AN INTELLIGENT TUTORING SYSTEM FOR INTERPRETING GROUND TRACKS

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Abstract

This paper describes an intelligent tutoring system for the space domain. The system was developed on a Xerox 1108 using LOOPS and provides an environment for discovering principles of ground tracks as a direct function of the orbital elements. The system was designed to teach students how to "deduce" a satellite's orbital elements by looking at a graphic display of a satellite's ground track. The system also teaches students how to use more systematic behaviors to explore this domain. Since the system is equipped with a number of online tools that were specially designed to help students better understand facts, principles and relationships, the student is free to investigate different options and learn at his own pace.

I. Introduction

A. General Introduction

One of the nine basic operational missions for the Air Force is the continuous monitoring of the exoatmospheric arena through ground and space surveillance. NORAD, through its Space Defense Center, maintains a worldwide network that senses, tracks, and analyzes the characteristics of orbiting systems.

In order to monitor and plan for satellite missions, the Air Force crew must be able to read and understand ground tracks. Ground tracks are two-dimensional displays that show the portion of the earth that a satellite covers in one orbit. If you can imagine being placed inside a satellite and being able to look directly down on the earth, then the "ground track" is that portion of the earth that you would see as you travelled through space. The ground track is a direct function of the orbital elements, so proper understanding of these functions and of the interactions between orbital elements is critical for anyone interested in satellite operations.

One way to teach students how to deduce orbital elements from a satellite's ground track is to present the various mathematical formulas that are used to compute the orbital elements and then show how to apply these formulas to situation- specific tracks [Bates et al., 1971; Astronautics, 1985]. In contrast to this approach, we discovered that experts store ground tracks as graphical representations, indexed by feature and shape. Based on previous experience, experts learn how to detect specific features such as size, number of loops, direction, etc., and then use this information to "estimate" the orbital elements. In order to duplicate this process, we decided to build a qualitative model of how the expert predicts orbital elements, and then use this model within a microworld, or simulated environment, that allows the student to manipulate various orbital elements and observe how each of the parameters affects the shape of the ground track.

B. Student/Computer Interaction

As previously mentioned, the microworld for the Ground Track problem offers a number of online tools that permit students to discover relationships between orbital parameters and ground tracks. This environment consists of an elaborate ground track display (Figure 1) and a number of interactive tools designed to encourage systematic behaviors for investigating ground track related problems. The student initiates a discovery activity by changing one or more orbital parameters or changing the injection parameters. This task is accomplished by positioning the cursor over the individual parameters and pressing the left mouse button to increase the value or the middle button to decrease the value. The injection point is changed by positioning the cursor over a particular point on the map and pressing the left mouse button, which automatically sets both the longitude and latitude. A student can observe the results of these changes by selecting Generate a Ground Trace from the main menu. After investigating the effects of changing different parameter values for different ground tracks, the student can advance to the Prediction window where he can make a hypothesis regarding the particular shape of a ground track.

In the Prediction portion of the program, the system displays a list of words that describe various features about ground tracks such as shape, size, and symmetry (Figure 2). From this list of descriptors, the student selects the words that "best" describe the current ground track under discussion. The student then tests his prediction by selecting this option from the menu and comparing his inputs to the Expert's conclusions. The student can then interrogate the Expert System by placing the cursor over any of the descriptors and pressing the left mouse button. A "Why" pop-up menu appears on the screen which the student can mouse and receive an explanation of the expert's reason for the correct descriptor. The student can continue this iterative process of changing parameters, making predictions, and asking why until he understand the various relationships between After making several successful predictions, the student enters a Test environment which is designed to check the student's predictive powers by asking him to

*The research reported herein was supported, in part, with funds from the Air Force Office of Scientific Research (AFOSR), and sponsored by the Air Force Human Resources Laboratory, Brooks AFB, Texas.

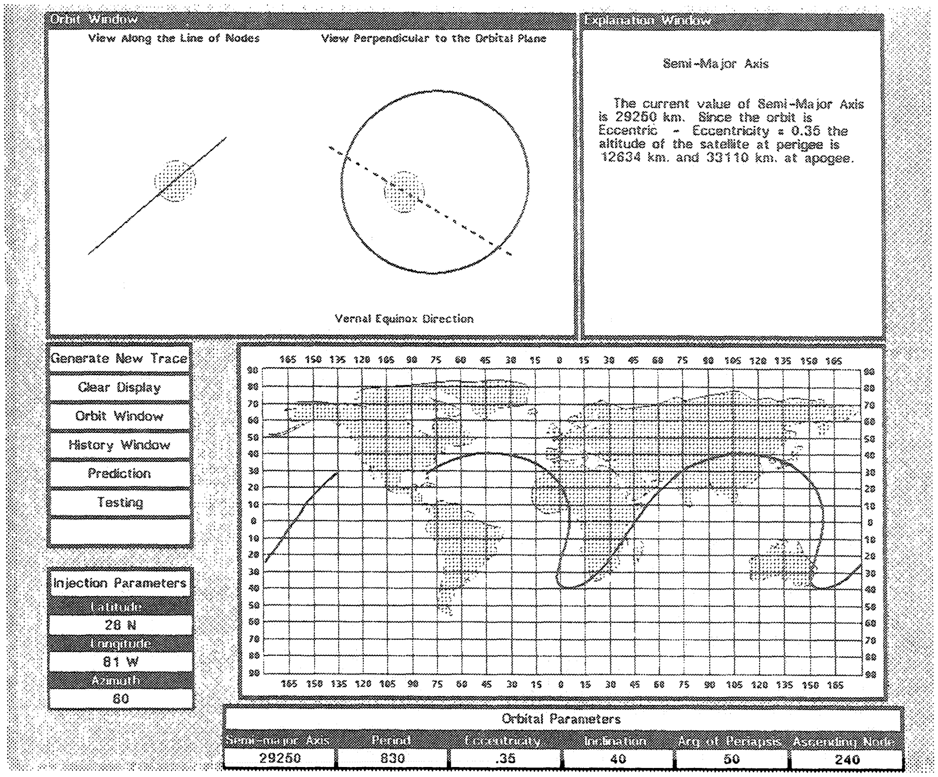

Figure 1: Examples of Ground Trace, Orbit Window, Definition

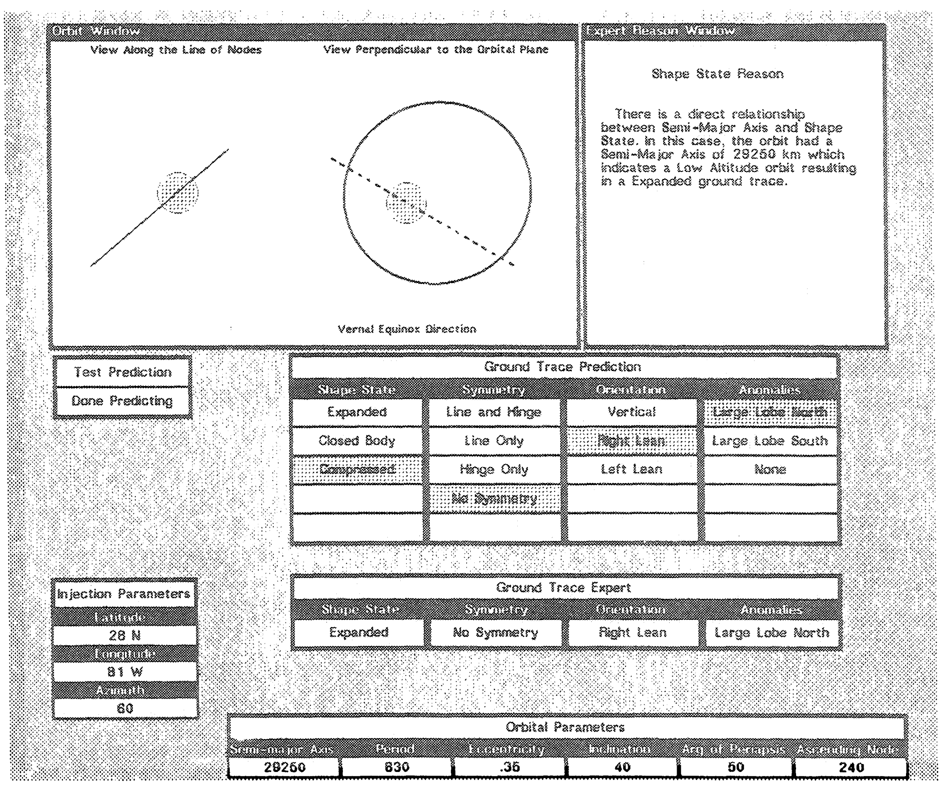

Figure 2: Prediction Window

perform a task in the reverse order of the one described above. The student is shown a specific type of ground track and asked to enter a "guess-estimate" of the corresponding orbital parameters. If the student is successful, then he can continue to explore different types of ground tracks. If the student is unsuccessful, then he receives information about why his answers are incorrect.

C. Tool Description

There are three major online tools that can be used by the student to gather information and to understand concepts and principles about ground tracks. These tools are a) a History Tool that allows the students to overlay previously generated ground tracks and note relationships between parameters b) an Orbit Window that displays a two-dimensional representation of the orbit (Figure 1); and c) a Definition/Example tool which displays factual information about different orbital parameters (Figure 1).

The History tool is specifically designed to help students recognize relevant patterns between and among previously generated ground tracks. As the student generates various ground tracks, the system collects and stores each transaction. The student can retrieve any of this data by selecting the History option from the main menu. A list of the past twenty ground tracks appears on the screen from which the student can select one or more related ground tracks. The system then overlays the selected ground tracks onto a single map. Again, the student observes the results of this exercise.

For any given set of orbital parameters, the student can obtain a two-dimensional display which shows the position of the satellite in relationship to the earth. The student selects the option labelled Orbit Window and gains immediate access to this particular display. The Orbit Window is especially useful for demonstrating the relationship between the ground track and the actual orbit and for illustrating the effect of perigee on elliptical orbits.

The Definition/Example tool provides the student with the factual knowledge about various parameters. A student can obtain definitions and examples for both the orbital parameters and the shape descriptors by simply placing the cursor over the keyword in question and pressing the right mouse button. A pop-up menu appears on the screen from which the student can select either the definition or example.

Thus by using the available tools, a student can obtain facts about the orbital world (through the Definition/Example tool), see relationships between different ground tracks (through the History window), and understand certain principles about satellite operations (through the Orbit Window). A student has the option of using any of these tools at any time during the computer/student interaction. If, however, the student is not making sufficient progress, the system interrupts and directs the student to use a specific tool to achieve an objective.

II. Design of the System

A. Overview

The system is composed of six major parts: (1) The Expert Module, (2) the Curriculum Model, (3) the State Model, (4) the Diagnostician, (5) the Student Model, and (6) the Coach. The Expert Module includes the rules and inference procedures used to deduce shape descriptors from a set of orbital parameters. The Curriculum Module contains the major concepts associated with the ground track domain. The State Module contains a list of appropriate behaviors for exploring the microworld. The Diagnostician is a set of software procedures which evaluates the student's answer, analyzes student errors, and updates the Student and Curriculum Models. The Student Model stores the student's current state of knowledge of both ground tracks and effective tool use. The Coach contains the instructional rules that tell the system when to intervene. The Coach makes this decision based on information it receives from the Student, Curriculum, and State Models regarding the student's current state of knowledge. A more detailed description of each module is presented below.

B. The Expert Module

This Module contains the rules and procedures used to deduce shape descriptors (e.g., closed-body, symmetrical, vertical; compressed, lean-right, hinge-symmetry, with loops) from a set of orbital parameters (eccentricity, period, semi-major axis, argument of periapsis, inclination). The Expert Module is invoked only when the student is making a prediction or is in the Testing mode. The Expert Module works by posting a series of goals which determine the various shape descriptors. The general problem solving strategy employed by the Expert Module is to determine a shape descriptor by examining a specific orbital element. If this fails, then the system looks at another shape descriptor and attempts to find its value, or looks at a combination of two or more orbital elements to see if the system can deduce a shape descriptor. For example, the Expert Module determines the symmetry shape goal by asking whether this is a circular orbit. If the orbit is classified as a circular orbit, then its eccentricity must be equal to zero. If the orbit is elliptical then its eccentricity is not equal to zero and the Expert Module must look at the orientation descriptor, which in turn must look at the argument of periapsis. In this manner, the Expert Module can determine a set of shape descriptors for a given set of orbital parameters (and vice versa). During the process of deducing shape descriptors, the Expert Module also determines the optimal "procedure" for deriving the shape descriptors. Thus both declarative and procedural knowledge is available to the rest of the tutor.

Another function of the Expert Module is to deduce parameter descriptors (such as a Circular, Synchronous orbit) at the same time that the system is deducing the shape descriptors. These parameter descriptors are used by the Curriculum Module to determine the essential skills that are necessary to understand a given ground track. Since the rules for determining the Curriculum Skills are embedded within the Expert Module rules, we now describe the organization of the Curriculum Module.

C. The Curriculum Module

Along with knowledge about shape descriptors for ground tracks, a student must also understand how this information relates to specific orbit types. For example, an orbit which has a semi- major axis equal to 42,250 kilometers is said to be in a synchronous orbit. This term applies to all ground tracks that have a semi-major axis equal to 42,250 kilometers, regardless of the numbers that might appear for the other orbital parameters. Thus it is important that students recognize the relationship between the specific domain knowledge and the qualitative model produced by the Expert Module. The Curriculum Module, therefore, contains the specific content that is used to categorize different orbit types. This knowledge is stored in the Curriculum Module according to how it is used (and deduced) by the Expert Module. For example, the Expert System determines whether an orbit is circular or elliptical as it deduces the symmetry goal. The knowledge about shapes and orbit types are part of the Expert System.

The Expert Module also provides a very powerful tool for organizing the content areas and for determining various levels of difficulty. For example, the rules that determine the shape descriptors associated with circular orbits tend to have fewer constraints attached to them, and also tend to be fired first, and, as a result, tend to be easier for the student to learn. The hierarchy of orbit types as represented in the Curriculum Module shows both the order that the knowledge should be learned and the relationships between the knowledge. This information is used by the Coach to recommend easier problems whenever the student becomes confused.

D. The State Module

The State Module contains a list of goals and subgoals which presumably indicate acceptable procedures for exploring the Microworld. As the student proceeds through each of the states, the tutor records his/her actions. The authors have hypothesized that a student indicates appropriate experimental behaviors if they, first, explore the microworld. The student explores a microworld by generating ground traces. The student then moves on to "making predictions," followed by testing and validating tests, and then generalizing these principles. Each one of these states, in turn, has separate subgoals which may or may not be met. The tutor uses the State Module in two ways. First, if the student is performing poorly, then the Coach checks to see if the student has proceeded through each state in an appropriate manner. Second, the Coach uses the State Module to reflect different "instructional" strategies. For example, if the student is conducting experiments (as defined as "making predictions") then the system gives a higher status to using tools correctly. If the student is "testing," then the Coach will switch its strategy and try rules that check for skill deficiencies.

E. Diagnostician

The major purpose of the Diagnostician is to analyze student's responses and update the Student and Curriculum Models. Whenever the student enters a prediction from the Prediction Window or changes parameters from the Testing environment, the Diagnostician compares the student's answer to the Expert's answer and determines exactly which rules the student understands and does not understand. This information is then transmitted to the Student Module which, in turn, stores it for further processing.

The Diagnostician is also responsible for identifying the student's errors and ill-defined strategies. The Diagnostician does this by combining information obtained from the Expert Module, History files, and a series of high-level rules that generate students' errors. For example, if the student enters an erroneous prediction for the orientation shape-descriptor, the Diagnostician looks at the Expert Module and obtains a list of the orbital elements which were used to make a correct prediction. The Diagnostician then looks at the the student's History file to see if the student is manipulating the correct parameters. If not, then the Diagnostician invokes some high- level rules that try to generate the student's error to match the student's input. Some of these high-order rules are: Look at the rules that are used to deduce this shape-type and drop all the AND portion of the rules and change them to OR's. (Student Bug: An overgeneralization of a rule). Look at all the rules that deduce this shape-type and find the "easiest" rules (i.e., rules with one or two constraints) and see if this is the parameter that the student is manipulating (Student-Bug : If a rule works in one case, it works in all cases).

The Diagnostician also monitors the student's use of the various tools. Every time the student selects a different activity, this information is passed to the Student Module.

F. The Student Model

The Student Model contains a record of the student's current understanding of both the domain knowledge and investigative behaviors. Whenever the student tests a prediction or changes parameters in the Testing Mode, the Diagnostician sends the Student Module a list of the rules that the student understands. The Student Model maintains a series of counters for each rule indicating the number of times a rule is used appropriately, inappropriately, or ignored (a "missed-opportunity" as defined in Carr and Goldstein, 1977). If the missed-opportunity counter exceeds the used-appropriate counter, then the Coach recommends intervention.

The system also records the number of times that an online tool is invoked. In addition to this counter, an effectiveness measure is maintained for both the History Tool and the Orbit Window. If the student demonstrates inefficient behavior as indicated by one of the effectiveness measures, then the Coach intervenes and offers advice.

G. The Coach

The Coach maintains the rules and procedures that direct the teaching portion of the Tutor. The Ground Track Microworld is designed for two major purposes: 1) to teach students about the relationships between/among orbital elements and ground tracks, and 2) to teach students how to use systematic behaviors to investigate this domain. Thus, the Coach intervenes when either one of these conditions is not satisfied. The Coach monitors the student's actions and determines when the student needs advice. Intervention occurs only when the student is making erroneous predictions or entering incorrect parameters in the Test Mode. The general or high-level teaching strategy for the Coach is as follows:

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If the student has made No errors
    and if the student is completing curriculum
        materials efficiently
then record progress

If the student has made No errors
    and if the student is NOT completing the
        curriculum materials efficiently
then recommend an easier curriculum
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If student has made error
then
a) Check ruleset for satisfaction of preconditions
b) Check ruleset for Correct Tool Use
c) Check ruleset for Skill remediations

The authors made the general assumption that when the student is in the Prediction Mode, then the Coach should help students discover the objectives by having them use the tools correctly. If this fails, then the system should address individual skill errors. This strategy is reversed whenever the student enters the Testing State.

The Coach's overall intervention strategy is to check whether the student has completed the necessary preconditions (as determined by the values stored in the State Module). If the student has satisfied all the preconditions for an exercise, then the Coach checks the measures for effective inquiry skills. The list of effective inquiry skills as originally defined in Shute and Glaser [1987] include: Systematic experimental behaviors such as making sufficiently large/small increments to orbital parameters; Inductive/generalization strategies such as replacating a test or prediction; Complexity of data organization such as isolating similar traces in the History file, selecting relevant ground traces in the History file; Strategies for disconfirming evidence such as re-doing the experiment or adjusting orbital parameters to fit a new prediction.

Every time a student enters a prediction or estimates the orbital parameters in the Test Mode, the Coach evaluates the Student Model and determines if intervention is required. If the student's effectiveness measures are low, then the Coach proposes possible remediation and offers assistance. In the event that the student fails to attain a level of proficiency after receiving instruction on effective Tool Use, then the Coach addresses the student's domain knowledge inadequacies.

At the present time, the Coach uses the information stored in both the Tool Objects and the Expert Module to advise the student concerning errors. Initially, the system suggests that the student use one of the available tools to correct his errors. If the student continues to have difficulty, then the Coach may display the definitions, examples or explicitly state the relationships between various parameters.

III. Summary and Future Direction

The current ground track microworld uses a qualitiative model to teach the basic concepts of orbital mechanics. This microworld provides the student with a discovery environment which allows him to explore relationships between orbital parameters and ground tracks. The microworld also has intelligence. It knows about the domain, about how to estimate orbital parameters from a ground track, and about how to use the inquiry tools effectively to achieve goals. As a result, if the student fails to make satisfactory progress toward the stated goals, then the system intervenes and offers appropriate assistance. This type of intelligent simulation provides a more active and adaptive environment for reinforcing training skills.

The initial prototype is now complete and has been formatively evaluated by members of the NORAD crew and instructors at the Space School. The authors performed further tests during the Spring Semester of '87 with students from the Space School at Lowry Air Force Base and from the Air Force Academy to determine if the tutor is more effective than traditional classroom experience. This data will also be used to improve the diagnostic portion of the tutor.

Several areas of research are also being investigated using the ground track domain. The intelligent tutor for this domain closely resembles an intelligent tutoring system developed by Schute and Glaser [1987] which is currently used at Lackland Air Force Base, San Antonio, Texas, to identify individual cognitive differences among students. We are planning to test the effectiveness of the acquisition of inquiry skills by comparing Airmen who use both the Shute & Glaser Economics Tutor and the Ground Track Tutor. From this data, we will be able to determine the extent to which individuals transfer experimental behavior. Because one of the primary purposes of this tutor was to create a vehicle for testing hypotheses for training effectiveness, we want to investigate specific questions dealing with this area such as: What happens in an instructional environment when you vary the order of the State Module? (Is it better to state a hypothesis and then conduct experiments?) What happens in the instructional environment when you vary the order of remediation? (Tool use versus Skill Diagnosis?) Finally, how can the information we obtain from these studies be made a dynamic part of the system so that it can adapt to individual student's needs? These and other issues will be explored in the coming months and should contribute to our understanding of how to build more effective training systems.

Acknowledgements

The authors gratefully acknowledge Dr. Valerie Schute whose contributions to this project were invaluable. The author would also like to thank the instructors and students at the Unified Space Training School (UST) for their assistance with this project.

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