

E202173

①

PL-TR-94-2013

AD-A283 244



INTRODUCTION TO HEFeS (HIERARCHICAL ENVIRONMENTAL FEATURE SIMULATOR)

Albert R. Boehm

Hughes STX Corporation
109 Massachusetts Avenue
Lexington, MA 02173

DTIC
ELECTE
JUL 26 1994
S F

21 January, 1994

Scientific Report No. 2

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.



PHILLIPS LABORATORY
Directorate of Geophysics
AIR FORCE MATERIEL COMMAND
HANSCOM AIR FORCE BASE, MA 01731-3010

94-23468

94 7 25

1 18

DTIC QUALITY INSPECTED 1

REPORT DOCUMENTATION PAGEForm Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)**2. REPORT DATE**

21 January 1994

3. REPORT TYPE AND DATES COVERED

Scientific Report # 2

4. TITLE AND SUBTITLEINTRODUCTION TO HEFeS (HIERARCHICAL
ENVIRONMENTAL FEATURE SIMULATOR)**5. FUNDING NUMBERS**F19628-93-C-0051
PE62101F
PR6670
TA GS
WU AC**6. AUTHOR(S)**

Albert R. Boehm

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)Hughes STX Corporation
109 Massachusetts Avenue
Lexington, MA 02173**8. PERFORMING ORGANIZATION
REPORT NUMBER**Hughes STX Scientific
Report #2**9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)**Phillips Laboratory
29 Randolph Road
Hanscom AFB, MA 01731-3010**10. SPONSORING / MONITORING
AGENCY REPORT NUMBER**

PL-TR-94-2013

Contract Technical Manager: Donald D. Grantham/GPAA

11. SUPPLEMENTARY NOTES**12a. DISTRIBUTION / AVAILABILITY STATEMENT**

Approved for public release: distribution unlimited.

12b. DISTRIBUTION CODE**13. ABSTRACT (Maximum 200 words)**

This report discusses a Hierarchical Environmental Feature Simulation (HEFeS) which is an object-oriented representation of the natural environment based on kinematics, climatology, and intricate detail produced from space/time structure functions. HEFeS is a compact storage and fast retrieval of all required environmental attributes at any required resolution within any specified space/time window.

14. SUBJECT TERMS

Simulation, object-oriented, clouds, climate, stochastic indexing

15. NUMBER OF PAGES

18

16. PRICE CODE**17. SECURITY CLASSIFICATION
OF REPORT**
Unclassified**18. SECURITY CLASSIFICATION
OF THIS PAGE**
Unclassified**19. SECURITY CLASSIFICATION
OF ABSTRACT**
Unclassified**20. LIMITATION OF ABSTRACT**
Unlimited

CONTENTS

1. OVERVIEW	1
2. HIERARCHY	2
2.1 Cascade Hierarchy	2
2.2 Proto Object Hierarchy	4
2.3 Hierarchy of Attributes	4
2.4 Error Hierarchy	5
3. ENVIRONMENT CONSISTANCY	5
4. GRADIENTS AND INTERPOLATION	7
5. ENTITY QUERY LEVEL	8
6. ARCHITECTURE	9
7. THE ORIGIN STAGE	9
8. THE SELECTION STAGE	11
9. HISTORY AND DEVELOPMENT TO DATE	12
10. CONCLUSIONS	13
11. REFERENCE	13

TABLES

TABLE 1 HEFeS object classes	3
TABLE 2 HEFeS Tasks	9
TABLE 3 Examples of the two kinds of attributes	11

Accession For	
NTIS CRA&I	☒
DTIC TAB	☐
Unannounced	☐
Justification _____	
By _____	
Distribution / _____	
Availability Codes _____	
Dist	Avail and/or Special
A-1	

1. OVERVIEW

HEFeS is an object oriented representation of the natural environment based on kinematics, climatology, and intricate detail produced from space/time structure functions. HEFeS can be a form of objective analysis using environmental observations, a Monte Carlo representation of the environment, or a combination of the two - e.g. large scale objects fitted to an observed state with consistent small scale objects chosen randomly. The purpose of HEFeS is a compact storage and fast retrieval of all required environmental attributes at any required resolution within any specified space/time window.

HEFeS is implemented in four separate stages.

1. The origin stage involves the building of a set of HEFeS objects. This process uses physical models, climatology, and statistical taxonomy.
2. The archive stage builds a library of HEFeS objects.
3. The selection stage selects a specific virtual environment. The selection can be constrained by a set of observations/forecasts, a desired type (e.g. rainy weather) and/or climatic frequency.
4. In the query stage, interface links are set up so that a general simulation can rapidly query HEFeS objects for environmental attributes.

Each process uses a variety of computer programs in Basic, FORTRAN, and C++ both for flexibility and to customize usage for

a particular application. These separate processes allow the optimal use of separate skills - a simulation computer programmer should not be using a physical model and a meteorologist should not be programming query linkage.

Intricate small scale detail is important to certain kinds of simulation. In particular, dynamic scene generation requires repeatability of small detail viewed from many angles.

Stochastic indexing is a method of encoding a myriad of detail with very rapid retrieval. Stochastic indexing requires zero storage! Along with hierarchical objects, stochastic indexing allows rapid generation of numerous very small details. It is ideal for image generating distributed simulation.

2. HIERARCHY

There are several different uses of hierarchy in HEFeS. There is a hierarchy of object cascade, the number of proto-objects, attributes, and of error.

2.1 Cascade Hierarchy

First, HEFeS uses a cascade of objects - each object is made up of attributes and sub-objects - and each sub-object in turn has its attributes and smaller sub-objects as shown in Table 1.

TABLE 1. HEFeS object classes

OBJECT CLASS	TYPICAL SIZE	TYPICAL TIME	EXAMPLE
Climate regime	global	1 month	hot summer
planetary wave	5000km	1 week	zonal jet
synoptic feature	1000km	3 days	cold front
meso feature	100km	12 hours	squall line
cluster	1km	1 hour	cloud cluster
cell	30m	10 min.	cloud cell
sheet	5m	10 sec.	rain streamer
voxel	1m	1 sec.	droplet dist.

For a given simulation, there is one master HEFeS object. This is usually climate regime. An example of a climate regime is {very cold winter}. A more complicated climate regime is {warm winter followed by an early spring}. All other objects are subordinate to the master object and must be consistent with it. Each sub-object must be consistent with its parent object. Rain virga is prohibited from being attached to a clear sky object. In the selection process these prohibitions are enforced by object conditional probability. A zero probability completely prohibits a sub-object while high probability facilitates the likelihood of a sub-object being attached.

For the query stage, the master object need not be implemented in the simulation if a sub object completely covers the time/space region of the simulation. For a 100km by 100km by

24 hour region, the synoptic feature object would usually be the lead HEPeS object. In this case, the climate regime and planetary wave objects are used in the selection stage but are not implemented in the query stage.

2.2 Proto Object Hierarchy

In the selection stage, specific objects are selected from a list of proto objects. There is a hierarchy in the number of proto-objects available. For example, a fast, low storage, low fidelity simulation can select from just one object of each type while a high fidelity simulation can choose from numerous proto-types. Note that a single proto object can produce different realizations within a simulation but only within the constraints imposed on its attributes.

2.3 Hierarchy of Attributes

Each level in the object cascade has assigned a mean value for all attributes. These attribute means allow for a hierarchy of attributes. For example, an attribute for {droplet distribution streamer} could be L band (radar) attenuation. The same attribute - L band attenuation - would also be an attribute of {cloud puff}, {cloud cluster}, {squall line}, etc. but attribute value of L band attenuation is the mean value for that object. Thus a radar simulation can query the value of L band

attenuation at the [cloud puff] level for a close object; for a distant object, the value at the {Squall line} level is queried.

2.4 Error Hierarchy

Each attribute has an assigned error variance and a maximum absolute error. This error results from:

analysis error (when derived from observations),
theoretical error,
computational error,
object truncation error (finite number of proto-objects),
mean attribute error (using a mean over an object rather
than more precise values using sub-objects),
Other known errors.

This ready availability of error measures makes it easy to set up an overall simulation error budget which is very important for verification, validation, and certification. It also allows a rational decision as to how low a level in the environment cascade must a simulation entity query to obtain a given degree of accuracy.

3. ENVIRONMENT CONSISTANCY

There should not be a blizzard in Florida on a clear day.

Along with sub-object selection policy mentioned above, attribute policy and boundary policy enforce environmental consistency and representativeness.

An attribute policy is the set of rules for assigning attribute values to a single object so that its various characteristics are consistent. An attribute policy consists of absolute constraints and conditional probability rules. An example of an absolute constraint is: if the temperature is 90 degrees then the dew point is not allowed to be over 90 degrees. An example of a conditional probability rule is: given that the temperature is X degrees, the dew point should be selected from a Weibull distribution with a mean of $X - 15$ and standard deviation of 11.

When a HEFeS virtual environment is selected, object conditional probability allows only the selection of sub-objects that are consistent with the parent object. In addition, object boundary conditional probability insures that consistent objects are located adjacent to each other both in time and space. Spatial boundary conditional probability enforces adjacent objects to be environmentally consistent. Temporal boundary conditional probability enforces that the time sequence of events is consistent. It also is used to select the duration of an event.

Attribute policy and object boundary conditional probability are invoked during the selection stage and are ordinarily not a part of a real time query stage. However, if during a real time

simulation a change of environment is desired, a selection stage program can be run which uses as an initial condition the current object selection at change time. The desired change must meet attribute policy and object boundary conditional probability.

For example, a real time simulation has non-impacting virtual weather. A change to the 99% worst weather is desired. The selection program selects, if possible, a new set of objects consistent with the current object state and the desired change. An error message is initiated if such a change is impossible within attribute and boundary policy.

4. GRADIENTS AND INTERPOLATION

Environmental variables do not always change abruptly nor are variables always homogeneously distributed within a region that has been selected as an object.

Within an object a variable has a mean, but it may also have a gradient across the object. For example, within the object {High pressure air mass} the mean temperature can be 60 degrees, but a north/south gradient of 1.2 degrees per 100 km is specified. The specification of a field can be as complex as necessary.

Each layer of complexity has a variance and max error attached to it. For the {High pressure air mass} object using only the mean could give a max error of 4 degrees, but using the mean plus gradient results in a max error of 0.8 degrees. If one

simulation entity is affected by temperature but only to a small degree, then the mean temperature can be used. If a more exact temperature is needed, the more accurate temperature can be queried.

Some applications require a seamless field between objects rather than an abrupt change at the boundary. In this case, interpolation is used between mid-points of objects. Again an error is associated with linear interpolation as well as higher order interpolations using gradient information.

5. ENTITY QUERY LEVEL

The level of gradient and interpolation complexity must be assigned to each type of entity prior to the start of a simulation to insure all entities of the same type and all sensors of the same type are receiving the same level of environmental information.

Also the level in the object hierarchy must be specified for each type of entity or entity sensor. For sensors, object hierarchy level is also a function of separation distance. But for each sensor type, the distance for using the next higher level should be set prior to the start of simulation.

These rules can be changed on the fly if the simulation needs to be speeded up (at greater environmental error) or greater environmental accuracy is needed. But all relevant entities need to be notified at the same time.

6. ARCHITECTURE

Implementation of HEFeS consists of 12 separate tasks as shown in Table 2.

TABLE 2. HEFeS Tasks

STAGE	PHASE		
	Development	VV&A	Operational
Origin	build objects	quantify error	object definer
Library	build archive	quality control	make library
Selection	build classifier	cascade error	select scenario
Linkage	link standards	interface check	query response

Each stage involves a stand alone computer capability as well as the ability to pipeline with the other stages. Making an archive library and the linkage stage are common enough not to require additional description in this introduction. More information on the origination stage and selection stage follows. Growth potential is a goal of each stage so that as time goes by, new objects can be added, additional libraries formed, new selection strategies implemented, and additional link standards coded.

7. THE ORIGIN STAGE

The origin stage defines a finite set of objects that represent within some degree of error the very large number of

possible environmental states. On the synoptic scale several methods are available to produce a finite number of states, e.g. map typing, dominant eigenvalues of fields, air mass classification, etc.

HEFeS goes beyond these basic classifications to also define a conditional distribution of sub-objects associated with each parent object. Also HEFeS defines a conditional distribution of object attributes. For example, a maritime high pressure system for a given climate regime has a surface temperature selected from a normal distribution with mean=50, standard deviation=8.

Thus a HEFeS virtual environment - a simulation scenario - is not just a selection from a finite set of fixed objects but a selection from a finite set of distributions from which a specific value is selected.

The origin stage also attaches attributes to objects. These attributes are of two kinds -- physical and impact. The physical attributes are those needed to adequately specify the physics of an object, e.g. droplet distribution, gust spectrum, etc. For the most part these attributes are meaningless to a simulation entity. An impact attribute, on the other hand, is the effect on an entity. Note that while impact attributes are entity class specific, they are kept as generic as possible. An example is given in Table 3.

TABLE 3. Examples of the two kinds of attributes

PHYSICAL ATTRIBUTE	IMPACT ATTRIBUTE
precipitation, soil type, slope, wind, etc.	tracked vehicle trafficability.
droplet distribution, sunshine, aerosols, etc.	LWIR visibility

Physical attributes are converted to impact attributes using physical and statistical models. This is not a trivial task but there are some very fine models available for some of the conversions. For poorly known conversions, HEFeS keeps track of the error introduced for uncertainty analysis in the simulation.

8. THE SELECTION STAGE

A cascade can be selected

1. randomly within climatic bounds,
2. to fit an observed state,
3. to fit an observed state at some scales and to
randomly select at the other scales, or
4. to match a specified condition -- a rainy day.

For a random selection, objects are selected by a random number generator. Each parent object has a set of possible sub objects (proto objects). Assigned to each sub proto object is a probability that varies according to the nature of the parent object. Rather quickly, a complete cascade of objects is specified that is consistent with the rules. A cascade that

occurs frequently is likely to be chosen. A cascade that never occurs can not be chosen.

When HEFeS is fitting an observed (or forecast) state, it is acting as an objective analysis scheme. In principle, the analysis is a simple minimization problem. The objective is to determine which set of objects has the smallest error given a set of observations. The HEFeS hierarchal object structure allows this to be an efficient task.

9. HISTORY AND DEVELOPMENT TO DATE

The first implementation of HEFeS was VISTA (Visual Translucent Algorithm) in May 1991. VISTA had a hierarchy of Slabs (horizontally bounded layers), cloud clusters, and cloud puffs. It used stochastic indexing to locate some 30,000 cloud puffs. A paper on VISTA was included in the CIDOS-91 proceedings and a slightly enhanced VISTA paper is in SIMULATION (Boehm, 1994).

Further work on HEFeS was postponed in favor of other projects until March 1993 under a new Phillips Lab. contract "Weather Constraints On Weapon Systems Using Simulation Algorithms Based On Rapid-Access Climatology". This research contract is limited to exploratory development of a proto-type HEFeS.

Most recent work on VISTA has brought it to the point where renderings of cloud fields of cumulus, stratus, and cirrus can be

simulated in less than 2 minutes on a PC. We believe clouds to be one of the hardest environmental features to simulate. Other parameters such as wind, density, etc. are relatively easy.

10. CONCLUSIONS

HEFeS is a very adaptable system for real time rendering of the environment. It is possible to set up a very limited version such as VISTA to provide a limited capability. Because of the hierarchical nature of HEFeS, it is possible to add to the number and complexity of objects.

Even when real time rendering of a scene is not a requirement, HEFeS still has a great deal of capability but in that case it may not be the optimal simulation methodology.

HEFeS performs the conversion from physical attributes to impact attributes offline -- not real time. Thus slow complex physical models can readily be used without any attempt to optimize runtime or to degrade their accuracy.

11. REFERENCE

Boehm, A. 1994: "Visual Translucent Algorithm (VISTA)," *Simulation*, 62, No.2, 91-97.