippon Institute of Technology, Japan

The 3D computer graphics (3D-CG) animation using a virtual actor's speaking is very effective as an educational medium. But it takes a long time to produce a 3D-CG animation. To reduce the cost of producing 3D-CG educational contents and improve the capability of the education system, we have developed a new education system using Virtual Actor. It includes a 3D-CG stage, many kinds of stage parts (3D-CG shaped models, photographs or text panels) and Virtual Actor(s). Virtual Actor is a software robot of various shapes based on 3D-CG and speech synthesis. Virtual Actor speaks English/Japanese by voice synthesizer with facial expressions and body actions. We have developed two kinds of education system, one is a Cyber Assistant Professor (CAP) and another is a Cyber Theater (CT). CAP has been designed for a self-learning system, which enables interactive communication between Virtual Teacher and learner. CT has been designed for a 3D-CG story maker, which is a new 3D-CG media player, attractive enough to arouse the pupil's interest. We also have developed the exclusive scenario language to write a scenario of 3D-CG animation. It is a tag-based hypertext language like HTML. Both CAP and CT convert this scenario to real-time interactive 3D-CG animations, which are not rendering movies. This paper describes the system architecture of CAP and CT, details of scenario language and results of experimental lessons.

Introduction

The 3D computer graphics (3D-CG) animation using a Virtual Actor speaking is very effective as an educational medium (Graesser & Hu, 2001), but it takes a long time to produce a 3D-CG animation. To reduce the cost of producing 3D-CG educational contents and improve the capability of the education system, we have developed a new education system using Virtual Actor (Matsuda & Shindo, 2005a). It includes a 3D-CG stage, many kinds of stage parts (3D-CG shaped models, photographs or text panels) and Virtual Actor(s). Virtual Actor is a software robot of various shapes based on 3D-CG and speech synthesis. Virtual Actor speaks English/Japanese by voice synthesizer with facial expressions and body actions. We have developed two

*Corresponding author. Nippon Institute of Technology, 345-850, 4-1 Gakuendai Miyashiro-machi Minami-Saitama-gun, Saitama, Japan. Email: hiroshi@nit.ac.jp

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kinds of education system, one is a Cyber Assistant Professor (CAP) and another is a Cyber Theater (CT). CAP has been designed for a self-learning system, which enables interactive communication between Virtual Teacher and the learner. CT has been designed for a 3D-CG story maker, which is a new 3D-CG media player attractive enough to arouse the pupil's interest. The stage parts can also move simultaneously, corresponding to the Virtual Actor's instruction. Sometimes Virtual Actor shows a question to the learner and the learner has to answer by clicking the specified stage parts, e.g., selecting the correct answer or entering the number. On response, Virtual Actor can change the scenario of 3D-CG animation or load the applicable external scenario file.

We also have developed the exclusive scenario language to write a scenario of 3D-CG animation. It is a tag-based hypertext language like HTML. Both CAP and CT convert this scenario file to real-time interactive 3D-CG animations, which are not rendering movies. We have developed some teaching materials for elementary school students (an elementary course of science) and have designed the Creative Lesson for junior high school and high school students, where pupils study how to make a 3D-CG animation by using scenario language and try to produce their original animations. The main subject of this lesson is to teach pupils that a computer is not only a tool for browsing information, but also a tool for creating the information. This paper describes the system architecture of CAP and CT, details of scenario language and results of experimental lessons.

Preceding research

The most popular method to produce a 3D-CG cartoon movie is to use some 3D-CG animation tools and a non-linear video editing system. But it takes great time to render 3D-CG animation frames and to integrate the animation, sound, music, and speaking. This way cannot construct an interactive system. Another way is to make a real-time 3D-CG animation by using the programming language and some libraries (e.g. OpenGL, Speech SDK and MCI library). But this production cost may also be too great for education. From this point of view, the SDK (System Design Kit) libraries for human-shaped 3D-CG models were reported. The most famous one is 'Jack' (Phillips & Badler, 1988; http://www.cis.upenn.edu/~hms/jack.html, http://ecust.isid.co.jp/public/products/jack/) developed by Pennsylvania University. It was developed as a LISP language SDK for military application. Although Jack has a lot of excellent functions, it cannot integrate a voice synthesizer, sound effects, music and facial expressions. Another one is Alice (Conway *et al.*, 2000; Cooper *et al.*, 2003), which is a 3D graphics programming environment developed by Carnegie Mellon University. Alice provides an environment where pupils can use or modify 3D objects and write programs to generate animations. Alice uses an exclusive programming code because it is designed for learning object-oriented programming or computer science. Although Alice has a rich gallery (actors and stage parts library) and has an excellent interactive capability, actors in the Alice gallery cannot speak by voice synthesizer and they have no body action database. The other way is to make a real-time animation by using a script language like a HTML language. MPML (Tsutsui, 2000) is a hypertext for the Web presenter, which is installed by Microsoft Agent. MPML has a lot of excellent functions. Utterance, movement and simple body performance of the presenter are managed by tag commands and it has a powerful affinity for

HTML language. Moreover, it has a speech recognition function. But it does not satisfy the specification we requested because:

- The presenter is not a 3D-CG model.
- It has no virtual 3D stages and stage parts.
- It has no 3D spatial management structure like a camera working.

TVML (Hayashi *et al.* 1999a, b) is a script language that creates a real-time CG animation of news shows automatically. TVML exactly reenacts the TV studio equipment and is able to describe the utterance, subtitles and simple facial expressions of a virtual newscaster. But it also does not satisfy the specification we requested, because:

- It is too complex to set up the environment.
- Body actions are restricted because these are customized for a newscaster.
- Stage parts cannot be moved!
- TVML listings look like a programming language, not a tag-based hypertext language.

We have developed the self-learning system named Cyber Assistant Professor (CAP) (Shindo & Matsuda, 2001a, b; Shindo *et al.*, 2002; Matsuda & Shindo, 2004a, 2005b, c) and the 3D-CG story maker named Cyber Theater (CT) (Matsuda & Shindo, 2003, 2004b, c, 2005a). These systems consist of the integration of multi-media high technology; these are OpenGL, SpeechAPI and MP3. Moreover, we have designed an exclusive scenario language just like a HTML, which can write scenarios of the interactive real-time 3D-CG animation of teaching materials.

Scenario language for teaching materials

In order to extend the possibilities of CAP and CT for non-expert users (especially for pupils in school) and to reduce the production costs of CAP and CT animation, we developed an exclusive scenario language. To describe an interactive 3D-CG animation scenario easily, we designed a ⟨TAG⟩ based scenario language similar to HTML. The way to make a scenario is just to put an appropriate text string between a pair of ⟨TAG⟩ markers (named Body Text). Some ⟨TAG⟩ markers include Option Switches to specify the system mode and set the state variables. ⟨TAG⟩ command and ⟨/TAG⟩ terminator define one block named a tag-block. To make a 3D-CG animation scenario, each scene would be defined by placing tag-blocks in suitable positions. By inserting a tag-block into another tag-block, Virtual Actors and stage parts can be moved simultaneously. This scenario language has more than 30 tags (see Table 1) and coding of it can be edited by using a text editor or word processor. By using it, even a non-expert is able to produce a real-time 3D-CG animation easily.

Specification of Virtual Actor's speaking

The basis of scenario language is Virtual Actor's speech text. When using ⟨TALK⟩, Virtual Actor speaks body text and changes facial expression automatically by detecting the lyric word in the speech text. It is convenient for short scenarios, but sometimes the facial expression would not match the author's expectation. ⟨SPEAK⟩ specifies the speech text without

Table 1. Main ⟨TAG⟩ of scenario language

Tag	Body text	Text function
⟨TALK⟩	Speak text	Speak the text string with facial expression
⟨SPEAK⟩	Speak text	Speak the text string without facial expression
⟨SCRIPT⟩	Display text	Display the Subtitles under the window
⟨FACE⟩	Lyric word	Apply the facial expression by specified Time Transition Code
⟨MOTION⟩	Action word	Play the body performance by Specified Times and Speed
⟨ACTION⟩	Action word	Play the body action by Specified Time Transition Code
⟨AU⟩	AU sequence	Apply AU sequence directly
⟨MODE⟩	None	Set the state variables
⟨WALK⟩	Action word	Walk to the Front or to the Rear in Specified Frames
⟨JUMP⟩	Action word	Jump up or down in Specified Frames
⟨SLIDE⟩	Action word	Slide to the Left or to the Right in Specified Frames
⟨ROTX⟩	Action word	Rotate Body at the X-axis in Specified Frames
⟨ROTY⟩	Action word	Rotate Body at the Y-axis in Specified Frames
⟨ROTZ⟩	Action word	Rotate Body at the Z-axis in Specified Frames
⟨TIMER⟩	None	Wait Specified Time
⟨MUSIC⟩	None	Play the specified MIDI file
⟨SOUND⟩	None	Play the specified WAVE file
⟨PLAY⟩	None	Start to interpret the CPSL2 or CTSL text
⟨STOP⟩	None	Stop interpreting the CPSL2 or CTSL text
⟨EXIT⟩	None	Stop interpreting the CPSL2 CTSL text and exit the application
⟨COM⟩	Comment text	Insert the Comment text
⟨ACTOR⟩	None	Create the Virtual Actor
⟨STAGE⟩	None	Create the Stage using 3D-CG models and Pictures
⟨CAMERA⟩	None	Move the Viewing Camera in Specified Frames
⟨LENS⟩	None	Setup the View Volume
⟨REQUEST⟩	Action word	Define the Answer Target and CASE number
⟨ANSWER⟩	Action word	Define the Entry point of Answer block specified by CASE number
⟨SCENARIO⟩	Action word	Load the external scenario file and execute
⟨SCENE⟩	Action word	Define the chapter scene just like a DVD player

automatic facial expression. But by using both ⟨SPEAK⟩ and ⟨FACE⟩, Virtual Actor can speak the speech text with facial expression as directed by the author. In the next example, Nana speaks with a smiling expression because the lyric word ‘happy’ generates the facial expression of ‘Smile’.

```
<TALK> & <SPEAK> Block

<TALK ACTOR = "Nana"> I am very happy because today is my birthday. </TALK>

<SPEAK ACTOR = "Nana"> Today is <FACE> happy </FACE> my birthday. </SPEAK>
```

ACTOR switch (Option Switch) selects the Virtual Actor while SCRIPT switch enables the display of subtitles under the window simultaneously. ⟨SCRIPT⟩ can display captions, which may be different from the speech text.

```
<SCRIPT> Block
<SCRIPT> Look at the pretty Cyber Girl.
    <SPEAK ACTOR = "Emi" > My name is Emi. I'm Nana's elder sister. </SPEAK></SCRIPT>
```

Table 2 shows the Option Switches of ⟨TALK⟩ and ⟨SPEAK⟩.

Specification of the facial expression

⟨FACE⟩ specifies the facial expression of Virtual Actor by using the lyric word written in the body text. Figure 1 shows the data flow of facial expression.

The lyric word is extracted and converted to the Facial Expression Name (FEN) by referring to the lyric word database. By using ⟨FACE⟩, FEN is converted to Facial Action Coding System—Action Unit (FACS-AU) sequence by referring to the facial expression database. FACS was developed by Dr. Ekman. It is a code of facial expression and a number table of facial muscles named AU. As shown in Figure 2, using FEN Encoder, it is possible to create new facial expressions and to register them in the FEN database.

Specification of body action

Both ⟨ACTION⟩ and ⟨MOTION⟩ tags specify body action by using the action word written in the body text. Figure 3 shows the data flow of body action. An action word is extracted and converted to the Body Performance Name (BPN) by referring to the action word database. By using ⟨ACTION⟩, BPN is converted to Body Action Coding System—Action Unit (BACS-AU) sequence by referring to the body motion database to play the specified body action. BACS-AU is an assigned number, which is a moving method of body joints just like FACS-AU. By using ⟨MOTION⟩, BPN is converted to the filename of motion capture data by referring to the body motion database to play the sophisticated body action performance. Motion capture data includes the sequences of transformation matrix assigned to the body joints. Option Switches

Table 2. Option switches of ⟨TALK⟩ and ⟨SPEAK⟩

Option switch	Content	Function
ACTOR	Virtual Actor's name	Name of active actor
SCRIPT	ON	Display the subtitle
	OFF	Display nothing

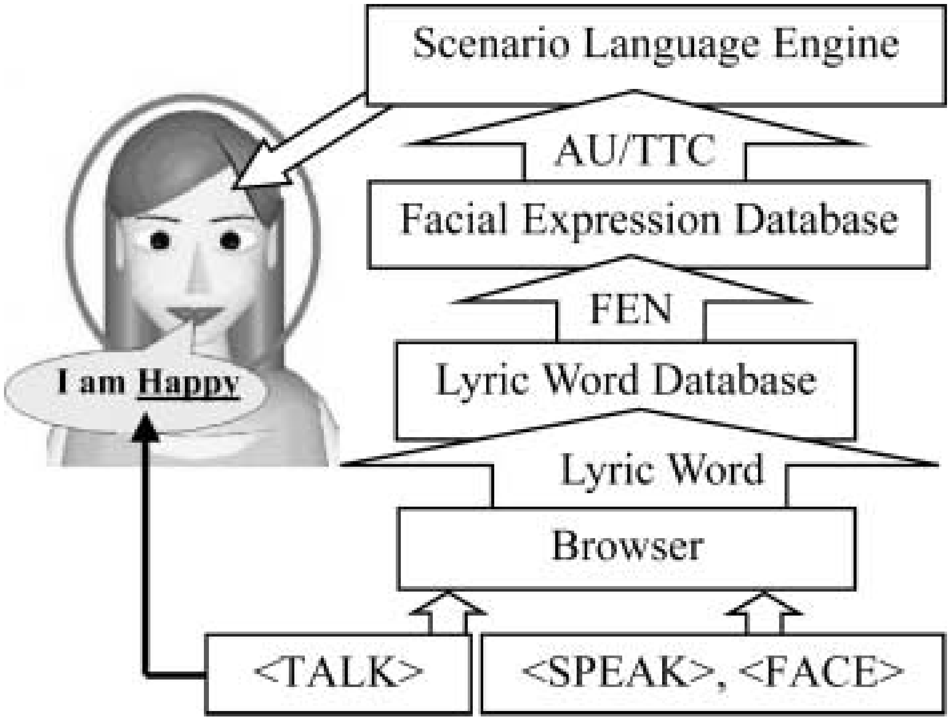


Figure 1. Data flow of facial expression

Figure 2. FEN Encoder

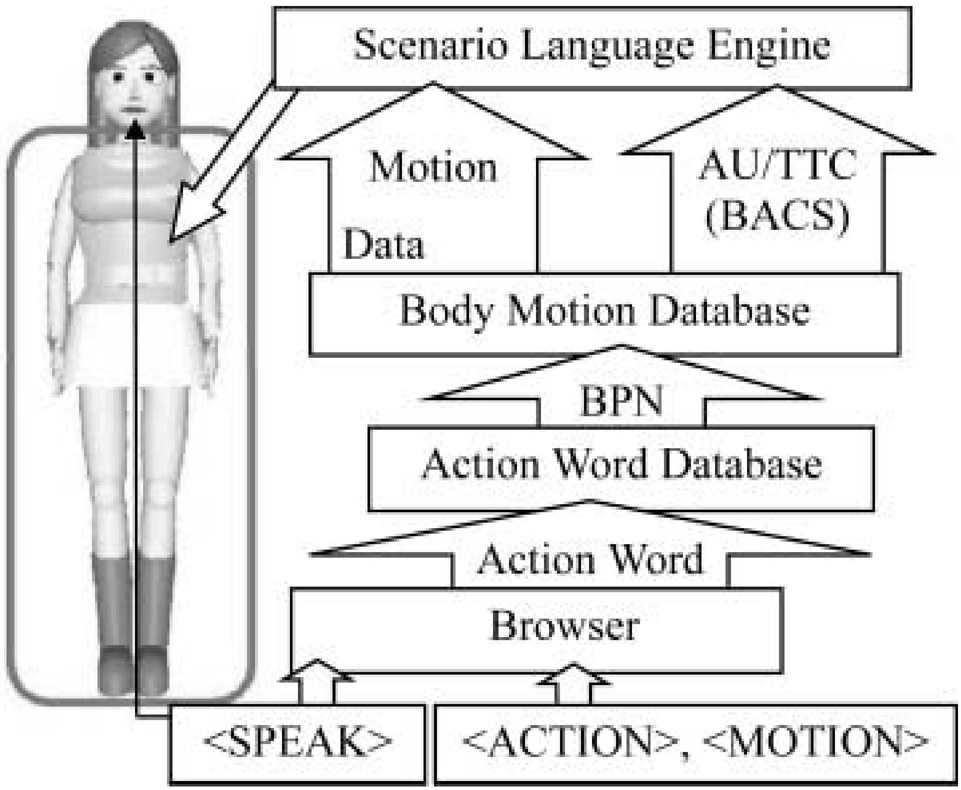


Figure 3. Data flow of body action

define the playback speed and repetition times. BPN can be designed and registered by a body action encoder (Figure 4).

Specification of the interactive communication

Both ⟨REQUEST⟩ and ⟨ANSWER⟩ tags provide the interactive communication. ⟨REQUEST⟩ defines the answer target with CASE number using specified stage parts. ⟨ANSWER⟩ defines the entry point of answer block corresponding to the CASE number. It is possible to change the scenario depending on the learner's reply (mouse clicking on the answer target). Table 3 shows the option switch of ⟨REQUEST⟩. Figure 5 shows an example of ⟨REQUEST⟩ and ⟨ANSWER⟩ coding.

Load the external scenario file

⟨SCENARIO⟩ loads the external scenario file and executes it automatically. By using ⟨SCENARIO⟩ in the ⟨ANSWER⟩ block, it is possible to construct large-scale structured scenario contents.

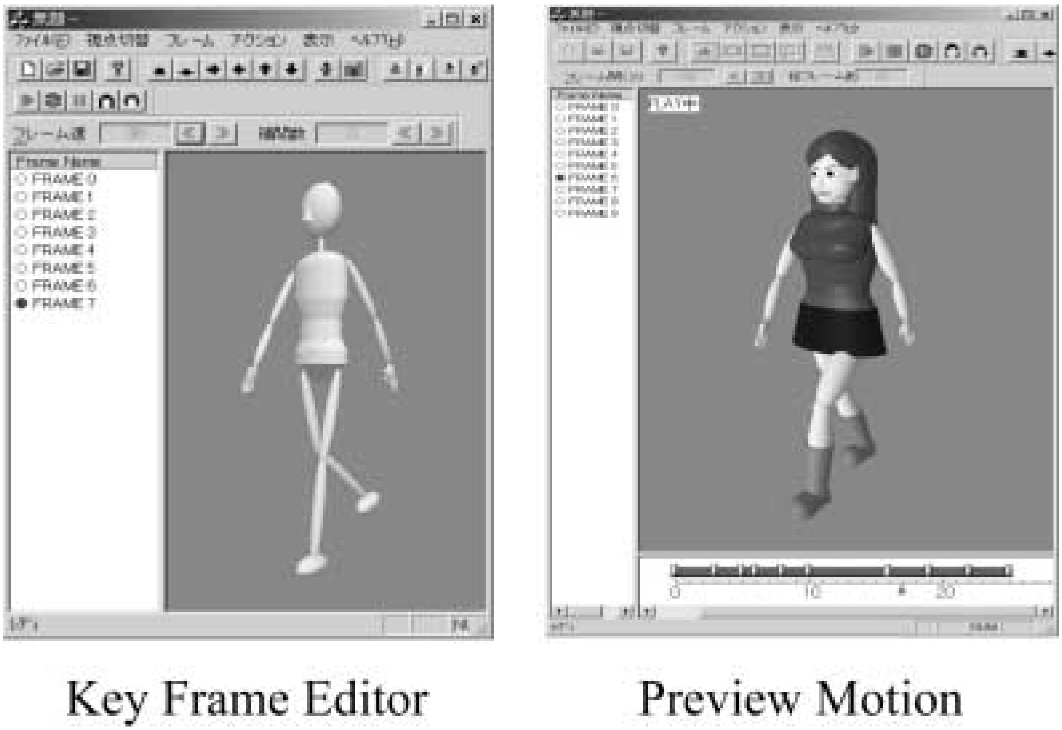
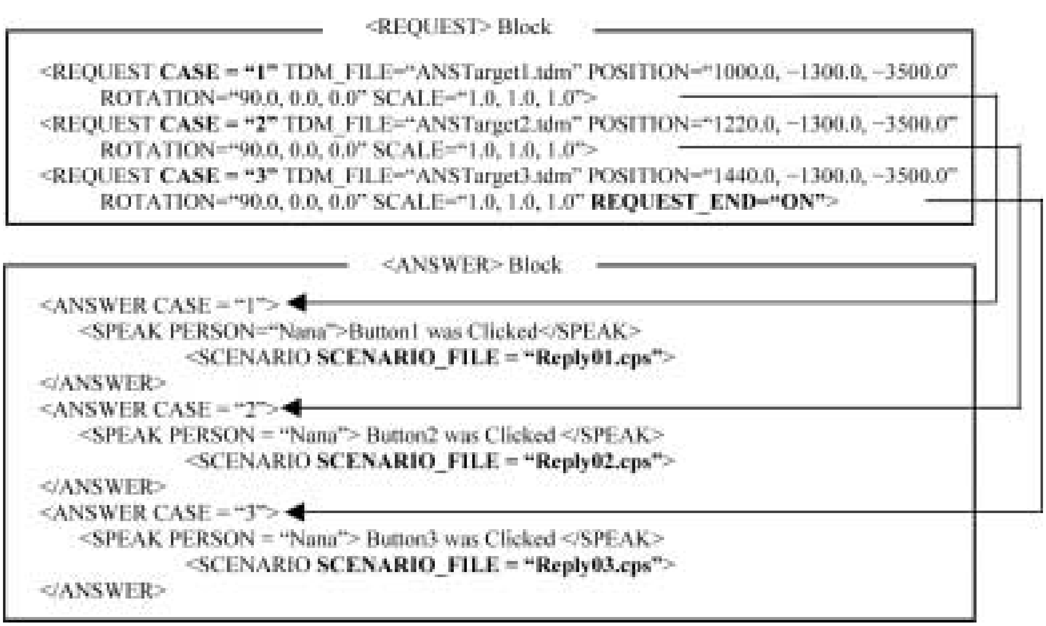


Figure 4. Body action encoder



```
<ANSWER> Block

<ANSWER CASE = "1">
    <SPEAK ACTOR = "Nana"> Button1 was Clicked. </SPEAK>
    <SPEAK ACTOR = "Nana"> I load next scenario file. </SPEAK>
        <SCENARIO SCENARIO_FILE = "Sample02.cps">
    <STOP>
</ANSWER>
                                    Loads and executes external scenario file
```

Table 3. Option switch of ⟨REQUEST⟩

Option switch	Content	Function
CASE	Integer number	Case number of answer target
TDM_FILE	File name	File name of the stage parts
POSITION	PX, PY, PZ	Specify the position of stage parts
ROTATION	RX, RY, RZ	Specify the rotation of stage parts
SCALE	SX, SY, SZ	Specify the scaling factor of stage parts
REQUEST_END	ON/OFF	End of REQUEST listings

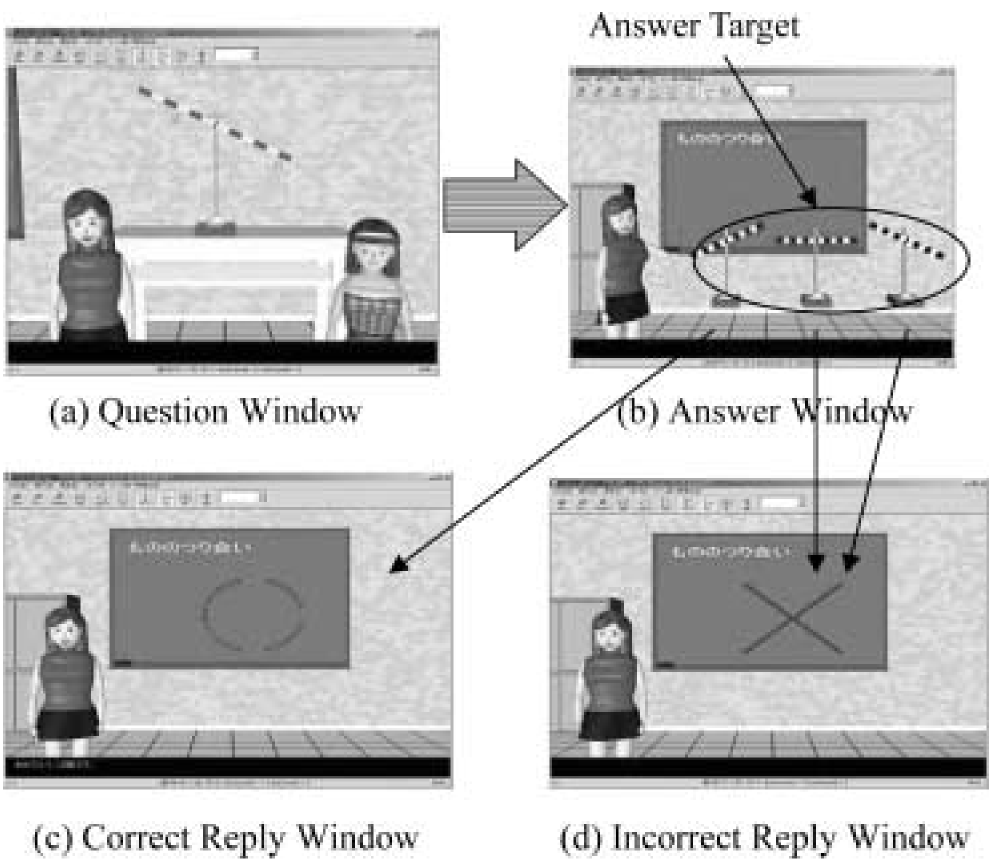


Figure 5. Screen of answer target

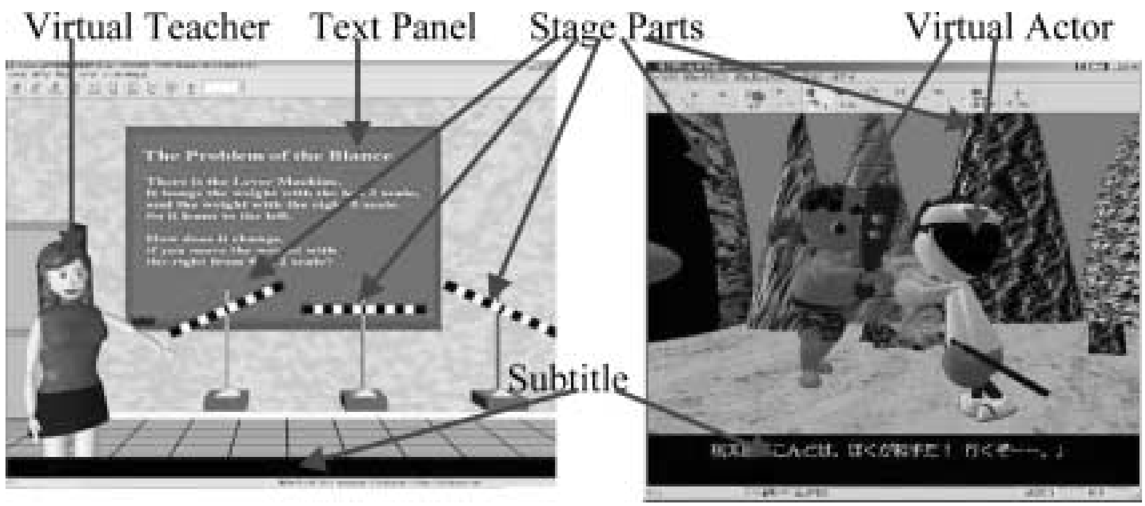


Figure 6. Cyber Assistant Professor (left) and Cyber Theater (right)

Cyber Assistant Professor (CAP) and Cyber Theater (CT)

We have developed two kinds of educational browsers, one is CAP and another is CT. CAP has been designed as a self-learning system, which enables interactive communication between Virtual Teacher and the learner. CT has been designed as a 3D-CG story maker, which is a new 3D-CG media player attractive enough to arouse the interest of pupils.

Both CAP and CT play interactive 3D-CG animation with the Virtual Actor (Teacher)'s voice speaking, sound effects and background music according to the scenario written by the scenario language explained earlier. Figure 6 shows the CAP self-learning system and the CT media player. We have named the scenario language for CAP CPSL2 (Cyber Person Scenario Language 2) and for CT CTSL (Cyber Theater Scenario Language). Both CAP and CT are independent application software installed in each learner's personal computer. Three kinds of stage part are available as follows:

- 3D-CG shaped model, which is the same structure as a Virtual Actor.
- Billboard Panel, which allows any photograph file (jpg file) to be mapped.
- Text panel, which displays English/Japanese text string.

Any stage parts can be defined as answer targets, to which the learner has to respond by a mouse click. This interactive function can be written in scenario files.

Teaching materials of Cyber Assistant Professor

In order to investigate the effect of the CAP system, we have developed teaching materials for elementary school pupils. We have decided to produce 'an elementary course of science' as teaching materials because:

- The combination of visual explanation and CAP speaking is effective.
- The moving of stage parts can represent the theory, principle or mechanism.

- The voice speaking and body action of CAP with thet Photograph Panel is effective.
- The interactive communication between CAP and the learner is effective.

Figure 7 shows the teaching materials of science we have developed.

Teaching materials of Cyber Theater

At first, we have produced stories of fairy tales for early-aged children in elementary school by using CT (Graesser & Hu, 2001; Matsuda & Shindo, 2005c). In elementary school, CT can be

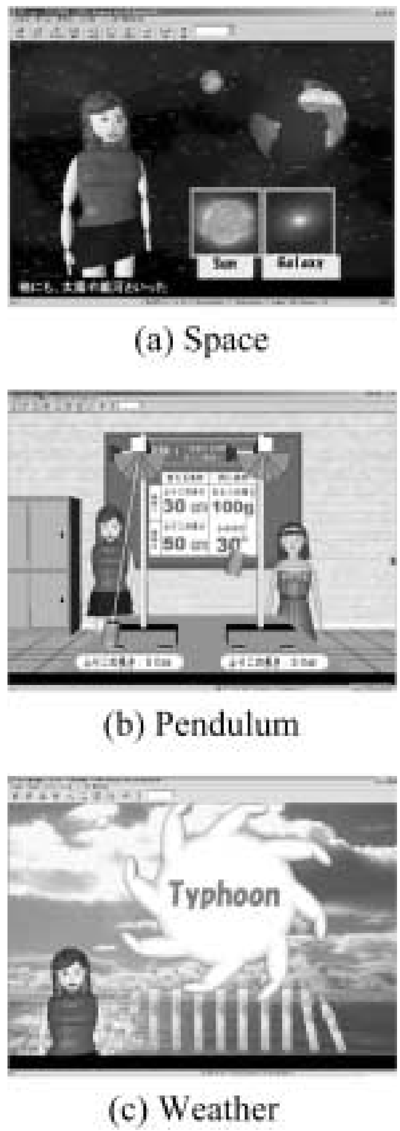


Figure 7. Teaching materials of science

used as teaching materials instead of picture books or illustrated picture cards. We have developed four stories: ‘Pinocchio’, ‘Wizard of Oz’, ‘Peach Boy’ and ‘Little Red Riding Hood’ (Figure 8). By using the results of these productions, we integrated the CT gallery, which includes many kinds of Virtual Actor, stage parts and body action databases. By using the CT gallery, we designed the Creative Lesson.

(a) Wizard of Oz

(b) Peach Boy

(c) Little Red Riding Hood

Figure 8. Fairy tales developed for Cyber Theater by using CTSL

Figure 9. View of experiment with CAP

Experiment of science lessons using CAP

We have decided that the target learner's grade is from fourth-year to sixth-year pupils in elementary school. We have done the experimental lesson with 55 pupils (4th, 12; 5th, 28; 6th, 15). Figure 9 shows a view of an experimental lesson using CAP. During the experiment, we found that most pupils concentrated on the CAP and some pupils answered questions reading aloud for confirmation. Figure 10 shows their impressions about this experimental science lesson using CAP. The percentage of pupils who were interested or very interested in this experiment is more than 70%. The percentage of pupils who want to use CAP again is about 80%. These results show that the experiment of science lessons using CAP is very suitable for pupils of this age group. Figure 11 shows the popularity of the science teaching materials we developed. The favorite one was 'Weather'; second was 'Space'. These items may be difficult for pupils to understand because they cannot look at them practically. Given this result, we are convinced that CAP could supply suitable teaching materials for science lessons in elementary schools.

Experiment of Creative Lesson using Cyber Theater

Creative Lesson has been designed for pupils in junior high school and high school. The main subject of this lesson is to teach pupils that a computer is not only a tool for browsing information, but also a tool for creating information. At first, we did the experimental lesson for pupils in junior high school. It works well and we got good results (Matsuda & Shindo, 2004a, 2005c). But there were few pupils. Next, we tried a large-scale class (80 pupils) in high school. Pupils had to study how to make 3D-CG real-time animation and then try to produce their presentation stories by using CTSL. To aid the learning process, we have developed the Cyber Theater Learning Kit (CTLKit), which includes 10 sample scenarios written in CTSL. CTLKit is

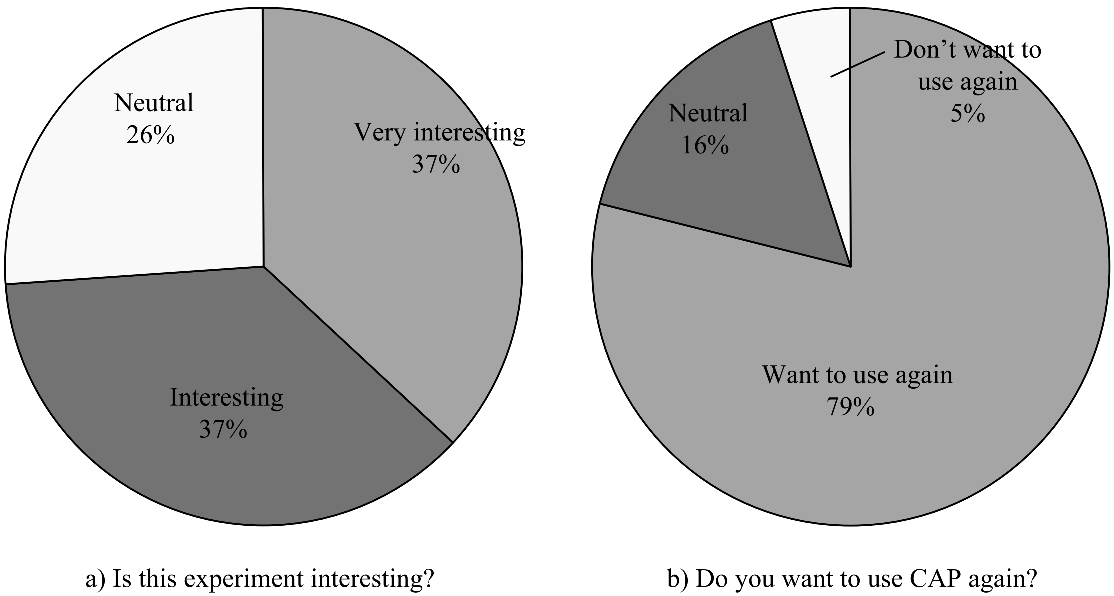


Figure 10. Impression of experimental lesson and CAP

designed for learning how to make 3D-CG real-time animation step by step. Table 4 shows the contents of the CTLKit. We designed the teaching style of Creative Lesson based on the C language programming education we have already developed (Matsuda *et al.*, 2001). It is as follows:

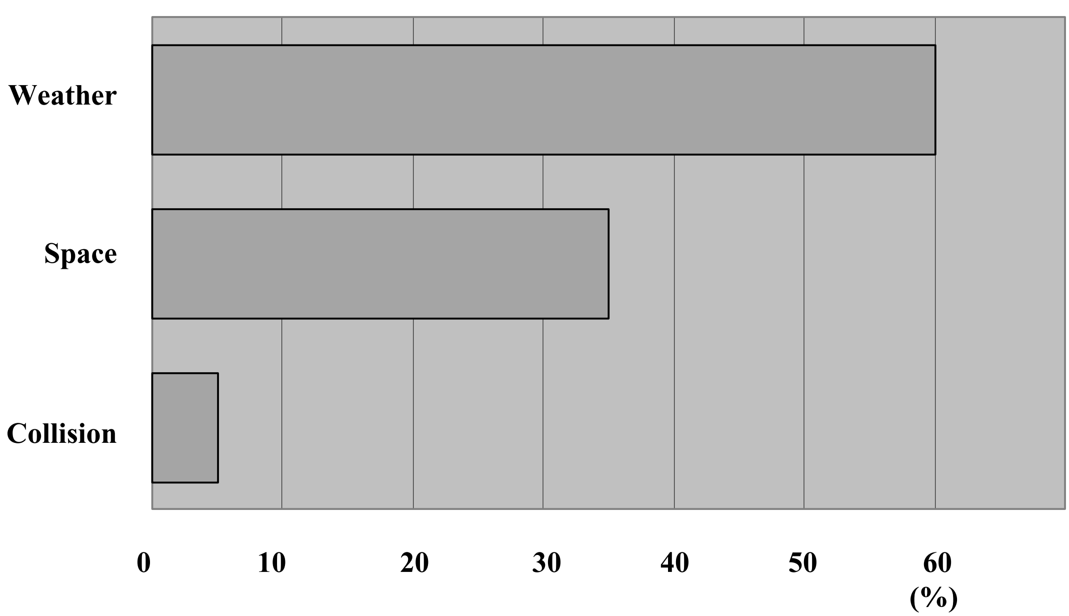


Figure 11. The popularity of the scenarios

Table 4. Contents of the CTLKit

No.	Contents
1	How to set up the Cyber Theater
2	How to create the 3D-CG stage
3	How to create the Virtual Actor
4	How to speak the text
5	How to display the subtitles
6	How to move and act the Virtual Actor
7	How to create more Virtual Actors and the stage parts
8	How to move the Virtual Actors and the stage parts simultaneously
9	How to move the cyber camera
10	How to define the scene

- The teacher supplies one of the CTLKit scenarios in order and then pupils study how to use it.
- Pupils try to edit or extend the CTLKit scenario according to the teacher's instructions (named Re-write Practice).
- Finally, pupils try to make their original presentation story. The teacher may show some themes and they select the one they want.

In Creative Lesson, the most important exercise is Re-write Practice. The aim of Re-write Practice is to understand the scenario construction step by step. An example of Re-write Practice is as follows:

- Pupils read the scenario to understand how to create the Virtual Actor (Figure 12a).

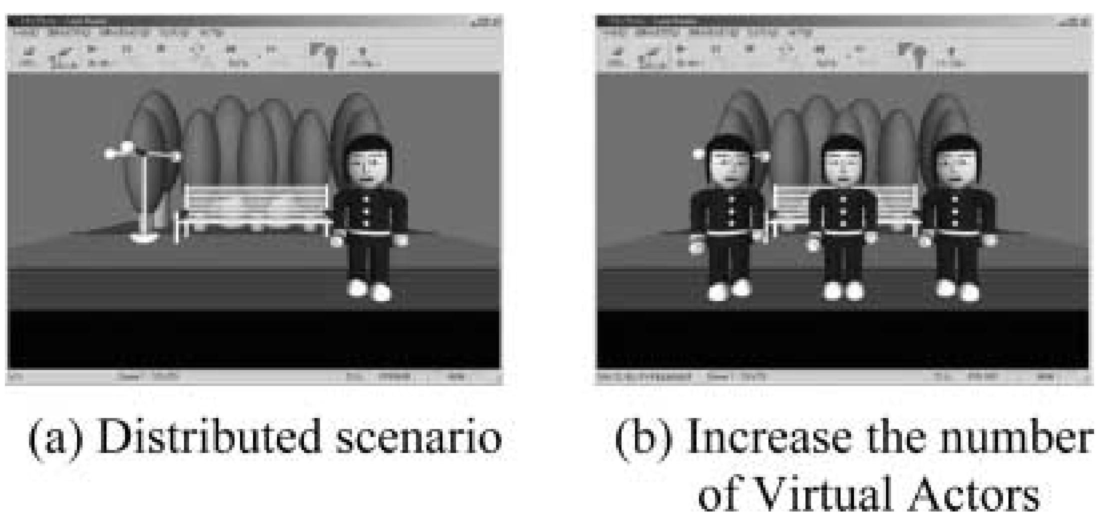


Figure 12. Example of Re-write Practice

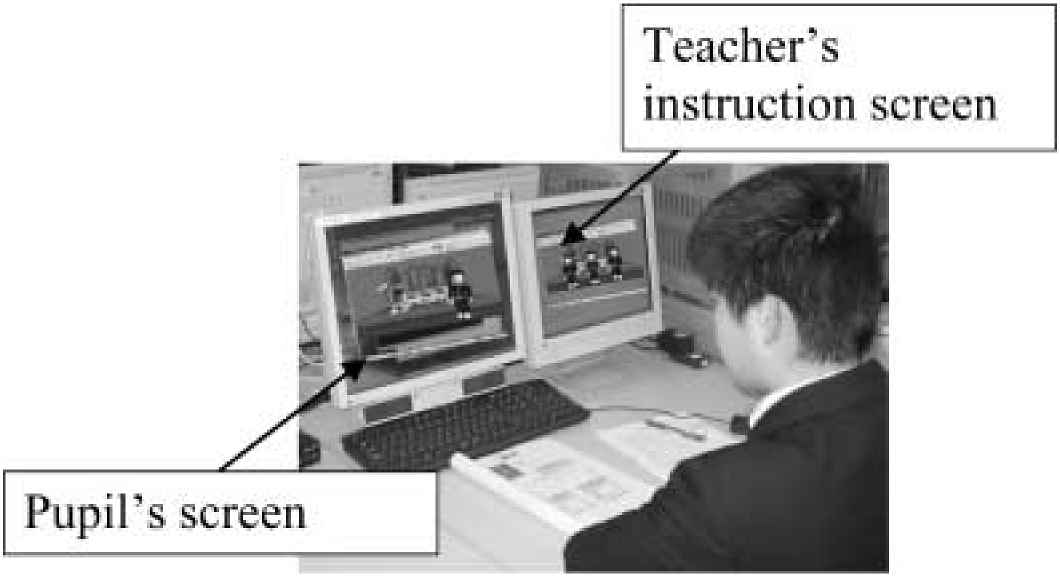


Figure 13. Re-write Practice

- Then, the teacher shows the visual subject on the instruction screen (Figure 13) and instructs how to modify the scenario to increase the number of Virtual Actors (Figure 12b).
- Pupils have to work hard to extend the scenario after repeated trial and error.

Next we supplied many Virtual Actors and their body action database from the CT gallery. They are the results of productions described earlier (Table 5); and we also supplied many stage parts: these are architecture, plants and some tools.

We carried out the Creative Lesson experiment with first-year pupils in high school. Figure 14 shows a view of the experimental lesson. During the Re-write Practice, we found that most pupils competed with their neighbors especially about Virtual Actor's movement and camera working of their 3D-CG animation and some pupils began to support less able pupils on their own initiative. The reason for this was that pupils could watch the situation of their neighbor's screen at any time. Figure 15 shows their impressions about Creative Lesson.

Table 5. Gallery of Virtual Actors for Creative Lesson

	Human style	Animal, monster
Pinocchio	5	2
Wizard of Oz	5	6
Peach Boy	8	3
Little Red Riding Hood	4	2
Others	0	32
Total	22	45

Figure 14. View of Creative Lesson

As a final part of this lesson, pupils made their presentation animation. The theme of it was 'eco-activity'. They used Virtual Actors and some stage parts they selected freely from the CT gallery. It took only one hour to make their original presentation animation (Figure 16). As the CTSL scenario can be re-usable, different stories can be easily made. If some stage parts are newly made, most of the Virtual Actors and stage parts may be usable without any change. As a result, we are convinced that CTSL is appropriate for Creative Lesson with pupils.

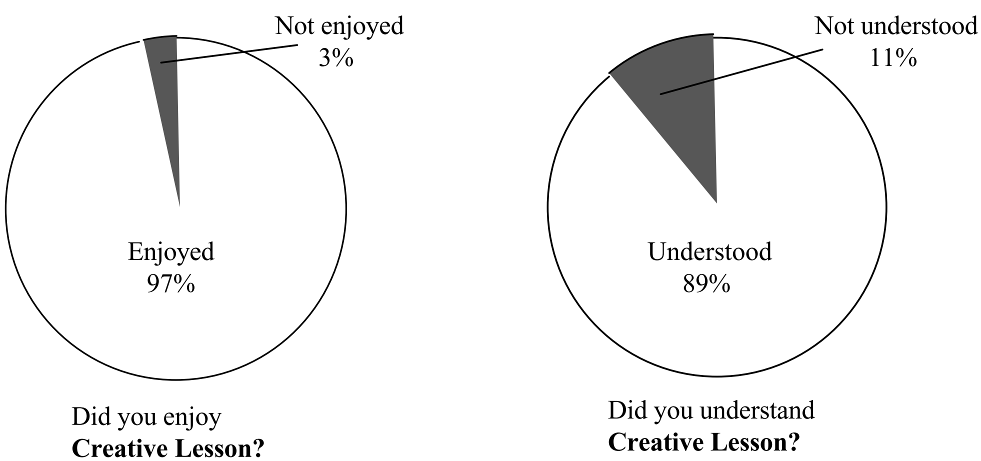


Figure 15. Impressions about Creative Lesson

Figure 16. Pupil's presentation animation

Conclusion

This paper describes a summary of the Cyber Assistant Professor (CAP) and Cyber Theater (CT) systems we have developed. These are based on real-time interactive 3D-CG animation and voice synthesis. This paper also described the details of the scenario language (CPSL2 and CTSL) for teaching materials. As a result of our experiments, we are convinced that our systems can supply suitable teaching materials to the students.

Finally, we concluded four points as follows.

- On teaching the theory, principle or mechanism of science, the most effective teaching material may be an actual video. However, actually the production of interactive actual videos taken on location as teaching materials is difficult in the case of space or typhoons, for example, but the production of interactive 3D-CG animation teaching materials in CAP is not difficult.
- The production costs of actual videos may be too large depending on the subjects and it is difficult to produce interactive educational content using actual videos. Against this situation, CAP provides the capability of producing 3D-CG interactive educational content as easily as producing a website on the Internet.
- CT provides the capability of producing 3D-CG presentation animation to teach pupils that a computer is not only a tool for browsing information, but also a tool for creating information.

- On the modification of scenarios, CAP and CT provide the capability of changing, revising and extending the story of virtual actor's action or moving of stage parts. This reusability is superior to actual videos.

CAP and CT are at an early stage, so we have not opened them to the public yet. But at an early date, after enriching the educational content and the preparation of databases, we want to open them by way of our website on the Internet.

Notes on contributors

Hiroshi Matsuda is Assistant of the Information Technology Center at the Nippon Institute of Technology, Japan. His research interests include 3D-CG animation and virtual reality. He has published over 30 research papers in authoritative journals, international conferences and books in the past five years.

Yoshiaki Shindo is Professor of the Department of Computer and Information Engineering at the Nippon Institute of Technology, Japan. He is also is Professor of the Graduate School of Computer and Information Major at the same university. He has a Ph.D. in Computer Science. His research interests include 3D-CG animation and virtual reality. His latest development works include the Cyber Person (software robot of human shape) based on the technology of 3D-CG real-time animation and voice synthesis in e-learning system. He has published over 40 research papers in authoritative journals, international conferences and books in the past five years. He is an Advisory Board Member of the journal *Educational Technology & Society*.

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