SELECTIVE SCENE MANAGEMENT IN FLIGHT SIMULATOR VISUAL SYSTEMS

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ABSTRACT

A variety of mission-dependent tasks are practiced in military flight simulators. A flexible way of meeting the diverse scene-content requirements employs a composite data base from which the appropriate feature models are displayed (and the less appropriate models may be excluded). Importance codes in the feature data are the basis for feature discrimination by the real time scene management software. This software monitors image generator loads, computes demand-variables based upon their deviations with respect to specified limits, and computes several control variables as functions of the maximum demand-variable. These control variables regulate the flow of feature data to or within the image generator. "Closed-loop" load optimization is thereby effected. Imagery and performance data from four example test flights (over the same path) contrast unmanaged, unselectively managed, and selectively managed image generation for two tasks. A given data base can be reoptimized by replacing importance code assignments. The prospects appear favorable for user-tuning of real time data bases to tailor them for particular training tasks.

INTRODUCTION

This paper is based primarily on a development program that was undertaken by the Link Flight Simulation Division of the Singer Company under the sponsorship of the U.S. Air Force Aeronautical Systems Division's Deputy for Simulators.

In addition to takeoff and landing exercises, a variety of mission-dependent tasks are also practiced in military flight simulators. Tasks such as aerial refueling, air-to-air or air-to-ground combat, and navigation and terrain avoidance at low altitude have differing requirements for visual scene content.(1)

Any visual system has limits on its capabilities to meet these requirements. In particular, computer image generation (CIG) systems have limits on the speed and precision of computations performed by various subsystems, limits on the storage capacity of buffers and random access memories employed therewith, and limits on the rate at which data can be transferred between various components. These limits tend to impose constraints on the content and the composition of scenes generated in real-time.

One way of meeting a typical set of diverse requirements (while avoiding performance degrading overloads in the CIG system) involves constructing a special purpose digital data base for each task. Presumably, optimal loading of the CIG system for each task would thereby be obtained at the expense of extensive data base development effort and some restrictions on simulator operation during task transitions.

Another approach involves constructing a composite data base from which the appropriate feature models are displayed (and the less appropriate feature models are excluded or portrayed with less detail) by the real-time image generator according to a scene control algorithm prescribed for each task. The set of task-dependent algorithms presumably embodies judgement or heuristics comparable to that employed off-line in the selection of models for the single task data bases.

A logical extension of the second method that gives the user more control over choices regarding features' "appropriateness," is the subject of this paper.

Selective Scene Management

In a CIG data base, real-world features are typically represented at several levels of detail. As the simulated eyepoint approaches or recedes from a given feature, a higher level (more detailed) or lower level (less detailed) representation is selected for portrayal. "Switching distance" criteria, based primarily upon considerations of the feature's projected size in the display, are normally used to decide when to switch levels of detail.

A data base that is sufficiently

complex to support a variety of simulated mission scenario tasks may overload the CIG system if the level of detail of each feature's portrayal is determined solely on the basis of its proximity to the viewer. Selective real-time scene management techniques are required to avoid overloads in such a situation. Sufficiently flexible means of exercising the required selectivity may permit changes to mission scenarios and changes to gaming areas to be accommodated by tuning a set of parameters in a CIG system of a given architecture.

A two-phase program was undertaken at Link's Sunnyvale, California, facility to produce a prototype implementation of flexible and selective scene management techniques. The resulting collection of enhancements to an existing real-time image generator control software program was called a "discriminator" as an abbreviation for "discriminating scene management and image generator load optimization software." The discriminator regulates feature portrayal on the basis of operator control selections, system constraints, system loads, and appropriate descriptors in the feature data.

An importance code in the range 0-15 is attributed to each level of detail of each feature in the data base to express the relative (a priori) significance of its portrayal during performance of the mission scenario task selected by the operator.

The discriminator employs importance threshold filtering that may override switching distance criteria; features most important to the current task may be portrayed at their highest levels, when appropriate, without causing performance degrading overloads. Raising or lowering a discriminator threshold tends to lower or raise system loads, respectively. The discriminator may also modify switching distances via variable scale factors; factors less than or greater than unity tend to reduce or increase system loads, respectively. Details regarding discriminator development rationale were reported with some scene samples obtained during Phase I (with controls varied manually by the operator) in an earlier paper.(2)

This paper focuses on the accomplishments of Phase II. Following a brief description of the host image generation system is a summary of the methodology used by the automatic load optimization software developed in Phase II. The evaluation data base and pertinent importance assignments are described next. Results from four real-time test flights along the same path are then presented and compared.

IMPLEMENTATION CONTEXT

Figure 1 is a simplified schematic of the Link DIG II image generation system in which the discriminator was developed. The on-line data base memory, a disc drive unit, stores all the real-time data base records that may need to be accessed during a given simulated mission. The data base records containing control data and object descriptors are read by the control computer, a Perkin-Elmer 8/32 minicomputer, from which the object descriptors are passed on to the active data base memory for repetitive access by the image generator. The associated control data are retained in the control computer memory for use in model switching criteria, occulting priority determination, discriminator threshold testing, and other control functions.

The image generator is a special-purpose hybrid machine that processes the digital descriptors of objects selected by the control computer to generate analog color video signals for the display at image update rates of 30 or 60 Hz. Figure 1 shows loading data (such as input data volume or actual processing time for the current frame) from a typical image generator subsystem entering the control computer for discriminator use.

For control purposes, each variable load is expressed in terms of percent of a corresponding capacity parameter. These parameters and a number of others used to modulate discriminator operations are loaded with the control computer programs; although shown as "system constraints" input to the control computer, dynamic variation is not to be implied.

For discriminator development and testing, the "flight data" (i.e., position, attitude, and associated rates of the ownship and other moving features) were synthesized at a local operator control station. The "operator controls" include selection of mission scenario task, selection of automatic or manual variation of each control variable, and control variable values for manual control modes.

Discriminator filtering of input data base records provides the basic memory loading control and coarse control over image generator loads. Filtering and modulation of the control information sent from the control computer to the image generator provides fine control.

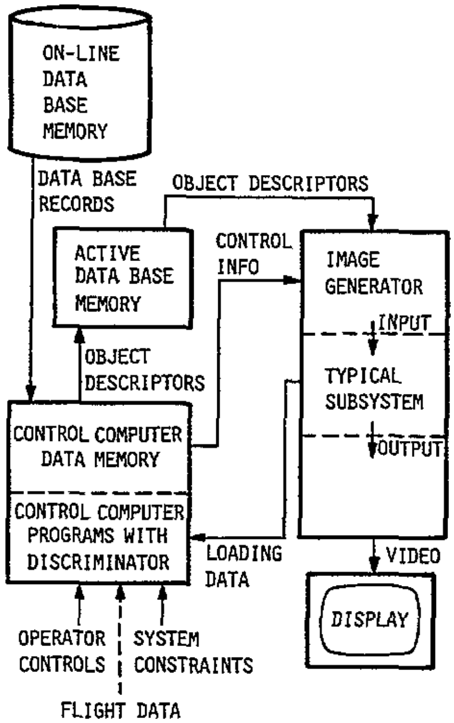

Figure 1 -- Simplified DIG II Schematic

LOAD OPTIMIZATION

During performance of a particular mission scenario task, *features which* have been assigned a relatively high importance for that task are given preferential treatment for their portrayal in the scene by the real-time scene management software. This software monitors a number of image generator load indicator variables (henceforth "loads") which quantify the dynamic usage of subsystems' memory and processing capacity. Monitored loads include numbers of bytes of control computer memory and active data base memory in use at a given time, the maximum number of edge-scanline intersections in a video frame, and maximum number of occulting priority relationships in any field of view. The *load optimization* software attempts to maintain the most significant load (at the time) within specified limits.

Retrieval Priority

When switching to a higher level of detail, preference is given to features which have been attributed higher importance for the operator-selected mission scenario task. Among features of equal importance which concurrently meet criteria for switching to a higher level of detail, those requiring larger blocks of contiguous memory for storage of their descriptor data are retrieved first, if possible, in an attempt to optimize memory usage.

Memory Overload Prediction

A somewhat conservative estimate is made regarding ability of the system memories to accommodate the higher level of detail of a feature before initiating its retrieval from the disc. (For this purpose, an off-line process inserts into the "bookkeeping data" of a given level of detail a compact summary of the memory allocation needs of the next higher level of detail.) When a prediction is positive, the retrieval is allowed to proceed. Retrieval of the higher level of detail is deferred (together with any other pending retrievals of lesser priority) and a "worry indicator" flag is set *if the prediction is negative;* the load control software responds as if the memory were full.

The *prediction of a memory overload* results in alteration of the dynamic retrieval criteria. The deferred retrieval may thereby be cancelled or some less important features may switch to a lower level of detail to free some of the occupied memory. In the latter event, the desired retrieval can be completed sooner as a result of the prediction.

Feedback Control Mechanisms

Loads are controlled by altering the criteria used in selecting feature data for retrieval or display. We use the *following* mechanisms and associated control variables:

Switching Distance Factor. A dynamic scale factor that modulates the prescribed ranges at which level of detail switching occurs for a given feature is a primary mechanism for automatic adjustment of system loads. When switching criteria are applied for a given feature, this factor is multiplied by a static function of the importance associated with the candidate level.

Dynamic Importance Thresholds. Two dynamic threshold values express the minimum importance required for (1) retention of the active level of detail and (2) initiation of switching to a higher level when the corresponding range criterion is satisfied.

Static Importance Thresholds. Two operator-set importance thresholds affect the display of active features. They represent potential aids for user-tuning a given data base for a particular mission task. One of these expresses the minimum importance prescribed types of features must have to be displayed. The other expresses the minimum importance (associated with any prescribed group of features) necessary to prevent application of the dynamic bias described below.

Resolvability Threshold Bias. The image generator hardware performs tests based on a feature's projected size in the display. Features which are not resolvable in the display are not displayed. A dynamic bias permits the real time software to adjust loads at the image update rate.

Feedback Control Computations

For each of the aforementioned dynamic control variables, unique demand-variables are computed for each characteristic load. The demand-variables are analogous to the output from a conventional three-element process controller. Each control variable is computed as a function of the maximum value obtained from evaluating its associated demand-variables.

In general, for a system having "m" characteristic loads and "n" control variables, the computations are typified as follows:

Let Ui = upper limit of control deadband for load "i"

and Li = lower limit of control deadband for load "i"

and Pi = value of load "i"

We compute the deviation of each load with respect to its control deadband as

$$Di = Max[Pi-Ui, Min(Pi-Li, 0)] \quad \text{for } i = 1,\ldots,m.$$

For each given load, the above quantities are expressed in convenient units such as percent of supplied capacity.

For each dynamic control variable, Fj, a demand-variable, Vij, is computed on the basis of load "i" behavior from startup to time "t" using

$$Vij = Aij\ Di + Bij \int_0^t Di\ dt + Cij\ dPi/dt$$

$$\text{for } i = 1,\ldots,m \quad \text{and } j = 1,\ldots,n$$

The Aij, Bij, and Cij are parameters whose values are determined empirically.

Each dynamic control variable, Fj, is computed as a function of the maximum demand-variable, Xj, given by

$$Xj = Max(V1j,\ldots,Vmj) \quad \text{for } j = 1,\ldots,n.$$

Figure 2 illustrates the functions associated with the dynamic control variables mentioned earlier.

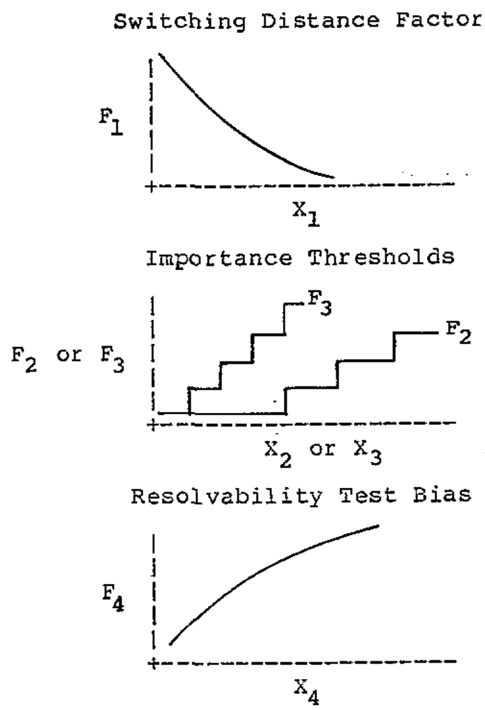

Figure 2 -- Control Functions

Performance Data

The following variables were also monitored or computed to provide quantitative indications of how well the automatic load optimization was performing:

1. Elapsed time in milliseconds
2. Count of control program iterations
3. Separate counts of each load's deviations below and above deadband limits
4. Separate integrals of each load's deviations below and above deadband limits

EVALUATION DATA BASE

Figure 3 shows a drawing of the central region of the composite data base that was assembled to aid in evaluating the scene management software. The scale is six nautical miles per grid interval.

Airbase and Environment

A model of Griffiss AFB and vicinity, which was being optimized for use in takeoff and landing exercises in the B-52 mission simulators, was selected as the host data base. This provided realistic appearing surroundings and sufficient detail for the takeoff and landing task.

Detailed Terrain Model

Detailed models of mountainous terrain were placed in the squares labeled "TERRAIN" in Figure 3 to support terrain following and terrain avoidance tasks. These models contain eight levels of detail with edge densities ranging from five to 100 edges per square mile (nautical). These models were generated from Defence Mapping Agency digital elevation data for a portion of a Nevada mountain range. The source data were scaled to attain continuity with the existing data base along three borders of each square. Automatic terrain fitting programs were then employed to produce the models.

Cultural Area

The square labeled "CULTURAL AREA" in Figure 3 was populated with numerous cultural features modeled at four levels of detail. These features are representative of those needed to support low-altitude navigation and air-to-ground combat tasks. A sports stadium, high-rise buildings, and a county airport were included primarily for the former task; a factory, missile launching complex, and an oil storage depot were included primarily for the latter.

Tree Clumps

The image generator used in Phase II of the discriminator development effort has considerably greater processing capacity than the one used in Phase I. In order to achieve percentage loadings comparable to those which had been observed in Phase I, numerous clumps of trees were added to the data base. Each tree clump is represented by a single green block at the lowest level of detail. The more detailed representations of the clump consist of five independently-controlled pairs of fruit trees modeled at three levels of detail. Twenty of these clumps were clustered near the NW end of the airbase runway; ninety eight clumps were distributed over the "CULTURAL AREA" square.

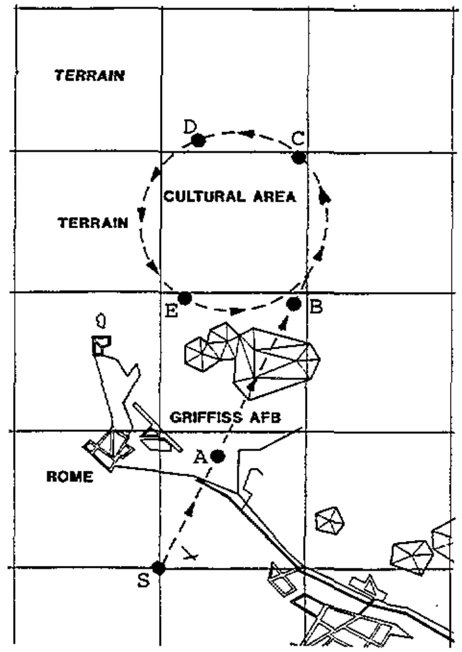

Figure 3 -- Data Base & Test Flights Path

IMPORTANCE ASSIGNMENTS

One table of importance assignment data is maintained for each mission scenario task. Using up to eight of these tables with a program that executes in the control computer (off line), the importance assignments for all the features in a given real-time data base file may be updated for the corresponding mission scenario tasks.

Using this capability, one can accommodate numerous variations in specific tasks of a given kind by making appropriate changes in the importance assignments. This involves copying and editing the original assignment table, updating the appropriate real-time file(s), and viewing the results during task performance.

The importance assignments used for the current presentation differ substantially from those used in the development program for two reasons: (1) four tasks have been "combined" into two for efficiency of presentation; (2) importance differences have been exaggerated to dramatize obtainable differences in scene content with obviously distinct imagery.

Terrain avoidance and low-altitude navigation tasks are represented by "Task 1." Air-to-ground combat and takeoff and landing tasks are represented by "Task 2." Assignments which differ between the two tasks are noted in Table 1. Assignments which are the same for both tasks are summarized in Table 2.

Table 1
Contrasting Importance Assignments
for
Ascending Level of Detail

Features	Task 1 Importances				Task 2 Importances			
	0	1	2	3	0	1	2	3
Airbase Detail	15	0	0	0	15	15	15	15
Stadium	15	15	15	15	15	0	0	0
Train Station	15	0	0	0	15	15	15	15
Mining Complex	15	15	15	15	15	0	0	0
High Mountains*	15	15	15	15	15	0	0	0
Factory	15	0	0	0	15	15	15	15
Tall Buildings	15	15	15	15	15	0	0	0
Farm Complex	15	15	15	15	15	0	0	0
Missile Complex	15	0	0	0	15	15	15	15
Oil Tanks	15	0	0	0	15	15	15	15
Misc. Weapons	15	0	0	0	15	15	15	15
Bridge	15	15	15	15	15	0	0	0
County Airport	15	15	15	15	15	0	0	0

* "Detailed Terrain" models with eight levels of detail were assigned zero importance at all higher levels for both tasks.

Table 2
Common Importance Assignments
for
Ascending Level of Detail

Features	Tasks 1 & 2 Importances			
	0	1	2	3
Tree Pair 1**	15	11	10	5
Tree Pair 2**	15	11	9	4.
Tree Pair 3**	15	11	8	3
Tree Pair 4**	15	11	7	2
Tree Pair 5**	15	11	6	1
Default	15	13	8	7

** A distinct pair in each ten-tree clump or a distinct tree in each of the few five-tree clumps.

EXAMPLE TEST FLIGHTS

Imagery from four example real-time test flights are compared at each of five viewpoints in Figures 4 through 8. Performance data from flights 1 through 4 are summarized in Tables 3 through 6, respectively.

Common Flight Conditions

Flights 1-4 all follow the path indicated by the dotted line (in the direction of the arrow points) in Figure 3 at identical altitude (400 feet), attitude (level with zero drift), and speed (400 knots). The views are directed 90 degrees to the left of the instantaneous velocity vector (toward the center of the "CULTURAL AREA" over the circular part of the flight path).

After establishing the unique conditions for each flight at point S in Figure 3, initialization transients were allowed to settle out and a set of performance data was recorded just before motion began. Upon arrival at each of the viewpoints A, B, C, D, and E, the real-time simulation and scene management programs were stopped while color and black & white photos were made of the images displayed on a color monitor CRT. A restart command allowed the programs to continue as though zero time had elapsed while stopped. A second set of performance data was recorded at the end of the flight; i.e., upon arriving at viewpoint E a second time.

Unique Flight Conditions

Flight 1. All of the discriminator scene management functions were disabled.

Flight 2. Unselective scene management is exemplified by this flight. Automatic variation of switching distance factor and resolvability bias was enabled but all importance-dependent treatment was disabled.

Flight 3. All selective scene management functions were enabled with Task 1 selected.

Flight 4. All selective scene management functions were enabled with Task 2 selected.

DISCUSSION OF RESULTS

Figure 4 shows that airbase detail was suppressed in flight 3 consistent with the importance assignments for Task 1.

Figure 5 shows that the detailed representations of the sports stadium and the high mountains were suppressed in flight 4 consistent with the importance assignments for Task 2. Retrieval of levels of detail higher than the fourth was apparent (not obvious) for the high mountains in flights 1 and 2.

Figure 6 shows that, under selective scene management, the tall building appears at its highest level of detail in flight 3 and lowest in flight 4; the factory (in the foreground) appears just the opposite. The most detailed representation of the factory has a row of windows on the front and rear walls of the more distant factory building. The windows (having the ability to occult portions of the building to which they are attached) were inadvertently modeled as inward-facing; hence, the rear windows appear to be visible through the building and the front windows are not displayed.

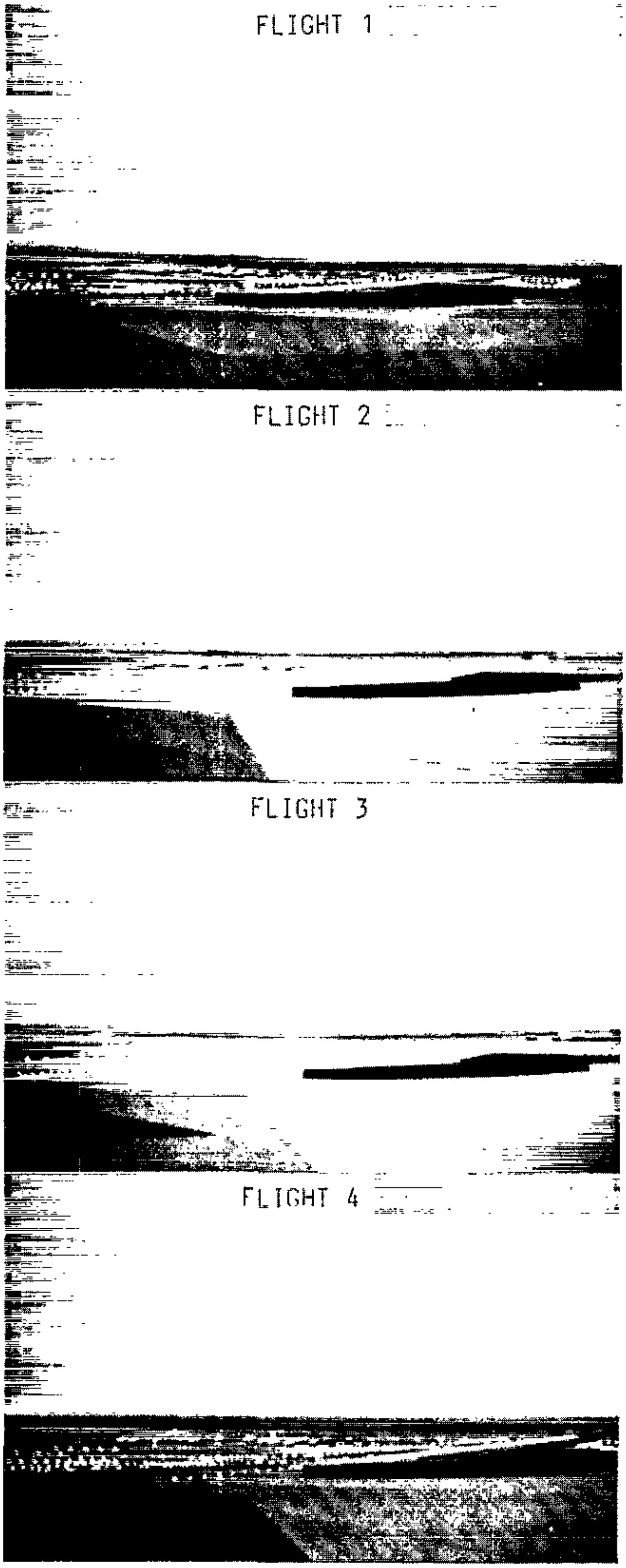

Figure 4 -- Viewpoint A Scenes

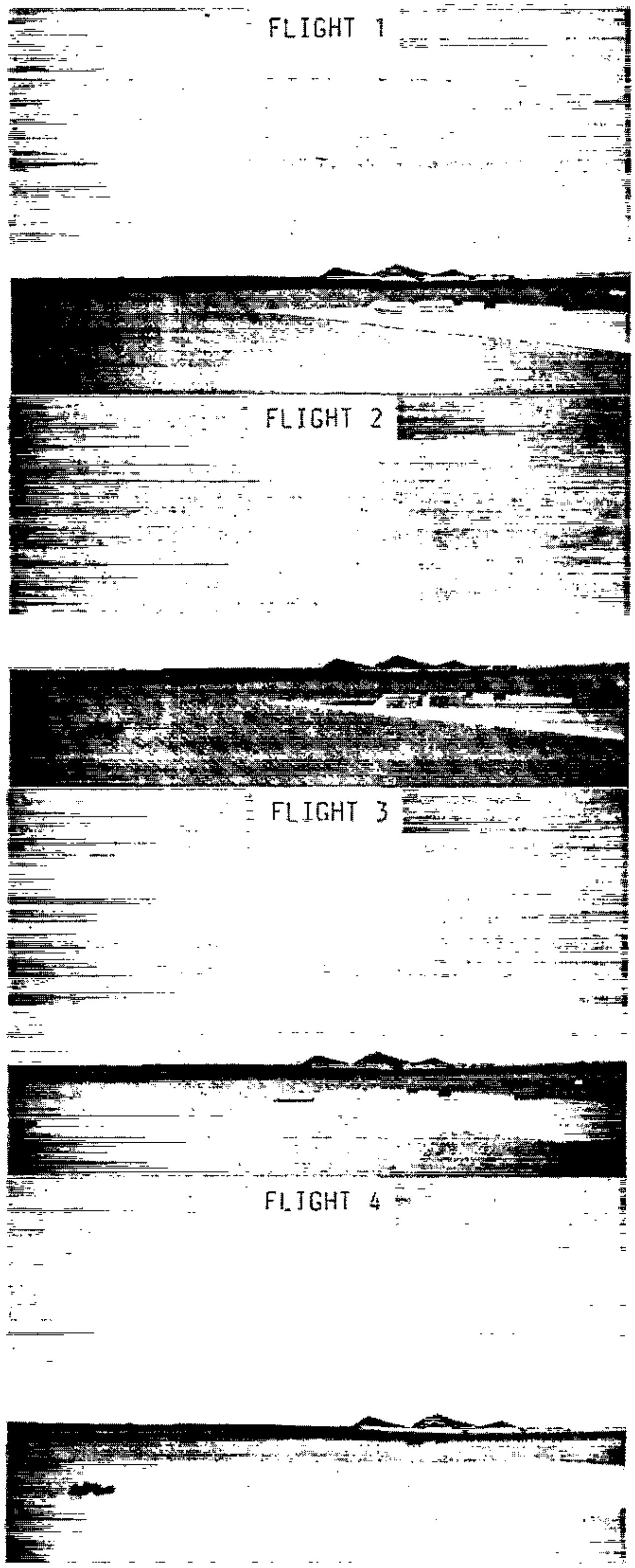

Figure 5 -- Viewpoint B Scenes

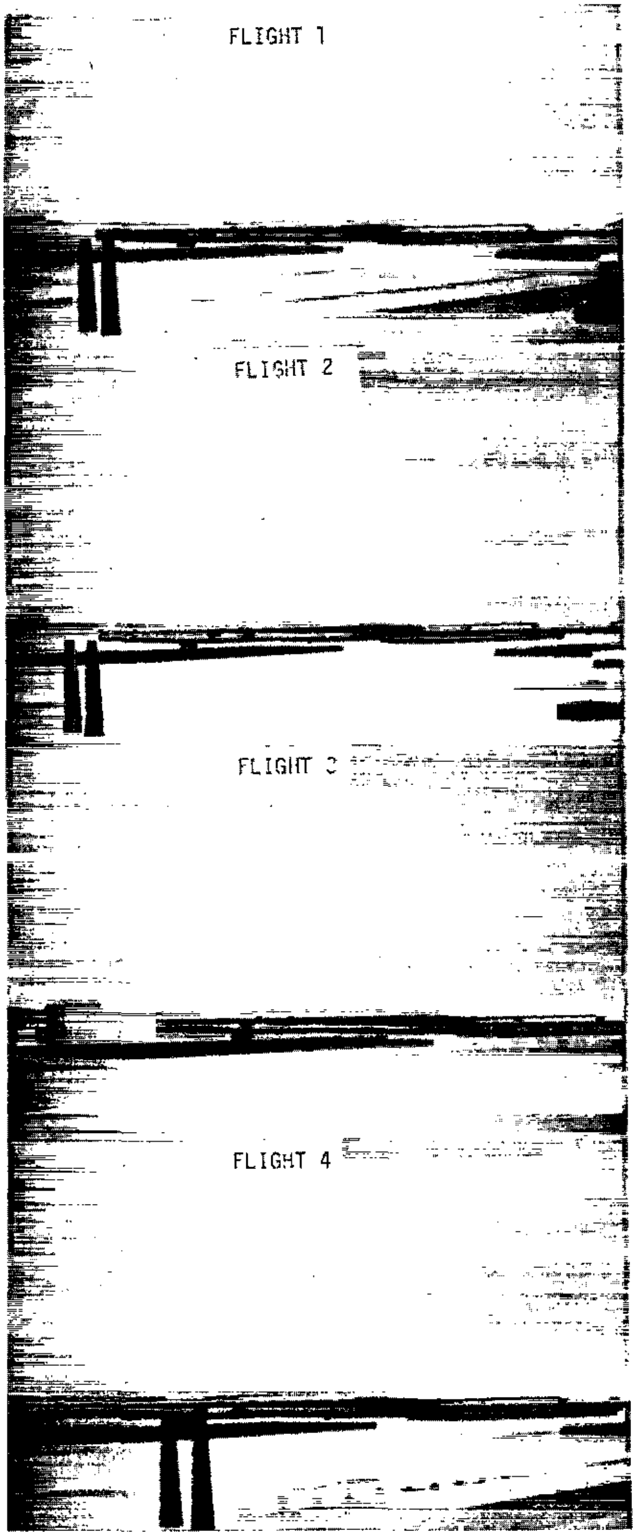

Figure 6 -- Viewpoint C Scenes

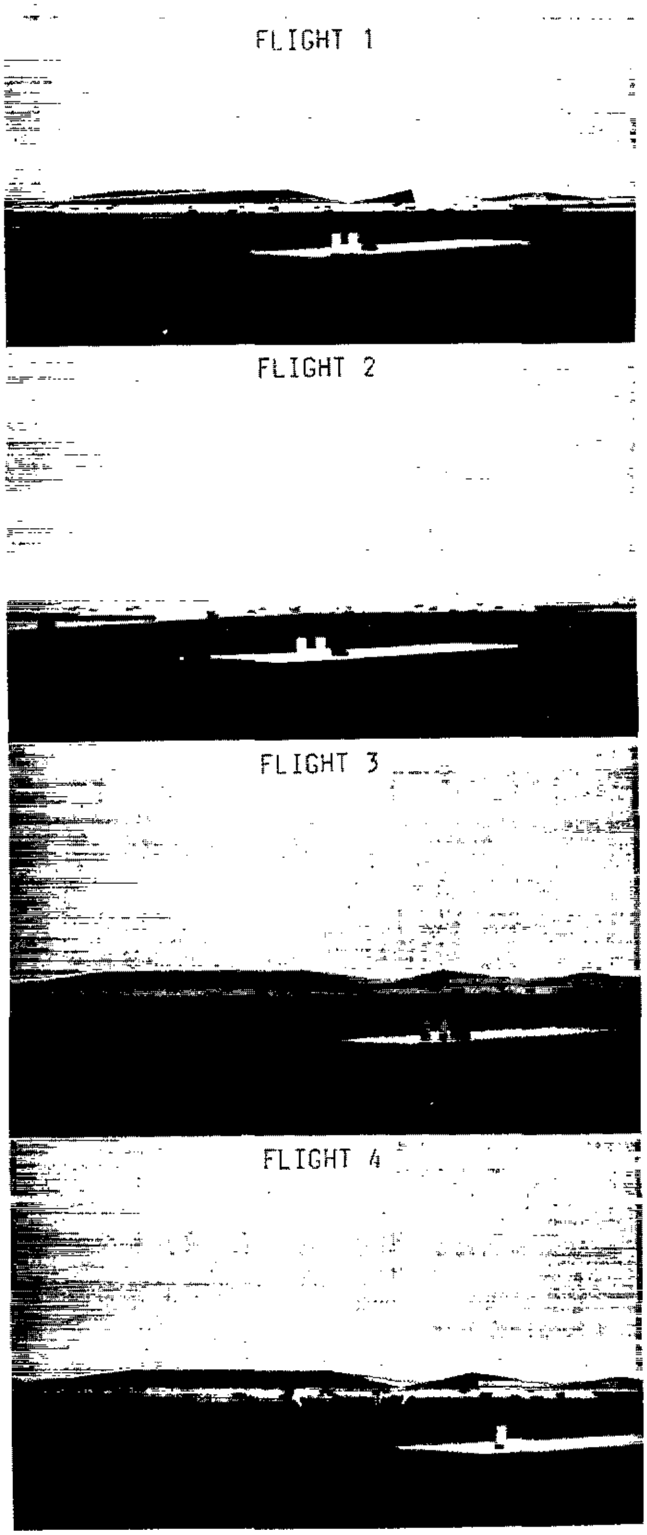

Figure 7 -- Viewpoint D Scenes

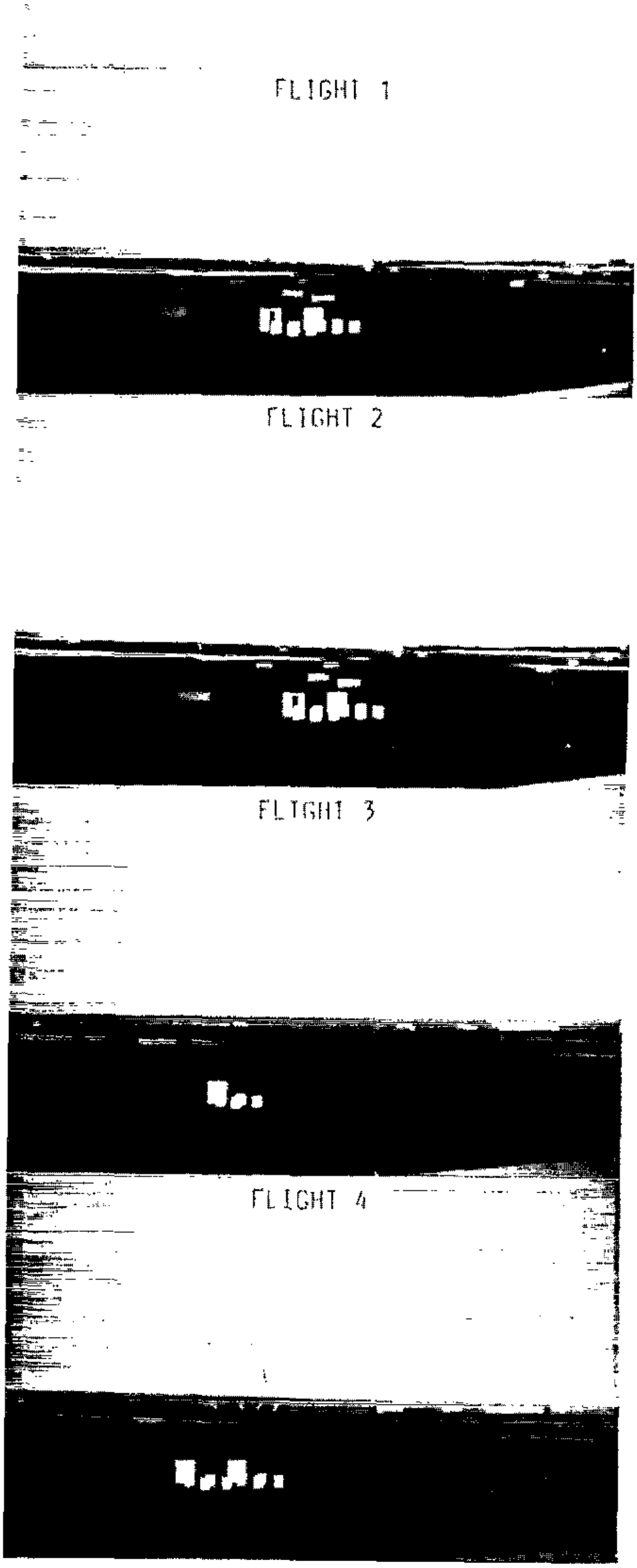

Figure 8 -- Viewpoint E Scenes

Table 3
Flight 1 Performance Summary*
(No Scene Management)

Load	% Counts Within Deadband	% Counts Above Deadband	Avg. Dev. Above Deadband
CM	0.0	100.0	0.93
AM	0.0	0.0	0.00

Table 4
Flight 2 Performance Summary*
(Unselective Scene Management)

Load	% Counts Within Deadband	% Counts Above Deadband	Avg. Dev. Above Deadband
CM	6.2	82.9	0.75
AM	0.0	0.0	0.00

Table 5
Flight 3 Performance Summary*
(Selective Management -- Task 1)

Load	% Counts Within Deadband	% Counts Above Deadband	Avg. Dev. Above Deadband
CM	21.7	54.0	0.50
AM	0.0	0.0	0.00

Table 6
Flight 4 Performance Summary*
(Selective Management -- Task 2)

Load	% Counts Within Deadband	% Counts Above Deadband	Avg. Dev. Above Deadband
CM	3.7	0.0	0.00
AM	4.3	40.2	>1.65

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* CM = Control Computer Memory
AM = Active Data Base Memory
% Counts = Percent of total iterations
Avg. Dev. = Average positive "Di" deviation (%)

The flight 3 and flight 4 scenes in Figure 7 contrast the portrayal of the *farm complex* and *the missile launching* facility. The mountains east of the airbase are absent from the background of the flight 2 scene, probably in response to a relatively low switching distance factor.

The oil storage depot in the foreground of the Figure 8 scenes is portrayed at its lowest level of detail in flight 3 and its highest in flight 4. The more prominent features in the two preceding figures appear in the middleground and background. The levels of detail portrayed for the county airport and suspension bridge (middle of background) were also consistent with importances assigned for the two tasks in flights 3 and 4.

Only the memory loads were of sufficient magnitude to affect the load optimization controls during the four flights. The low and high limits of the control deadband for control computer memory usage were set at 98% and 99%, respectively; corresponding limits for active data base memory usage were 88% and 93%, respectively. The maximum deviations attainable by these loads are 1% (former) and 7% (latter).

The non-zero values of, and differences between, the average load deviations given in the rightmost column of Tables 3 through 6 are significant in comparison to their corresponding maximum attainable values. (The tabulated averages express the net change in the integral of positive deviations divided by the net change in real-time clock readings for the flight; elapsed flight time was approximately 8 minutes in each case.)

Control computer memory usage was the most significant load in flights 1, 2, and 3. This memory was loaded above 99% for the duration of flight 1 (at 100% during most of the flight). As expected, the average positive deviation was reduced by unselective scene management (flight 2) and further reduced by the addition of importance-dependent controls (flight 3). The high mountains (at the fourth or higher level of detail) contributed substantially to the "CM" load in all of these three flights.

Active data base memory usage became the most significant load in flight 4. An upper limit on integrals was reached by the integral of positive "AM" deviations; hence the ">" prefix on the rightmost "AM" entry in Table 6. Suppressing portrayal of the high mountains to the lowest level of detail reduced appreciably the overall "CM" load. Retrieval of the highest level of detail of the missile launching facility (located near the center of the circular portion of the flight path) was prevented by unavailability of a sufficiently large block of contiguous memory in active data base; the "AM" load was consequently considered to be 100% until switching distance factor reduction rendered the retrieval inappropriate. At this point, the "AM" load dropped to actual "in-use" values in the neighborhood of 80% (below deadband). Subsequent increase of the switching distance factor led to cyclic recurrence. Meanwhile, retrieval importance thresholds increased to their upper limits (13 had been selected for concurrent variation with switching distance factor variation) so tree clumps became suppressed to their lowest level of detail. Apparently, this did not make available contiguous blocks of active data base memory of sufficient size.

The unretrieved level of detail required two separate contiguous blocks, each at least twce as large as those required by any of the other retrievable entities in the data base. For a training application, the highest level of detail could be remodeled to require four or more smaller blocks of contiguous memory; meanwhile, further tuning of the data base and control parameters could proceed with a lower importance assigned to the unretrieved entities.

CONCLUSIONS

Incorporating mission-dependent importance assignments in the on-line data base has been shown to be a workable basis for effecting selectivity in scene management for multi-task flight simulator visual system applications.

The concept associates one set of importance values with each task in a given mission scenario. (Each set consists of the importance values attributed to each level of detail of each feature in the data base.) We assume the data base includes adequate representations of: (1) all the features regarded as essential to each particular task; (2) a complement of additional features whose presence can enhance the orientation cues or motion cues or realism of the scenes.

A given data base can be reoptimized, if necessary to accommodate additional or different multi-task missions, by replacing sets of importance values. Sequential reassignment to all features in a data base, the method employed in our development program, is suitable for this purpose. To facilitate quick turnaround while adjusting importance assignments to reoptimize a large data base, an interactive, random-access edit capability should be included.

The concept appears to be applicable to a variety of system architectures although considerable variation in implementation details is implied. Real-time load optimization techniques incorporating the concept are expected to evolve with refinements tending to render imperceptable the effects of scene management activity.

Therefore, the prospects appear favorable for user-tuning of real-time data bases to tailor them for particular training tasks.

REFERENCES

1. Beck, Robert W., "The Challenge of Visual Simulation for Air Force Flight Simulators," Proceedings of the Third Interservice/Industry Training Equipment Conference, Orlando, Florida 1981

2. Lewandowski, Frank P. and Newhard, Jack W., "Computer Image Generator Scene Management System," Proceedings of the IEEE 1983 National Aerospace and Electronics Conference, Dayton, Ohio 1983

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