AUTOMATIC SCENARIO GENERATION USING PROCEDURAL MODELING TECHNIQUES

by

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ABSTRACT

Training typically begins with a pre-existing scenario. The training exercise is performed and then an after action review is sometimes held. This "training pipeline" is repeated for each scenario that will be used that day. This approach is used routinely and often effectively, yet it has a number of aspects that can result in poor training.

In particular, this process commonly has two associated events that are undesirable. First, scenarios are re-used over and over, which can reduce their effectiveness in training. Second, additional responsibility is placed on the individual training facilitator in that the trainer must now track performance improvements between scenarios. Taking both together can result in a multiplicative degradation in effectiveness.

Within any simulation training exercise, a scenario definition is the starting point. While these are, unfortunately, re-used and over-used, they can, in fact, be generated from scratch each time. Typically, scenarios include the entire configuration for the simulators such as entities used, time of day, weather effects, entity starting locations and, where applicable, munitions effects. In addition, a background story (exercise briefing) is given to the trainees. The leader often then develops a mission plan that is shared with the trainee group. Given all of these issues, scientists began to explore more purposeful, targeted training. Rather than an ad-hoc creation of a simulation experience, there was an increased focus on the content of the experience and its effects on training.

Previous work in scenario generation, interactive storytelling and computational approaches, while providing a good foundation, fall short on addressing the need for

adaptive, automatic scenario generation. This dissertation addresses this need by building up a conceptual model to represent scenarios, mapping that conceptual model to a computational model, and then applying a newer procedural modeling technique, known as Functional L-systems, to create scenarios given a training objective, scenario complexity level desired, and sets of baseline and vignette scenario facets.

A software package, known as PYTHAGORAS, was built and is presented that incorporates all these contributions into an actual tool for creating scenarios (both manual and automatic approaches are included). This package is then evaluated by subject matter experts in a scenario-based "Turing Test" of sorts where both system-generated scenarios and human-generated scenarios are evaluated by independent reviewers. The results are presented from various angles.

Finally, a review of how such a tool can affect the training pipeline is included. In addition, a number of areas into which scenario generation can be expanded are reviewed. These focus on additional elements of both the training environment (e.g., buildings, interiors, etc.) and the training process (e.g., scenario write-ups, etc.).

I dedicate this to my mother and father.

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I found that dealing with the death of your parents makes you very reflective. I look back on my father's and mother's lives and I see how they have influenced my life and made me the person I am today. My father was a hard worker, and he would take work home at night and often take me with him into the office on Saturdays. I still remember trying to hit the "control" and "c" keys in unison on a keyboard for the first time in my life (as an eight or nine year old); it was on a giant CAT scanner in Elliot Hospital in Manchester, NH. My mother always had a free spirit, and she enjoyed seeing new places and trying new things. I will forever remember the trips to Boston and how

one time she agreed to take the train back to Nashua (again, I was probably eight or nine years old) even though I'm sure we already had bus tickets. A fairly known quotation (author unknown) says "*A hundred years from now it will not matter how much I earned, what my job title was, or what type of car I drove, but the world may be different because I touched the life of a child*." This certainly applies to my parents. Thanks, Mom and Dad.

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LIST OF ACRONYMS/ABBREVIATIONS

AAR	After Action Review
CAN	Combined Arms Network
CAS	Close Air Support
COGS	CAN-oriented Objective-based Generator of Scenarios
DVTE	Deployable Virtual Training Environment
EBAT	Event Based Approach to Training
FAA	Federal Aviation Administration
FEAST	Framework for Enabling Adaptive Scenario Generation for Training
FiST	Fire Support Team
FL-systems	Functional Lindenmayer Systems
GPA	Grade Point Average
GUI	Graphical User Interface
IDF	Indirect Fire
IRL	Interactive Realities Laboratory
ISAT	Interactive Specification Acquisition Tools
ISS	Instructional Support System
IST	Institute for Simulation and Training
JSAF	Joint Semi-Automated Forces
JTAC	Joint Terminal Attack Controller
KSA	Knowledge, Skill and Attitude
L-systems	Lindenmayer Systems
MSDL	Military Scenario Definition List

PYTHAGORAS	Procedural Yielding Techniques and Heuristics for Automated Generation of Objects within Related and Analogous Scenarios
RRLOE	Rapidly Reconfigurable Event-Set Based Line-Oriented Evaluations
STRIPS	Stanford Research Institute Problem Solver
T&R	Training and Readiness
UJTL	Universal Joint Task List
XML	eXtensible Markup Language

CHAPTER ONE:
INTRODUCTION

Ever since the first flight simulator was created by Edwin Link, researchers have investigated using simulators for training. Since this advent of the field, engineers and computer scientists have created increasingly advanced simulators with constantly improving realism. Similarly, psychologists have developed theories for improving the effectiveness of simulation-based training. However, in only a few cases have the two camps come together to develop a realistic simulation for effective training.

The Training Process

Within the training process there is a series of steps that are followed. The typical training event begins with a pre-existing scenario, which is followed by a plan created by the trainee(s). The training exercise itself is then performed and a subsequent after action review is sometimes held. This procedure is repeated for the various scenarios that may be used in that training session. Any conceptual connections between scenarios must be handled by an exercise facilitator. Such a process looks like the one in Figure 1.

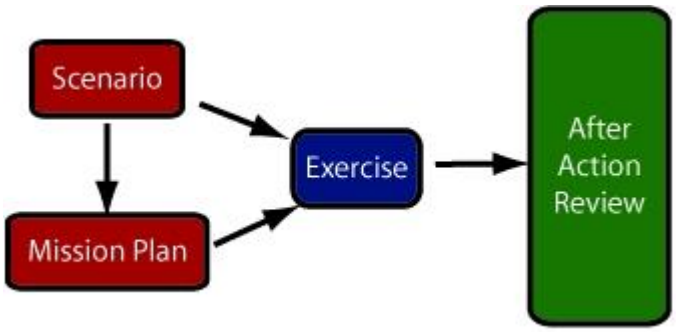


Figure 1: Typical Training Sequence

Unfortunately, this process can lead to two events that are undesirable. First, the same scenarios are re-used over and over again, which can reduce their effectiveness in training. Second, the individual training facilitator becomes responsible for tracking performance improvements between scenarios. The combination of these two events can lead to a multiplicative degradation in effectiveness.

There is a very old notion that you should not train specifically for the test [1]. In addition, training in terms of new missions can also be an issue. The facilitator must select a scenario for continued training, but has only a small set of scenarios from which to do so. The same notions can exist for other domains when well-known scenarios wish to be avoided or new types of scenarios are needed.

Due to these and other training issues, there has been increased attention on the overall training process. Recently, a number of additional steps have been included to aid in improved training effectiveness. One of these steps, scenario generation, is of particular importance to the research presented in this thesis and so is reviewed here in a bit more detail.

Scenario Generation

Running a simulation training exercise requires that we develop a scenario definition as a starting point. However, prior to developing the scenario, a training needs analysis should be performed that determines the set of Knowledge, Skill and Attitude (referred to as KSAs) that are required as part of the training. Identifying the KSAs help drive what the scenario must provide in order to satisfy the goals of the training and are used to form the learning objectives (the underlying goals of the training). Furthermore,

completing this analysis helps drive the context of training; an analysis of the task is performed, scenarios formed, an exercise run, and an after action review performed.

Typically, the scenario definition includes all the parameters for the simulators themselves such as entities used, time of day, weather effects, and entity starting locations as well as munitions effects. In addition, a story (or more formally, a mission briefing) is given to the trainees based on similar information augmented with the mission description (e.g. deliberate attack, search for weapons cache, etc.). The unit leader then develops a mission plan that is shared with the trainee group as appropriate.

The notion of scenario generation can be generalized to other domains. For example, a cognitive rehabilitation scenario could include the task to be practiced, locations of items needed for the task, and possibly the layout of the training area itself. Ultimately, scenario generation is required for all training exercises to provide the context for the training to occur. This is a relatively expensive process that can benefit from tools to aid in quickly creating such elements.

Scenario-based Training

While previous training tried to focus on the needs of the trainee as much as possible, it was typically done in an ad-hoc fashion and, as noted, focused too much on existing scenarios. In fact, some evidence of "negative training" has been reported [2][3][4]. Negative training refers to the notion where a trainee learns a process incorrectly or gains incorrect understanding. It is often not even recognized by the trainee, which is why it is such a serious problem.

Given these issues, scientists began to explore more purposeful, targeted training. Rather than an ad-hoc creation of a simulation experience, there was an increased focus on the content of the experience and its effects on training. This resulted in two new approaches: the event-based approach [5] and the scenario-based approach [3]. In reality, both approaches are fairly similar. They focus on the role of events or the scenario in learning. Specifically, the goal is to bring an order of events to the trainee to present a "desired psychological state" [6].

So called "scenario based training" has gained wide acceptance as a training concept. It provides the capability for trainees to explore a wide range of learning including practice, cognitive skills and naturalistic decision making [7]. However, as indicated above it is not always performed in practice (at least not all aspects).

This characteristic of a limited breadth of experiences is particularly troubling as it has been found that development of advanced cognitive skills is dependent upon extensive varied experience [8][9]. Specifically, the process of how an expert has built up and integrated that knowledge was studied. It was found that experts use their large quantity of experience and integrate them using the differences as a guide to larger understanding.

Similarly, work in naturalistic decision making has theorized that experts make decisions by leveraging a repository of experiences and use that collection to compare situations [10]. This theory suggests that expertise depends upon exposure to a varied set of experiences. Scenario-based training can provide that variability. In fact, a review of scenario-based training found several ways where varied scenarios can enhance training.

Multiple, varied scenarios help trainees generalize their understanding and to be able to adapt it to new situations [8]. In addition, varied scenarios allow trainees to try different courses of action within a single scenario and also to practice an intended course of action across different scenarios [9].

Effective Scenario-based Training

Scenario-based training, just by name, is not enough. What needs to go into a scenario to support effective scenario-based training? Previous reviews of this topic found five components to effective training scenarios [6]. Each is reviewed here.

Embedded Triggers

Training scenarios should provide the opportunities for trainees to practice their skills, demonstrate their proficiency of those skills, and receive feedback on that performance [3][11]. By designing scenarios to contain these "embedded triggers," their effectiveness is increased. For example, the Event Based Approach to Training (EBAT) was created as a framework for providing events within an exercise that allow for observation of specific behaviors of interest from the trainees [5].

In addition to EBAT, constraints such as empirical accuracy and empirical precision provide another model for planning scenarios [12]. Empirical accuracy refers to the degree to which all training objectives are built into a scenario; empirical precision refers to whether only the desired training objectives (no extraneous objectives) are included.

Clearly-defined Goals

When creating a scenario (whether by hand or in any assistive way), the process must also have clear goals [11]. Not only should the goals be clear to the scenario designer (or instructor) but to the trainees as well. If the latter is missing, then the trainees may not respond in expected manners and may not practice the desired knowledge and skills.

Furthermore, the goals should include performance measures. If the goals are well defined, but not measured, then there is no indication of how well the trainee completed the goals. If the goals are clearly defined, then having such performance measures is an easier burden as well.

Variety

The need for scenario variety has been discussed earlier. However, it is still essential to define what is meant by variability. Variety could be defined as the generation of non-trivially diverse scenarios, meaning that they are not redundant for training purposes [12]. Specifically, two scenarios are not redundant if they fulfill all the requirements of the selected training objectives and differ by at least one significant event. Fundamentally, what is needed is the ability to create scenarios that are somehow qualitatively the same, yet still appear different to the trainee. How to do this or what it means to be "qualitatively the same" are very interesting questions. In fact, scenario variety is a ripe topic for further work.

Psychological Fidelity

Psychological fidelity refers to the "degree to which the trainee perceives the simulation to be a believable surrogate for the trained task" [13]. To be successful, the scenario has to be believable. This is particularly important as it has been found that scenarios must be believable in order to be effective *training* scenarios [7]. Outlandish scenarios may provide great entertainment value, but they are not effective in training.

Complexity

Similar to variety, trainees should also be tested on scenarios with varying complexity in order to provide effective learning [14]. The term "complexity" is used here in order to avoid the subjective term "difficulty." What is difficult for one person may not be for another. However, complexity is a more objective concept. Scenario complexity can be a measure of task complexity and structure. Task complexity refers to the number of discrete behaviors that form a task and the cues to be processed (referred to as component complexity) and their integration for successful task completion (known as coordinative complexity) [15]. Task structure refers to the degree of ambiguity within a task [16].

Organization

This dissertation pursues the question of making training more efficient (both for the trainees and the trainers) and whether an automated approach to scenario generation can be created to fulfill the goal of targeting trainee needs. Specifically, the use of a procedural modeling system known as Functional L-systems is used to create a variety of

scenarios that are different, yet qualitatively similar. Chapter 2 reviews the background literature in this area including contributions from past scenario generation efforts and interactive storytelling. A conceptual model of a scenario and how its various components can be represented is then developed in Chapter 3.

Chapter 4 then maps the proposed conceptual model to a computational one. The components of a scenario are developed into data structures and a manual approach to scenario generation is reviewed to illustrate the process of scenario generation using these structures. Automating this approach is the focus of Chapter 5. It includes a review of procedural modeling and the approaches used to date, followed by a presentation of the approach of Functional L-systems for scenario generation (including examples and analysis of strengths and weaknesses of the approach).

Chapter 6 reviews the implementation of the scenario generation system developed as well as the first scenario generation application built using it. The system is analyzed using a form of the Turing Test, presented in Chapter 7, along with results. Finally, Chapter 8 concludes and provides some discussion of improvements and additions to the current system that are possible to improve the range of scenarios.

CHAPTER TWO:
BACKGROUND

In this chapter work related to scenario generation systems is reviewed. Most are limited approaches that attempt to guide the user. However, some do provide important improvements to scenario generation based on modern day design concepts.

Existing Scenario Specifications

In order to generate scenarios, there must be a way to represent them. Two pieces of work from the U.S. Department of Defense are relevant here. The Universal Joint Task List (UJTL) is a list of all possible tasks that may be part of an exercise within the U.S. military. It provides a common language for commanders, support agencies, planners and trainers and allows them to communicate mission requirements [17]. For the purposes of scenario generation, it provides an exhaustive list of all possible tasks that may or may not be executed as part of a military training scenario.

The Military Scenario Definition List (MSDL) attempts to provide a standard language for representing military scenarios [18]. Its focus is on representing the scenario in an application-independent manner and utilizes eXtensible Markup Language (XML) in order to do so. The use of XML avoids scenario descriptions from being tied to one particular application or platform, and also allows these descriptions to easily contain all relevant data across the various components (planning, simulations themselves, and scenario development applications).

The major limitation of both UJTL and MSDL is that they are very much tied to military operations. Each works very well representing its respective aspects of military scenarios; however, they are not easily extensible to other domains.

Existing Semi-automated Scenario Generation Systems

A number of projects in semi-automated scenario generation have been pursued in recent years. In this section the most relevant of these are reviewed. In addition, lessons to be learned from each are discussed.

An event-based approach to scenario generation is the Rapidly Reconfigurable Event-Set Based Line-Oriented Evaluations (RRLOE) Generator [19][20][21]. RRLOE, used in Federal Aviation Administration (FAA) simulators, builds scenarios from small sub-scenarios that have been pre-approved by the FAA. The notion is that a larger scenario made up of pre-approved, valid sub-scenarios will also be valid. RRLOE uses a set of 128 heuristics to determine the adequacy of each scenario being constructed. The heuristics are continuously evaluated while sub-scenarios are added; the process stops when an acceptable scenario is reached. RRLOE is still used by the FAA for pilot qualification testing and training.

Another tool, the Interactive Specification Acquisition Tools (ISAT), also uses heuristics to build a scenario using smaller scenario pieces [22]. However, each scenario piece is pre-built with a very specific sub-goal. As the scenario pieces are assembled into the scenario, ISAT performs analysis to determine any error states that may exist within the heuristic model. For example, ISAT can identify states that are never executed in a scenario as well as those with conflicting "next" states. In addition, ISAT also has a

feature allowing users to interrupt the scenario generation process, alter the approach being taken, and then resume the generation process. This allows the user to more finely tailor a scenario.

Pffefferman developed a system for semi-automatic scenario generation associated with combat simulations [23]. His system took, as input, a structured "mission file" in order to create a scenario. The mission file includes standard military data on the situation, mission, execution, service support, and command and signal elements. This file follows a fixed format specified by the military, which Pffefferman uses to his advantage. His application parses the mission file to create a scenario for use within a training simulation. One important facet of his work, however, is the use of domain-specific information to "fill in the gaps" of information that may be missing from the mission file itself. Military doctrine is used to fill in these missing scenario elements.

The Framework for Enabling Adaptive Scenario Generation for Training (FEAST) uses context analysis and knowledge modeling methods to support the generation of scenarios [24]. Rather than depending on pre-exercise scenario generation, it focuses on dynamic and adaptive training during the exercise. It uses a "domain ontology" to drive the generation of the scenarios. The use of a domain ontology is the facet of scenario generation that makes FEAST unique.

Di Domenica et al. use a stochastic programming approach in their scenario generation method [25]. Stochastic programming uses a model of optimum resource allocation and a model of randomness and incorporates the notion of uncertainty in the form of probability distributions of parameters. Applied to scenario generation, their

method generates a tree structure of scenarios that best approximates a given distribution of the random parameters. The parameters (and their behaviors) are chosen based on a model of the scenario and are calibrated (often subjectively). These parameters are used to generate paths, which are sampled to create the scenario tree with the desired properties. The domain for this work was largely in economic systems; however, the basic concept can still apply to other domains.

Reynolds defines a framework for scenario generation [26]. However, the domain in which the work is based is risk management. She comments "the quality of the resulting analysis, however, depends on the ability to generate relevant scenarios, a task that grows increasingly complex with the proliferation of risk factors, models and sampling techniques." In other words, the number of potential variables can affect the generation of the scenario itself. However, Reynolds also uses five questions for providing an outline of the scenario set to be generated:

1. What is the purpose of the scenario set?
2. What risk factors must the scenario set include?
3. Do the risk factors need to be grouped or altered? If so, how should it be done?
4. What marginal distribution or process is most appropriate for each risk factor?
5. What are the technical considerations, such as run-time or memory?

Reynolds then creates a framework built around a scenario set definition, scenario generator, and a set of "blocks" (a group of risk factors) and models.

Many valuable lessons may be learned from these previous efforts. RRLOE and ISAT show the advantages of using smaller, pre-made sub-components (which are pre-certified, thereby helping with acceptance of the overall scenario. Pfefferman's approach shows that the data and rules of a specific domain can be used to support automated generation by allowing it to fill in missing information. FEAST takes that notion one step further using a full domain ontology to support scenario generation. Di Domenica and Reynolds each show alternative approaches to scenario generation.

Even with these significant contributions, many challenges remain. For example, none of these systems support more than one domain. Having a flexible system would help avoid a "stovepipe" approach where a system works with only one set of training applications. In addition, most of the systems reviewed do not incorporate the training needs of the trainee; they take a "one size fits all" approach to scenario generation, which does not lead to the most efficient use of training time (RRLOE is the exception). Finally, the systems here take different computational approaches to scenario generation. The heuristics-based approaches may or may not produce the best scenario whereas others that search for a satisfactory scenario may be computationally inefficient.

Interactive Storytelling

Interactive storytelling is a relatively new field. It concerns a form of entertainment where players take on the role within a storyline (particularly the protagonist role). One important component of interactive storytelling is a strong

connection between a player's actions and the story [27]. A number of interesting systems have been created and some of the most relevant and most known are reviewed here.

Façade is one of the most well-known interactive storytelling systems [28]. It is based upon a story where you visit two friends who are married but quickly become involved in a dispute leading towards the dissolution of their marriage. The player is given situations attempting to force support to one side of the argument or the other. Façade itself is a framework to create structured hierarchies of behaviors [28]. While the behaviors are integrated together within Façade, a human author must take the time to create each individual behavior. For the typical 20-minute Façade game, approximately two man-years were spent creating it. Façade tries to blend an approach between structured narrative and typical simulation. Much like some of the training-based work already reviewed, Façade's goal is to provide a well-formed experience where all parts of the experience are necessary and the experience is well-paced, yet provides a sense of immersion and freedom to act [28].

Mimesis is another well-known system [29]. However, rather than being a system on its own as Façade is, it uses the Unreal Tournament as its base. UnrealScript is written to represent conditions and actions for the story to take. However, Mimesis distinguishes between preconditions and persistent preconditions. The latter are conditions that must be true throughout the execution of the respective action. For example, for a character to walk through a doorway, it must remain open for that entire

action [29]. A software "mediator" manages inputs from a user and uses intervention of accommodation to prevent the story from breaking down.

Haunt 2 also uses the Unreal Tournament game engine and couples it with the Soar artificial intelligence (AI) engine [30]. The story is written by a human author and is fed into the software "director" software. It uses a partial-order plan, much like the Mimesis system. The story is split into atomic events, which the system calls plot points. These represent some story-based change to the world and are partially ordered to assemble the scene. Each plot point can have a set of preconditions and a set of post conditions. The preconditions represent what must be true in the story in order for the plot point to be considered; the post conditions represent the actions to perform once the preconditions are met.

Haunt 2 also provides a function to leave some content undefined. As opposed to Façade or Mimesis (which keeps content of plot points fixed), the author can leave plot content to be assigned by the "director." The director will recognize missing plot content and create it as appropriate.

IN-TALE is a system that focuses on the use of an experience manager, which is an agent that alters the virtual world to provide an experience to the participant that conforms to a set of properties [31]. It generates content that adapts to the user's actions within the world. Similar to other systems reviewed here, IN-TALE uses partially-ordered plans. However, it uses a STRIPS-like language that includes parameters, preconditions and effects. STRIPS (Stanford Research Institute Problem Solver) is an

automated planner developed in 1971 focused on tuples of current states, goal states, preconditions and post conditions [32].

Scribe is an authoring tool being used within a project investigating interactive storytelling for training [33]. The focus on the project is to combine interactive storytelling with intelligent tutoring within a game environment. Scribe's goals include generality, improved debugging capability, usability, environment representation, pace and timing, and story scope. In many ways, Scribe is similar to IN-TALE. The latter focuses on the behaviors of agents and how the behaviors affect the story; the former focuses on story representation and how actions influence the storyline for a trainee [33]. However, Scribe still uses plot points based upon a set of preconditions, a set of events and a set of actions. Such an approach works well for generality, though, which is an important advantage of these approaches.

Ponder et al. developed a virtual reality system that used interactive story for decision training [34]. Their system is built around decisions as the basic building block of a scenario. A decision is the "expression of the choice made to perform an action" where an action is defined as a finite state machine with idle, activating, active and terminating states [34]. Decisions can be grouped into decision sets where all decisions must be taken in order to transition. This provides the ability to support compound conditions before moving to the next scenario step.

Interactive storytelling provides many alternative approaches to developing stories. In turn, stories have many similarities with scenarios. The Mimesis approach is particularly illuminating in its distinction between preconditions and persistent

preconditions. Similarly, Haunt 2 and IN-TALE are interesting in their approach to leave some of the content intentionally undefined until "run-time." In many ways, they blur story generation and story adaptation. Scribe and Ponder et al. use general approaches that adapt to many different stories in a very easy fashion. Each of these examples provides many compelling attributes to scenario generation.

Computational Approaches

In this section various computational approaches of current scenario generation systems are reviewed. The basic approaches to scenario generation have been seed-based, heuristic-based and enumeration-based in nature.

The seed-based approaches use a starting scenario as a basis and then perturb it in order to create a new scenario [12]. The starting scenarios are typically created by a human (normally a subject matter expert) so this approach is a semi-automatic one. Since the starting scenarios are created by an expert, the basis for all the scenarios is of relative high quality. However, the perturbations available can often reduce the variability of the new scenarios. In addition, there is still the relative high cost of creating the original seed scenarios; depending on the range of seed scenarios necessary, this can be prohibitive.

Heuristic-based approaches use a set of rules (heuristics) to create scenarios that satisfy some set of constraints. The components of the scenario are randomly selected and then compared to the heuristics. If the constraints are satisfied, then the component is kept within the new scenario. This process is repeated as components are added to the scenario. This approach can also be quite effective in producing scenarios with

variability; unfortunately, it is also relatively computational inefficient. However, the heuristic-based approach taken by RRLOE uses off-line computation (i.e., before the training session itself) to reduce the time needed with trainees present.

Enumeration-based approaches are similar to their heuristic-based cousins. Rather than using heuristics to select a component to add to a scenario, enumeration-based approaches create all possible scenarios given starting conditions and then use heuristics to evaluate each potential scenario. Such a technique can work where run-time is not restricted and where the domain is not complex enough to rapidly expand the size of the enumeration space.

All of these computational approaches have advantages and disadvantages. They vary in set-up time, variability supported and computation time. However, there are other computational models still available for use. One, procedural modeling, has been seeing increased use in recent years as computer hardware has advanced.

Procedural modeling includes various techniques. One technique, Lindenmayer Systems (or simply L-systems), are a recursive, rule-based system that operates in a parallel fashion. Functional L-systems are an enhancement to L-systems that replace symbols in the rules with functions, providing a greater computational capability. This enhanced expressive power could provide a satisfactory approach to creating scenarios. Chapter 5 will describe these techniques in greater detail.

Before a semi-automatic scenario generation system can be built, however, the notion of a scenario must first be defined. These elements include both structures for representing components of the scenario and also how each addresses a training

requirement as well as support for different trainees. The next chapter discusses a conceptual model of a scenario.

Automated Scenario Generation

Given the lessons that can be taken from the works reviewed in this chapter, the rest of this dissertation heads towards the goal of automated scenario generation. In order to achieve this, a conceptual model of a scenario was created, mapped to a computational model, implemented using Functional L-systems and then its results analyzed. The remainder of this dissertation addresses these major contributions.

CHAPTER THREE:
CONCEPTUAL MODEL

Before any kind of automated scenario generation system can be approached, a model for representing a training scenario must be created. The model should include not only the parameters of a scenario, but also the sub-components of a scenario, a definition of scenario complexity and a framework for linking the sub-components to learning objectives and each other. Concrete definitions of each of these elements will enable software to generate appropriate scenarios for specific trainees. However, a distinction here is made between scenario generation (i.e., pre-exercise) and scenario adaptation (i.e., during exercise); the focus here is on the former.

This chapter describes the conceptual model of a scenario and its components. It is based upon the notion of selecting "training objectives" that are used to choose a "baseline scenario" and modifications, called "vignettes," that add increased complexity to the scenario. The training objectives are based upon the training audience (e.g. a system for cognitive rehabilitation will have very different training objectives from a system for military training). Baselines represent the overall environmental setting; they include a virtual world to use as well as time-of-day and weather effects. Vignettes are added to the baseline and provide for a greater overall complexity of the scenario. Given the background of a trainee, a system should be able to assemble vignettes with a baseline that results in a scenario that supports the specific training objectives, reaches appropriate levels of complexity for that trainee, and provide adaptive training opportunity for the trainee(s) to further their understanding and performance.

In addition to scenario generation based on trainee background, training science suggests that scenarios for effective training should support varied pedagogical approaches [35]. For example, a "compare and contrast" scenario where a particular event is specified in two different ways or a "disequilibrium scenario" where the worst-case scenario is given can enhance the trainee's understanding.

What is a Scenario?

Before getting into the details of the conceptual model, a common understanding of the term "scenario" is required. Specifically, a distinction between a simulation and a scenario is made. A simulation refers to the use of a virtual environment to support practice of a task (so called "simulation-based training"). In contrast, a scenario supports scenario-based training where scenarios are used to create the purposeful instantiation of simulator events to produce desired psychological states [36].

Given scenarios, however, there is a distinction to be made between a "scenario" and a "situation." Situations refer to instant snapshots, which occur at any given time within an exercise; whereas scenarios can be thought of a series of situations over time [37]. Therefore, one can think of a training scenario as a series of events that create specific situations.

Finally, a training scenario uses a series of specific situations in order to facilitate learning. In addition to simply describing the environmental context, training scenarios should include pedagogical accompaniments such as training objectives and performance measures. The former was already alluded to earlier whereas the latter is used for

tracking performance in order to better facilitate future scenario generation for that trainee.

Scenario Generation Process

The basic process behind automated scenario generation can be conceptualized by an Input-Process-Output model [38]. Inputs may include specific training objectives and information about the trainees. Once these inputs are specified, the software will process them and assemble a scenario. Finally, the software will then output a scenario definition file.

Specifically, the inputs include preselected training objectives, an optional recommended pedagogical approach and information about the trainees. The trainee data can include the number of trainees, the roles in which they will participate in the simulation as well as their levels of expertise. Once inputs are provided, the generation system constructs a valid scenario that emphasizes the given training objectives that are tailored to the specific trainees' needs. A scenario actually has a number of specific building blocks (briefly discussed above). All together these blocks are referred to as facets of the scenario, each with a specific role to fulfill in formulating the scenario. The output scenario definition is automatically assembled from pre-existing scenario baselines and "vignettes" that represent an element of a scenario. The scenario is then output and used within the various simulations for initialization of the exercise.

Training Objectives

The military formally defines training objectives in its Training & Readiness (T&R) manuals. Each objective in the T&R includes a list of "conditions" that describes the context under which the action can be performed. In the conceptual model for scenarios, this basic approach is followed. Note, however, that training objectives can be created for any particular domain desirable; it just happens that the approach used in the T&R manuals generalizes well so it was included in the model posed here. However, regardless of the domain being trained, it is important to enumerate the training objectives for that domain. For more civilian domains (such as cognitive rehabilitation), this enumeration would likely have to be completed with the aid of appropriate subject matter experts.

Regardless of the domain in question, the training objectives for it will likely include some context under which the actions within the objective can be performed. In the conceptual model, these conditions become requirements for elements that must be present in the scenario. For example, to train an artillery gunner to fire upon an enemy convoy, the simulation must include available supporting arms, munitions, and an enemy convoy to target. Thus, the selection of a particular training objective causes a set of conditions to become "active" (i.e. valid for use in this scenario).

The training objectives in the military's T&R manuals typically have broad definitions. For example, Figure 2 from the Marine Corps Infantry T&R Manual describes training objective "0302-FSPT-1302: Employ Supporting Arms" [39].

Given a radio, call signs, frequencies, available supporting arms, equipment, a scheme of maneuver and a commander's intent…achieve desired effect(s) on target that support(s) the ground scheme of maneuver.

From Infantry Training & Readiness Manual [39]

Figure 2: A Training Objective

Such a description is not sufficiently detailed on its own for automated scenario generation. Therefore, an approach must be devised to break down training objectives into what is referred to as learning objectives (taken from the knowledge, skills, and attitudes, or KSAs, found in the training needs analysis) [35]. The learning objectives are core tasks and actions that make up the training objective and typically are measurable. Essentially, the set of learning objectives define the "domain ontology" of the training domain. For instance, the "Employ Supporting Arms" training objective may include learning objectives related to spatial and temporal coordination, battlefield sense making, tactical positioning, and communication (just to name a few). Even though the training objectives act as the interface to the user of the scenario generation system, it is really the learning objectives that drive the training.

Complexity

Before discussing the components of a scenario, the notion of complexity of the scenario must be defined. The term "complexity" is used rather than "difficulty" as the latter is very subjective. A scenario that may be "easy" for one person may be quite

"hard" for another. However, a scenario that has many concurrent activities can be objectively referred to as "complex."

Given the use of "complexity," all that is needed is a representation of a scenario complexity as well as each facet complexity. In addition, there must be some formula for combining the different scenario facets into an overall single scenario complexity. Recall that complexity can be measured as a function of task complexity (including component complexity and coordinative complexity) and task structure. Dunne et al. developed a definition of scenario complexity built around these notions, a task framework and cognitive context moderators [40]. With these aspects defined, the system can now represent scenario complexity.

Baselines

After training objectives are chosen, the next step is the selection of a baseline. Baselines define the environmental setting in which the scenario is taking place. It includes the terrain (possibly, generated itself), time-of-day and weather effects (wind, rain, snow). Baselines can support the simplest scenarios (since they provide a setting for the conditions as specified in the training objectives). While they may be in any terrain (even harsh ones) or in poor illumination or weather, the training objective requirements will state the need for minimal assets for the scenario itself. Therefore, the scenario will be simplest in assets although the environmental effects may cause it not to be the absolute simplest in nature.

Although baselines can support training, these simple scenarios only offer minimally beneficial training experiences. Since they are so simplistic, baselines only

support training the most novice trainees in mostly procedural operations. Baselines lack variability (other than entity location) and additional complexity. In order to expand baselines to better support advanced training, additional scenario elements are needed.

Augmentations

How does a baseline represent different environmental conditions? In the conceptual model, it uses a notion called augmentations. These elements possibly add complexity to the scenario and can affect aspects of the baseline itself. Examples include moving a Fire Support Team scenario to night or adding rain. Each of these potentially adds complexity to the generated scenario (note that the complexity added by an augmentation is domain dependent; e.g., switching to night would add complexity in a Fire Support Team task but perhaps not in a non-visual task domain). However, not all augmentations may be applicable to the chosen training objectives. In addition, some augmentations may need to be limited. It would make no sense to add a "night" augmentation to a scenario more than once. Therefore, when augmentations are specified, they include parameters that better define their use (such as restrictions on the quantity allowed).

The adding of augmentations to a baseline begins to add complexity to the training scenario. However, it is important to reiterate that augmentations to baselines simply change the initial environmental situation. Augmentations will later be used to enhance vignettes as well, but in different ways.

Vignettes

The training objectives and baseline (with or without augmentations) selection sets the basic initial situation. Vignettes add learning-objective content to the baseline in order to make a larger (and more complex) scenario. Vignettes are pre-packaged alterations and/or additions to the scenario that exist in a library for selection.

Scenario vignettes are defined as sets of associated triggers and adaptations. Triggers are defined as any kind of check or comparison that returns a Boolean (true or false) value. Triggers may be based simply time-based or be based upon specific events (e.g. a detonation occurred nearby). When a trigger is determined to be true, its corresponding adaptation is executed. A trigger could have more than one adaptation associated with it in which case all adaptations would be executed (serially). Triggers can also be chained to provide "if-then" type logic or even Boolean "and" logic; we can even include triggers that provide a branching type mechanism.

Adaptations are alterations made to the current situation within the simulation. They range from those that provide entity manipulations (create, kill, move, fire weapon) to those that provide environmental manipulations (reduce rain, raise sun). Their primary purpose is to adjust the training (cause an event to occur). However, they can also be used to adapt the scenario in a pre-planned way (provide remediation or add complexity to the scenario). In addition, they can also be used to repair an exercise. For example, if a critical entity is killed, then an adaptation can be used to recreate it to facilitate the completion of the scenario. Since training can be expensive (both in terms of cost and time), each training opportunity is important and adapting the scenario in this way avoids

that exercise from being lost. In summary, adaptations cause changes to occur within the scenario itself. Together with triggers, they form the basis for adjusting scenarios during the simulation itself.

Note that the trigger/adaptation scheme also provides an additional capability. While not the focus of this work, this scheme can also support dynamic scenario adaptation. This adaptation can work with pre-defined rules (or other machine intelligence schemes) to create new triggers/adaptations during the running of the simulation. In other words, the system could create new simulation events to satisfy instructional needs identified during the exercise. For example, if a trainee accidentally gets killed (virtually) during an exercise, the adaptation system may detect this (with a trigger already in place) and dynamically prepare an adaptation that would re-spawn the trainee (again, so that the training opportunity is not lost). Similarly, if a trainee's performance falls outside of a predetermined range, then the system could trigger an adaptation that escalates the training (e.g., introducing the next training objective) or one that offers remediation.

Satisfying Requirements

Before the scenario is considered complete in this conceptual model, one additional step is required. The training objectives, baselines and vignettes may have specified additional requirements for the scenario. For example, a training objective may require a target to exist. However, that objective has not specified the type of position of that target (just that it must exist). These details, the requirements, are left as the final step.

Again, in the conceptual model, requirements can be satisfied either manually, by a user, or via an automated approach. The types of requirements that may be necessary are enumerated for each training domain. This allows the system to prompt for the specification of that requirement type. For example, knowing that a target is required, the system can prompt for type and position of that entity. Once all requirements are specified, then the scenario is considered complete.

Review of Concepts

The conceptual model has many elements. In order to help the reader, each is summarized here. Table 1 describes each concept. Figure 3 shows a diagram that depicts how elements relate to each other.

Conceptual to Computational

While a conceptual model of a scenario is now complete, this is not yet concrete enough for building scenarios. The conceptual model must be mapped into a computational one. The next chapter discusses this mapping in detail.

Table 1. Table of Concepts in Conceptual Model.

Concept	Definition
Training Objective	Higher-level task being trained.
Learning Objective	The tasks that underline the training objective. Related to KSAs. Ultimately, it is these that are being trained.
Trainee	The person being trained.
Profile	A table tracking what a trainee has attained; includes measures of performance of each training and learning objective.
Performance	A measurement of a particular training or learning objective.
Simulation	The tool used to train or practice. Typically, a virtual environment.
Event	An action within the simulation or possibly an interaction with the trainer/instructor.
Scenario	All the elements needed to run a simulation; represented in this work as a set of facets with parameters set and requirements satisfied.
Situation	A specific snapshot at a precise moment of a scenario.
Complexity	Measure of how complex a scenario or facet is.
Facet	A component that makes up a scenario; a baseline, augmentation, trigger, adaptation or vignette.
Baseline	The simplest facet; includes virtual world to use with environmental parameters. Can also declare requirements that need to be satisfied. Has a complexity level.
Augmentation	Facet that adds an element to the scenario. Element can be environmental or a new entity. Can also override parameters or declare requirements that need to be satisfied.
Trigger	Facet that is a Boolean check on some event (could be within the simulation or set by the trainer). Can declare requirements that need to be satisfied.
Adaptation	Facet that changes the simulation in some way. Can override parameters, generate new entities or manipulate entities. Can declare requirements that need to be satisfied.
Vignette	Set of augmentations, set of triggers and set of adaptations that represents some sub-scenario. Facets within the vignette can be chained for complex actions. Has a complexity level.
Parameter	Some value of the scenario; mostly environmental (e.g. time of day).
Requirement	Additional information needed to fully define a facet.

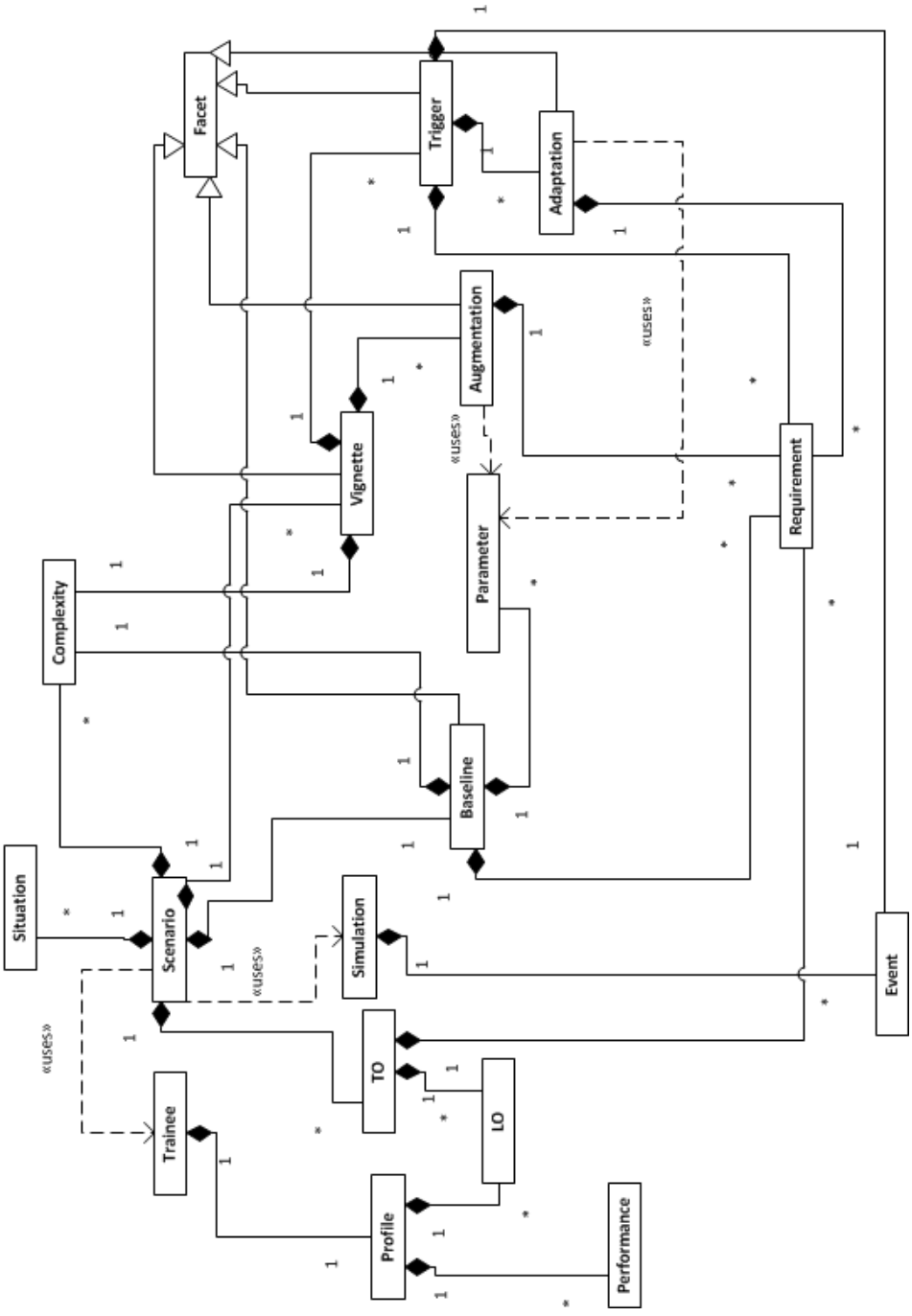


Figure 3: Diagram of Concepts

CHAPTER FOUR:
COMPUTATIONAL MODEL

With the conceptual model defined, the idea of automating the scenario generation can begin to be investigated. However, before a scenario generation system can be built, the ideas within the conceptual model have to be made more concrete within a computational model.

Mapping Conceptual to Computational

To map the conceptual model into a computational one, each conceptual component will be considered and a computational model built to represent it. This includes how to represent the training objectives, the notion of a scenario complexity, the baselines and vignettes (in turn, defined in terms of the augmentations, triggers and adaptations).

Training Objectives

In order to support training objectives, a tiered system is used. Objectives are mapped into a three-tier hierarchy with levels being a major category, a minor category and a "code" within the major-minor category. While this maps well into existing T&R manuals, it also provides a very good, yet simple, approach to mapping training objectives across all domains. Any given domain can likely be categorized into this three-tier hierarchy. XML also represents such a hierarchy very well and is used to store the training objectives in files. Figure 4 shows the XML representing just a single example training objective.

```
<objectives>
   <major code="INF" filename="INF.png">
      <minor code="FSPT">
         <objective code="6302">
            <name>Conduct FiST Operations</name>
            <requirements>
               <requirement id="FiST"/>
               <requirement id="Target"/>
               <requirement id="Artillery"/>
            </requirements>
            <los>
               <lo>Adaptability</lo>
               <lo>Integration (Coordiation and Deconfliction)</lo>
               <lo>Battlefield Sensemaking</lo>
               <lo>Combinated Arms Resource Allocation</lo>
               <lo>Rehearsal</lo>
               <lo>Intelligence Gathering</lo>
               <lo>Asset Sequencing</lo>
               <lo>Battlespace Geometry</lo>
               <lo>Orientation to Target</lo>
               <lo>Information Exchange</lo>
            </los>
         </objective>
      </minor>
   </major>
</objectives>
```

Figure 4: An Example Training Objective

In the figure, note the “requirements” section. This section lists all elements that must be specified when using this training objective. For example, it specifies that a “target” must be declared. A target must exist for this training objective but resolution of its specific parameters can be postponed. This allows the specification of the training objectives to be more qualitative in nature and, therefore, more flexibly used.

In addition, note the list of learning objectives connected with the training objective. As mentioned in the previous chapter, the learning objectives are the specific actions necessary to complete the training objective and are more concrete than the stated training objectives. Ultimately, these are the actions whose performance is being measured and are used to gauge the trainee’s abilities.

Complexity

In order to measure complexity of the various scenario facets as well as the total complexity of the scenario being created, the notion of complexity must be made concrete. How to measure complexity and compare vignettes with each other could easily be a dissertation topic on its own (and, in fact, a colleague is working on this very topic). For this work, complexity is defined simply as a number in the range of 0 to 100, inclusive.

Baselines and vignettes are assigned complexity scores by a subject matter expert. Computationally, regardless of how these scores are computed (whether using the model by Dunne et al. or another), those values are merely stored in the respective facet definition. As each facet is added to a constructed scenario, the complexity scores of each facet are simply summed. This sum is tracked and the overall complexity of the scenario is enforced to be within a range designated appropriate for the trainee. If a scenario has a complexity outside the desired range, it is adjusted, accordingly, to reach the goal.

Baselines

Similar to the training objectives, XML can also be used to store the baselines. Each baseline contains a name, description, visual database, constructive database, a map, and reference points to map the world into the databases. In addition, each baseline also includes a list of training objectives that it is said to "support." If a baseline supports a training objective, the baseline will be listed as a possible choice for the user when that training objective is chosen for training.

Baseline definitions also include a list of parameters. These are stored in a computational structure to represent the environmental augmentations defined in the previous chapter. Each parameter defines an environmental factor and overrides any previous setting. Figure 5 shows an example to bring all these concepts together.

The next facet to review is the vignettes. However, before discussing vignettes in detail, augmentations, triggers and adaptations are first reviewed.

```
<baseline type="1001">
   <name>29 Palms</name>
   <description>29 Palms</description>
   <imagefilename>29Palms.png</imagefilename>
   <mapfilename>29Palms.png</mapfilename>
   <visualdb>\data\terrain\29palms_alpha\archive.txp</visualdb>
   <constructivedb>29palms_ver40</constructivedb>
   <maprefpoints>
      <refpoint>
         <worldpoint>
            <x>-2349768.0</x>
            <y>-4729349.0</y>
            <z>3564665.0</z>
         </worldpoint>
         <pixel>
            <x>0</x>
            <y>2285</y>
         </pixel>
      </refpoint>
      <refpoint>
         <worldpoint>
            <x>-2292590.0</x>
            <y>-4757691.0</y>
            <z>3564186.0</z>
         </worldpoint>
         <pixel>
            <x>2900</x>
            <y>2285</y>
         </pixel>
      </refpoint>
      <refpoint>
         <worldpoint>
            <x>-2279703.0</x>
            <y>-4732399.0</y>
            <z>3605603.0</z>
         </worldpoint>
         <pixel>
            <x>2900</x>
            <y>0</y>
         </pixel>
      </refpoint>
   </maprefpoints>
   <supports>
      <objective major="0302" minor="FSPT" objective="2302"/>
      <objective major="INF" minor="FSPT" objective="6302"/>
   </supports>
   <parameters>
      <parameter name="tod">1500</parameter>
      <parameter name="weather">clear</parameter>
      <parameter name="windspeed">10</parameter>
      <parameter name="winddirection">N</parameter>
   </parameters>
</baseline>
```

Figure 5: An Example Baseline

Augmentations

The discussion of augmentations here refers to those augmentations that would be part of a vignette and somewhat ignores those specified as part of a baseline. However, they can have commonalities as all augmentations override parameters (whether defined in the baseline or vignette). For example, a "night" augmentation could specify the time-of-day to be at 2:00 A.M. In reality, however, augmentations are really a superset of the baseline's parameters. While they can and do change these parameters, they actually do a lot more.

Augmentations also specify new elements within the scenario. For example, an "additional target" augmentation may exist to indicate that a second target should be added to the scenario. Augmentations can also be used to specify other players within the scenario.

Augmentations are specified by a name, description, a complexity level that represents how much they add to the scenario, a notion of quantity allowed (again, it makes no sense to add a "night" augmentation more than once), a set of parameters being assigned (in the case of a baseline, parameters being overridden) and a set of requirements. The requirements are exactly like those from the training objective. They are additional elements that are required for the scenario although their precise parameters are postponed for later resolution.

Similar to previous facets, XML is also a good representation for augmentations. In particular, it allows for a variable set of elements (the parameters and requirements) that may or may not be a part of the augmentation. It also allows for easy editing, which

is also a big advantage. Figure 6 shows two augmentations; one focuses on overriding parameters while the other adds new requirements to the scenario:

```
<augmentation type="2001">
   <name>Night</name>
   <description>Change time of day to nighttime</description>
   <imagefilename>night.png</imagefilename>
   <complexity>30</complexity>
   <quantity>1</quantity>
   <parameters>
      <parameter name="tod">200</parameter>
   </parameters>
</augmentation>

<augmentation type="2002">
   <name>Add'l Target</name>
   <description>Add an additional target to the scenario</description>
   <imagefilename>addlTarget.png</imagefilename>
   <complexity>30</complexity>
   <quantity>10</quantity>
   <requirements>
      <requirement id="Target"/>
   </requirements>
</augmentation>
```

Figure 6: Two Example Augmentations

Triggers

Triggers, as defined previously, are simple tests or comparisons that are Boolean in nature. They are relatively easy to take from concept to computational entity at least as far as specifying. They include a name, description, and an optional set of requirements. In this case, the requirements represent the parameters of the Boolean check itself. For example, a trigger checking to see if an explosion occurred near an entity needs to have the entity in mind specified. A trigger prompting the instructor before continuing needs the prompt itself specified. Even a time-based trigger that waits until some specific time in the exercise is met needs that time specified.

XML is, again, a good candidate for this representation. Figure 7 shows an example of a trigger of a detonation occurring near a given position.

```
<trigger type="3003">
   <name>Detonation Nearby</name>
   <description>Activated when detonation near a position</description>
   <imagefilename>detonationNearby.png</imagefilename>
   <requirements>
      <requirement id="Position"/>
   </requirements>
</trigger>
```

Figure 7: An Example Trigger

Adaptations

Adaptations are the "result" component of a trigger and describe the effects of the trigger occurring. In practice, they are very similar to triggers, however. They include a name, description, an optional set of requirements and an optional set of parameters. Here, the requirements represent the parameters of the object of the action. For example, an adaptation that moves an entity must declare which entity to move and to what location. The parameters represent changes to the environmental setting. For example, an adaptation that wants to change the time-of-day must specify that new time.

Again, XML is a good candidate as it provides an easy mechanism for optional information. Figure 8 shows two examples of adaptations; one that includes a requirements list and one that alters parameters:

```
<adaptation type="4003">
   <name>Move Entity</name>
   <description>Causes entity to move to a given position</description>
   <imagefilename>moveEntity.png</imagefilename>
   <requirements>
      <requirement id="EntityRef"/>
      <requirement id="Position"/>
   </requirements>
</adaptation>

<adaptation type="4006">
   <name>Make Daylight</name>
   <description>Changes time of day to daytime</description>
   <imagefilename>makeDaylight.png</imagefilename>
   <parameters>
      <parameter name="tod">1500</parameter>
   </parameters>
</adaptation>
```

Figure 8: Two Example Adaptations

Vignettes

Vignettes consist of a name, description, additional complexity value, a list of training objectives that they support (exactly like the baselines) and a tree of facets. The facet tree is made up of augmentations, triggers and adaptations. The tree-like fashion allows a powerful mechanism of building up larger structures. For example, an "and" condition can be represented by placing a trigger under another trigger. An "or" condition is represented by placing two triggers side-by-side at the same level in the tree. By expanding this tree, the vignette can become fairly expressive.

Due to the tree nature of vignettes, XML is the perfect representation (and really drove the use of it elsewhere). The facet tree simply refers to previously defined augmentations, triggers and adaptations as nodes within the tree. Figure 9 shows a vignette for moving a target based upon instructor cue (and possibly a second time on a second cue).

```
<vignette type="5006">
   <name>CFF Hostile Near Friendlies</name>
   <description>On the instructor's cue, moves a target entity close to
a friendly unit, then even closer on a second cue</description>
   <complexity>50</complexity>
   <imagefilename>hostileNearFriendlies.png</imagefilename>
   <supports>
      <objective major="INF" minor="FSPT" objective="6302"/>
   </supports>
   <facets>
      <augmentation type="2005"/>
      <trigger type="3004">
         <adaptation type="4003"/>
         <trigger type="3004">
            <adaptation type="4003"/>
         </trigger>
      </trigger>
   </facets>
</vignette>
```

Figure 9: An Example Vignette

Requirements

Even though the facets making up the scenario have been made more computational concrete above, satisfying requirements have still been postponed. To satisfy these computational, they must be represented. In the XML examples above, the requirements are referenced by name (e.g. “Target” or “Position”). In fact, the requirements are *only* referenced by name.

Computationally, these names are mapped to primitive types that will be well known to the system. While this may seem odd, upon inspection one can see that these requirements truly are primitive types within the system being considered. Some are fairly low-level across any domains (both military and civilian simulations will likely be concerned with positions); some are low-level within a given domain (“friendly unit” is well known within a military context). However, this is satisfactory as they do not

change once in existence for a given domain. It is enough to enumerate the possible requirements that will need to be addressed and develop a method for doing so. The exact method used in this work will be reviewed in later sections.

Manual Scenario Generation

Before getting into automating scenario generation, it is useful to review a manual approach. A user first selects the training objectives and complexity desired; ideally, these may also be selected automatically based on a trainee's profile, but they are selected in a manual approach. The user then selects a baseline (which can include environmental augmentations), which sets the initial situation of the exercise. Then, zero or more vignettes are selected. Each facet adds a complexity cost to the total scenario with the system enforcing the desired complexity level. Finally, the user satisfies the requirements of training objective and facet that remain unspecified. Figure 10 shows an example of a scenario (with a single vignette) and how the elements help form a scenario.

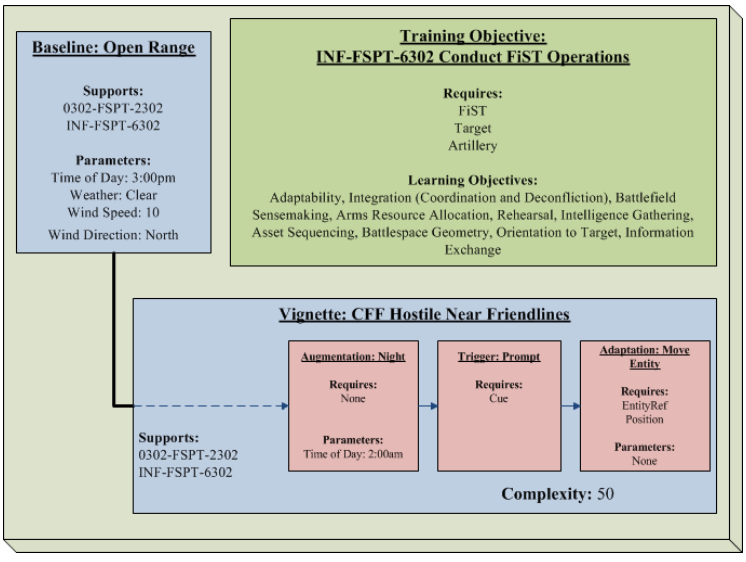


Figure 10: Scenario Example

The goal of an automated approach is to replace many, or all, of these steps. Chapter 2 reviewed some previous methods for creating scenarios and also some aspects from other domains (e.g. interactive storytelling) that are valuable to maintain in generated scenarios. In the next chapter, procedural modeling is reviewed in more depth and Functional L-systems are presented as a solution applying the computational model developed here to automated scenario generation.

CHAPTER FIVE:
PROCEDURAL SCENARIO GENERATION

Given the need for scenario generation mentioned earlier, there has been a large interest in generating such scenarios automatically. Performing the process by hand is a very expensive proposition and causes a lack of scenarios for use in training. Those hand-created scenarios that do exist are re-used and not adapted in any way for an individual trainee.

With the conceptual model defined and translated into computational structures, automatic scenario generation can now be addressed. As seen earlier, past approaches have used seeded, enumerated and heuristic approaches. While all have been valuable efforts, they also have their weaknesses. In this work, an alternative, procedural modeling techniques, is pursued.

Procedural modeling refers to a technique in computer graphics of using a set of rules to create models, textures and/or animations for a scene or part of a scene. It is used when manual creation of the component would be cumbersome or expensive. Procedural rules are stored that can be used to create (or even re-create) the component as needed. A particle system for representing smoke is one example. Rather than modeling a set of spheres by hand to create a smoke plume, it is programmed within a software system and simulated automatically.

Procedural Modeling Process

Procedural modeling has existed since the start of computer graphics. Indeed, the first graphical systems generated everything procedurally with the notion of content-

based systems coming later. First, simple geometry was generated with color and texture following. Indeed, in the 1980s procedural modeling for realistic textures (such as marble) was developed [40]. In addition, in 1989 Pixar's RenderMan system and its shading language is credited with greatly expanding procedural modeling [40]. Developed since 2009, Minecraft is an online independent game that uses a large procedurally generated terrain with various terrain types [42].

The major benefit for modern procedural modeling is known as data amplification [43]. A description of the data to be generated is stored rather than the data itself. Typically, the description is smaller than the data and can be used to generate the data relatively quickly. Sometimes this can be beneficial for memory storage. Moreover, it can also provide a mechanism for generation of similar, yet different, versions of the data. This is a key aspect in our work and will be used in our scenario generation.

A related issue to data amplification is self-similarity. This concept is the basis for many procedural generation techniques. Many things in the world appear self-similar at different scales – either exactly self-similar or so called statistically self-similar [43]. Exactly similar objects look exactly the same when any region is enlarged; statistically similar objects that contain noise appear the same on the average when enlarged. Clouds and branches on a tree are two common examples of self-similar objects.

Procedural Modeling Methods

Over the years many basic approaches have been developed for procedural modeling. These include fractals, L-systems, Shape Grammars and Functional L-

systems. We review each of these methods here before reviewing specific systems related to our approach.

Fractals

Fractals are based on geometric shapes that possess self-similarity. They contain subdivided parts, each of which is a copy of the whole shape. The term fractal was coined by Benoit Mandelbrot [43]. The boundary of the Mandelbrot set is a popular example of a fractal. The "Koch Snowflake" is another popular fractal that begins with a single equilateral triangle with the "middle third" of each side repeatedly replaced with an equilateral "bump" [44].

Fractals are generated in three ways [45]. Escape-time fractals define a recurrence relation in some point-space (the Mandelbrot set is an example). Iterated function systems use a fixed geometric replacement method (the Koch Snowflake being the prime example). Random fractals use stochastic (rather than deterministic) methods that generate objects such as fractal landscapes.

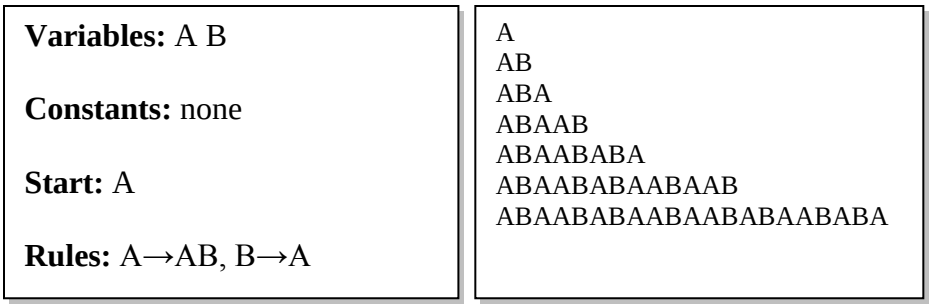
Within nature and virtual environments, fractals represent items such as clouds, plants, river networks and mountain ranges. Lightning, blood vessels and crystals can also be defined using fractals. In addition, fractals have been applied to areas such as analysis of music [46] and seismology [47].

L-systems

Lindenmayer Systems, or L-systems as they are more commonly known, are based on formal grammars [48]. They are often used to model the growth of plants and,

hence, are used to generate virtual plants. L-systems use a recursive definition, which leads to a self-similarity quality and makes them related to fractals. As opposed to formal grammars that operate in a sequential fashion, rewriting just one symbol or substring at each step, L-systems progress from one string to the next by rewriting all variables simultaneously.

L-systems are defined by a set of variables, a set of constants, a start state of the system and a set of production rules. For example, Figure 11 shows Lindenmayer's original system for the growth of algae (reproduced from [49]):



(a) (b)

Figure 11: An Example of an (a) L-system and (b) one string it produces

In order to graphically render the output of L-systems, each alphabet letter must be connected to a drawing action. For example, a letter could mean "move forward", "turn 45 degrees" and such.

Extended L-systems

Parish and Müller have built a rule-based system for creating cities named CityEngine [50]. Their approach is based on what they call Extended L-systems. These

are L-systems with the parameters set by functions rather than built directly into the rules. This provides a capability to flexibly change a parameter without having to re-write a number of rules within the L-system. The steps used in Extended L-systems are as follows:

1. Run the L-system and find the ideal successor. The parameters within the modules of the successor are left unassigned.
2. Call a "globalGoals" function that will set the parameters based on overall global goals. All parameters within the modules are set after this step is complete.
3. Call a "localConstraints" function that will check the parameters against any local constraints within the environment. This function can adjust the parameters or return a "failed" condition if the parameters are not suitable, yet unadjustable within the constraints of the rules or environment.

Their approach first creates road networks, divides the land between roads into lots, creates buildings on the lots and then textures the buildings. Image maps that represent geographical (e.g. elevation maps) and socio-statistical data (e.g. population centers) can be used as input to the system. For example, Figure 12 shows how image maps for water, elevation and population density can feed into the road network generation.

From Parish and Müller [50]

Figure 12: Water, Elevation and Population Density Maps Affect Road Networks

Moreover, CityEngine does not consider all roads equal. The notion of highways and local streets is also supported. Highways connect areas with highly concentrated populations by scanning the population density input map for peaks. Streets cover the areas between highways according to local population density (which gives transportation access to the nearest highway). To find the next population center for a highway, every road-end shoots a number of rays radially within a preset radius. Population at every sample point on the ray is then weighted with the inverse distance to the road-end and summed up. The direction with the largest sum is chosen for continuing the growth and placing the highway.

CityEngine uses a set of rules for creating road networks. These are as follows:

- **Basic rule:** Simply follow population density (older parts of cities)

- **New York rule:** Follows a given global or local angle and maximal length and width of a single block
- **Paris rule:** Highways follow radial tracks around a center
- **San Francisco rule:** Streets and highways follow route of least elevation (roads on different height levels are connected by smaller streets)

After the road network is defined, the areas between the roads are split into blocks and then building lots. This is a relatively straight-forward process given that most lots are convex and rectangular. An image map can be used to define a maximum building height in areas to accomplish design goals such as keeping skyscrapers together in one area.

Building geometry is then created using a stochastic L-system that consists of transformation modules (scale and move), an extrusion module, branching and termination modules, and geometric templates [50]. Textures are then procedurally generated using a grid on each building side as a basis. Location also drives the texture process with doors appearing on the ground level and slight texture enhancements made for realism (such as door frames).

CityEngine is impressive and shows the flexibility of procedural modeling techniques. However, the input it requires (image maps of geographical and socio-economic data) is limiting in the context of automatic scenario generation. The approach can likely be altered, though, and the concept of Extended L-systems that use external functions to set parameters would definitely be useful in future systems.

Shape Grammars

Müller et al. developed a method for procedural creation of buildings based on a notion of shape grammars called CGA Shape [51]. Shape grammars were first used for architecture by Stiny [52]. However, Müller extended the notion by modeling buildings with consistent mass models and focusing on application details such as a concise notation and defining the "most important" rules within a set of rules.

Wonka et al. simplified shape grammars to split grammars, which are based upon set grammars [53]. Split grammars are based on object replacement with basic objects being *split* into multiple terminal objects (or alternatively, replaced by another basic object). CGA Shape is also based upon set grammars with extensions. The grammar defines the replacement of lower detail items as well as rules to add, scale, translate and rotate shapes. Müller argues that while "parallel grammars like L-systems are suited to capture *growth* over time, a sequential application of rules allows for the characterization of *structure*." Therefore, as opposed to the parallel replacement used in L-systems, CGA Shape uses a sequential grammar.

Within CGA Shape, production rules are defined in the form:

id : predecessor : cond → successor : prob

where *id* is a unique identifier for the rule, *predecessor* is a non-terminal that is to be replaced by *successor* and *cond* is an expression that must evaluate to true for the rule to be applied (at which time the rule is selected with probability *prob*). As an example, the rule:

1 : fac(h) : h > 9 → floor(h/3) floor(h/3) floor(h/3) : 1.0

would replace the shape *fac* with three shapes *floor* if the parameter *h* is greater than nine with probability 1.0 (from [51]).

CGA Shape also supports scope rules that use a stack with push and pop operators, which allows the transforming of one object without affecting others. In addition, a split (subdivision) rule exists to split an object into a set of smaller shapes (such as a side of a building into multiple floors), and a repeat rule exists to tile a shape (such as placing multiple windows along one floor). There are also rules for working with 2-D objects to allow operations such as extruding.

One final aspect of CGA Shape is snapping. Since a building is often composed of multiple shapes, grammar rules are included for the creation of invisible snap lines. These snap lines are used by other shapes within the building to snap their geometry to create a better appearance. For example, a skyscraper using tapered sections will still align all of its floors rather than each shape deciding the split of its floors independently.

CGA Shape is fundamentally built upon the concept of shape replacement rather than the L-system concept of string replacement. It should be noted, however, that CGA Shape's major application is the creation of models from imagery and blueprints. The focus is on re-creating actual locations as opposed to creating various buildings with similar qualities.

Functional L-systems

Marvie, Perret and Bouatouch developed a system based on a modified L-system to render building exteriors [54]. Known as FL-systems (or Functional L-systems), they define each component as one of two types of functions. The first, those that do not

return a value, replace a typical L-system terminal symbol (and are known as terminal functions). They are used to *generate* or *modify* the content of an object that is given as a parameter to the function. The second type of function describes those that return a value that contains a parameter and are used to *create* objects. When these functions exist within rule parameters, they are executed and their return values are used as the parameters within the rule.

Fundamentally, each terminal or non-terminal includes a function that is executed to generate necessary components within the rule system. Compare this to the architecture in CityEngine where global and local constraint functions are called. FL-systems call functions at each sub-derivation step whereas CityEngine only calls the constraint functions after a derivation is complete. The FL-system not only controls which rules are to be applied, but can also stop the derivation process associated with the rewriting mechanism based on the function return values.

An important advantage of FL-systems is that they map to scene graphs and object creation and manipulation very easily. Furthermore, FL-systems support an iterative mechanism to generate nodes in the derivation in a breadth-based method (rather than a recursive mechanism that would produce objects in a depth-based manner).

Functional L-systems and Scenario Generation

This work focuses on the use of FL-systems for automated scenario generation. Users will still be prompted for the training objectives to be used and a desired complexity range. After that, however, an automated system will choose a baseline and a set of vignettes to create the scenario.

FL-systems, in particular, are well suited for providing such a system and offer two major advantages. First, the extra power provided by having terminal functions (as opposed to terminal symbols) allows higher complexity decision making by the rule system. Details about the training objectives chosen as well as the trainee profile can be used by the terminal functions in their decision-making processes.

The second advantage is in the terminal functions allowing the postponement of resolving requirements. This allows the basic rule system to be written with fewer rules. The parameters of the requirements can be satisfied within a terminal function.

The limitations of FL-systems include the additional work necessary to author the rule systems and the need to write the terminal functions themselves. However, both limitations are minimal in that each is only performed once per training domain. When another training domain is desired (a rehabilitation scenario, for example), then a new set of rules and terminal functions must be written.

Grammar Representation

In order to use FL-systems for scenario generation, a representation for the rules (grammar) must first be developed. The basic rule structure from CGAShape is used [51]:

id : predecessor : cond → successor : prob

where *id* is a unique identifier for the rule, *predecessor* is a non-terminal that is to be replaced by *successor* and *cond* is an expression that must evaluate to true for the rule to be applied (at which time the rule is selected with probability *prob*).

With the basic structure of the rules set, specifics for the symbols are needed. In order to promote readability, multi-character symbols will be allowed. In order to support parsing more easily, braces will surround the name of the symbol. For example, {SCENARIO} might be used to represent an initial rule. In order to represent non-terminal symbols from terminal functions, case is used. {SCENARIO} would represent a non-terminal symbol while {scenario} would represent a terminal function.

A Simple Example

To illustrate the grammar representation, an example is now reviewed. Consider the set of rules in Figure 13: Simple Example of Grammar Representation.

```
Rule 1:     {SCENARIO}    :    → {TO1}                        : 1.0
Rule 2:     {TO1}         :    → {TARGET}{A}{OBS}             : 1.0
Rule 3:     {A}           :    → {artillery}{POSITION}        : 1.0
Rule 4:     {OBS}         :    → {observer}{POSITION}         : 1.0
Rule 5:     {TARGET}      :    → {tank}{POSITION}             : 0.5
Rule 6:     {TARGET}      :    → {apc}{POSITION}              : 0.5
Rule 7:     {POSITION}    :    → {position}                   : 1.0
```

Figure 13: Simple Example of Grammar Representation

This is a simple set of rules for the creation of a target, an observer of that target and some artillery unit to shoot at that target. Rule 2 lists the basic components needed by Training Objective 1. Rules 3 and 4 have terminal functions that will cause the creation of each respective entity (Rule 7 consolidates the position selection by calling that respective terminal function). Rules 5 and 6 show how probability can add variety by selecting different target types. When the two rules are applicable to rewrite {TARGET}, each rule is considered at the given probability; in this example, there is an

equal probability that the target will be satisfied with either a tank or an armored personnel carrier. Probabilities are assigned by the rule author and can be weighed equally (as in this case), or the choices may be biased, if desired. Obviously, the set of rules can be made much more complex to provide even greater capabilities and variety than this simple example can show.

A More Complex Example

The simple example above does not show off passing parameters to the terminal functions. As written, it would likely place all entities in the same location. For a more complex example, consider the set of rules in Figure 14.

This example demonstrates many of the powerful computational additions that FL-systems provide. In addition, it is a more complete example than the first. Rule 2 demonstrates the selection of a baseline (in this case, there is only one to choose from so it is chosen with probability 1.0). Rules 3 and 8 show examples of training objectives and entity elements, respectively, being satisfied in parallel. Rules 4 to 7 show the "conditional" component restricting the use of the rules (these rules should only be used if the corresponding training objective has been chosen by the user).

Rules 9 to 12 demonstrate parameters being passed into terminal functions. Note that the same terminal function can be re-used simply by passing different parameters. The parameters, in these cases, refer to either known entity types to the scenario generation system or known positional concepts. The positions can either be areas declared as part of the baseline or even computed by a knowledge computational system. For example, Fire Support Teams are typically up on a hill overlooking a valley. These

hills can either be declared as part of the baseline record or could be intelligently determined by a function performing some terrain analysis.

```
 1: {SCENARIO} :                    → {BASELINE}{OBJS}                          : 1.0
 2: {BASELINE} :                    → {baseline}("29Palms")                     : 1.0
 3: {OBJS}     :                    → {TOCFF}{TOCAS}                            : 1.0
 4: {TOCFF}    : selected("TOCFF")  → {FIST}{TARGET}{IDF}                       : 1.0
 5: {TOCFF}    : selected("TOCFF")  → {FIST}{TARGET}{TARGET}{IDF}               : 1.0
 6: {TOCFF}    : selected("TOCFF")  → {FIST}{TARGET}{IDF}{NIGHT}                : 1.0
 7: {TOCAS}    : selected("TOCAS")  → {FIST}{TARGET}{ADA}{AIR}{IDF}             : 1.0
 8: {FIST}     :                    → {FOM}{FOA}{FAC}{FTL}                      : 1.0
 9: {FOM}      :                    → {type}("fom"){position}("fistloc")        : 1.0
10: {FOA}      :                    → {type}("fom"){position}("fistloc")        : 1.0
11: {FAC}      :                    → {type}("fom"){position}("fistloc")        : 1.0
12: {FTL}      :                    → {type}("fom"){position}("fistloc")        : 1.0
13: {TARGET}   :                    → {type}("btr80"){position}("targetloc")    : 0.5
14: {TARGET}   :                    → {type}("bmp2"){position}("targetloc")     : 0.5
15: {IDF}      :                    → {MORTAR}                                  : 0.5
16: {IDF}      :                    → {ART}                                     : 0.5
17: {MORTAR}   :                    → {type}("mortar"){position}("mortarloc")   : 0.5
18: {ART}      :                    → {type}("artillery"){position}("artloc")   : 0.5
19: {ADA}      :                    → {type}("zsu"){position}("adaloc")         : 1.0
20: {AIR}      :                    → {AV8B}                                    : 0.75
21: {AIR}      :                    → {COBRA}                                   : 0.25
22: {AV8B}     :                    → {type}("av8b"){position}("fixedloc")      : 1.0
23: {COBRA}    :                    → {type}("cobra"){position}("rotaryloc")    : 1.0
24: {NIGHT}    :                    → {tod}("0300")                             : 1.0
```

Figure 14: More Complex Example of Grammar Representation

Rules 13 and 14 show scenario variability. These two rules choose, with an equal chance, two different targets that appear differently and could have different weapon ranges, etc. In addition, rules 20 and 21 show further variability. Here, there is an unequal chance of a fixed wing aircraft being chosen over a rotary wing aircraft as an air asset. Each is used differently by the Fire Support Team so this provides slightly different training opportunities. Rule 24 shows an example of an environmental parameter being set.

Analysis

In the second example, rules 8 to 24 provide basic components of all Fire Support Team scenarios. Therefore, these rules would be re-used as support for larger quantities of training objectives was provided. Additional rules of the type seen in rule 2 could be added to support alternate baselines. Furthermore, rules similar to rules 3 to 7 could be added to support other training objectives. Only if additional basic components were necessary (such as friendly ground units represented) would rules similar to rules 8 to 24 be added.

Rules similar to rules 3 to 7 are the equivalent of a user selecting a vignette. When one of these rules is applied, it is equivalent to the user manually selecting a vignette and adding it to the scenario. The right-hand side of the rule roughly represents the scenario facets (augmentations, triggers and adaptations) of a vignette. In addition, the terminal functions are roughly equivalent to satisfying the requirements in the manual approach. They decide the type and other data (e.g. position) much like a user does when satisfying the requirements manually.

The use of probability allows for variations in the scenario. In rules 4 to 7 the probability is used to randomly select one vignette over another. In rules 13 and 14 a target is randomly chosen. By using multiple rules to represent different, but equivalent, decisions, the system provides variation while still maintaining a qualitative equality between different scenarios. If two or more rules are qualitatively equivalent, they will be written together and the probability range split across them. In other words, the rules, themselves, maintain the qualitative equivalence of the generated scenarios.

The parallel nature of L-systems (and FL-systems) allows for consideration of multiple "vignette rules" or in the satisfaction of "requirements." In the former, each rule that represents a vignette can be explored simultaneously. One is then chosen based upon the relative probability. Rules 4 to 6 in the previous example illustrate this. However, some complications can arise as well.

One issue is tracking total scenario complexity. The system must carefully track total complexity so as to avoid the situation where two vignettes contain an appropriate complexity increase but both together would result in a scenario with too high a complexity. Rule 3 in the previous example will consider two training objectives in parallel. If both objectives are selected, this results in four rules being considered in parallel (rules 4 to 7). Three of them (rules 5 to 7) are mutually exclusive based upon matching non-terminals and the probability distribution of each rule. However, rule 4 and the selected rule from among rules 5 to 7 could potentially both apply in parallel. This is essentially a race condition. Therefore, while multiple vignettes can be evaluated in parallel, some control on the decision process is necessary. Rather than encoding this into every rule selection, the system tracks this itself and enforces selection of a single vignette before evaluating a next step. Unfortunately, this is a weakness of the L-system approach to scenario generation. However, this occurs only at the vignette selection stage and the benefits of such an approach still suggest that it works well for scenario generation overall.

Implementation

With the new approach of FL-systems to automated scenario generation complete, an actual implementation was created to verify the design. In addition, having an actual system allows the verification of its ability to create adequate scenarios. The next chapter delves into the details of the implementation.

CHAPTER SIX:
SCENARIO GENERATION FRAMEWORK

With the scenario defined, computational model created and an approach for automated scenario generation completed, this chapter ties everything together.

A Scenario Generation System

As part of validation for this research, the Procedural Yielding Techniques and Heuristics for Automated Generation of Objects within Related and Analogous Scenarios, or PYTHAGORAS, was designed and implemented. However, PYTHAGORAS is not a new scenario generation system in itself. Rather, PYTHAGORAS is a scenario generation *engine*. By "scenario generation engine" we mean a system that provides the common functionalities across all (or more precisely, all conceived of in this research) potential scenario generation systems within a single foundation for all (or at least most) training environment scenarios (much like a game engine provides the common needs of games).

Whether military or another domain, there are many capabilities needed in a scenario generation system. For example, display and selection of training objectives is a function that must exist across any scenario generation system. In addition, support for a graphical user interface and potentially other interfaces (such as three-dimensional rendering) could be included. On the other hand, there are also some features that may be specific for each domain and the ability to support that is also necessary. To address these issues PYTHAGORAS was constructed to have a fundamental architecture of common functionalities coupled with a plug-in architecture for specific domain features.

Plug-in Architecture

The plug-in architecture of PYTHAGORAS allows users to write their own new capabilities to include in their scenario generation system. Furthermore, they could even write a set of plug-ins to create a scenario generation system for their own, new domain. Figure 15 shows a diagram of the PYTHAGORAS architecture with example modules in place for what exists for the CAN-oriented Objective-based Generator of Scenarios (COGS) [55]. COGS will be covered in more detail later in this document (at this point, it is enough to know that it is a specific scenario generation system built upon PYTHAGORAS).

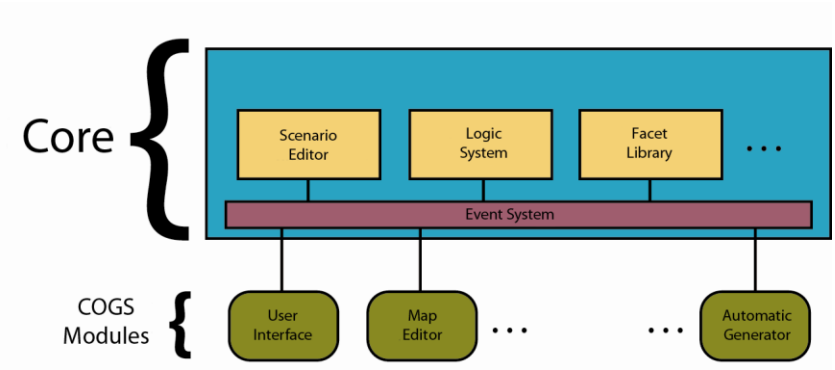


Figure 15: COGS Modules within PYTHAGORAS

As suggested, such an architecture allows other modules to be loaded to essentially create a new scenario generation system. Indeed, PYTHAGORAS supports all sorts of general scenario generation systems. For example, one could build such a system for cognitive rehabilitation where a patient practices making breakfast in a kitchen setting. In this case, friendly units and targets may not be required, but a coffee maker and spoon might be [56]. PYTHAGORAS supports this by allowing a different set of

plug-ins and rules to be loaded; essentially, an entirely new application is created built upon PYTHAGORAS. In addition to providing flexibility, the plug-in architecture also provides the capability not to load a feature if desired. In this manner, building systems to generate scenarios in other domains can be performed at reduced cost and with reduced resource requirements.

Core

The core system ties everything together. It handles the loading and initialization of plug-ins and can provide a common database of key information if desired. The core actually is built to handle multiple threads of plug-ins, with each plug-in assigned to its given thread group. Besides making the code more flexible and easier to implement, the thread system also allows PYTHAGORAS to more easily work on processors with increasing number of cores.

A common "Configuration for PYTHAGORAS Initialization" (or .cpi) file provides the core with instructions for initialization of the system. It includes basic information for the specific application being run on top of PYTHAGORAS as well as a list of plug-ins (with their corresponding threads) to load and initialize. It is a bit of a simplification, but it is this "cpi" file that defines how each PYTHAGORAS application is different from all others.

Message System

In order to allow the core functions and the plug-in modules to communicate, an event system was built. Events can be both issued and received by each component.

Some events are well-known, meaning that all components may need to process these (such as when training objectives are selected) while others may be specific to a subset of modules and all other components will ignore them.

PYTHAGORAS actually contains two different types of messages. The first are passed from plug-in to plug-in. When a plug-in is first initialized, it registers for the types of messages in which it is interested. As of now, registration is only performed by type; however, the system is open to allow registration by other forms (such as by origination point of the messages). When a plug-in issues a message, a copy of it is placed into a queue for the receiving plug-in to retrieve.

The second form of messages used in PYTHAGORAS is sent from a plug-in to the core. These are less used than the first form but are still quite important. For example, the user interface plug-in might issue the "quit" message to indicate to the core that the user wishes to exit the program.

This approach also allows each plug-in to be very loosely coupled. A key feature of this loose coupling is that it provides a very easy method to explore alternative approaches. For example, different plug-ins for handling scenario complexity or automated generation can be implemented and simply loaded at different times in order to do comparison studies between the various approaches.

As discussed earlier, complexity is modeled as a simple value between 0 and 100, inclusive. If a higher fidelity complexity model is desired, the complexity plug-in can simply be re-implemented without affecting the rest of the system. In addition, a plug-in

to explore shape grammars could easily be pursued by switching it for the FL-system plug-in.

Review of Key Plug-ins

Among all the plug-ins in PYTHAGORAS, some are key components required for its functionality. For example, the "gui" plug-in handles all elements associated with the graphical user interface (GUI) and supports dynamic registration of the scenario facets. The GUI plug-in also handles interface issues related to the user satisfying scenario requirements and contains the drawing window for the scenario tree.

The Scenario Editor plug-in handles the tracking of all selected scenario facets (baselines and vignettes) and their relation with each other (e.g. the scenario tree). It is also responsible for the loading and saving of scenarios (both complete and incomplete). It is the organizer of the scenario itself and collects all the data together for output.

The Facet Library plug-in handles reading the facets from an XML file and instantiating them within the system. This includes sending data to the GUI plug-in about each facet. Data is also sent out that details the parameters and requirements for each facet. The Logic System plug-in receives the data about the facets from the Facet Library plug-in and handles tracking all the requirements declared by selected training objectives, baselines and vignettes. It also enforces whether all requirements have been satisfied and, therefore, whether the scenario is ready for exporting.

Authoring

PYTHAGORAS also contains an "authoring" plug-in where the user may select augmentations, triggers and adaptations in order to define a new vignette. Once the vignette tree is built, the complexity is set for the entire vignette and then training objectives supported by the new vignette are selected. Essentially, this is precisely the reverse process (step-wise) of creating a scenario; Facets are selected, then a complexity set and then training objectives chosen. The new vignette is then transmitted to the Facet Library plug-in where it is saved for later use.

As part of authoring, PYTHAGORAS also supports the complexity definition step as a plug-in. This allows various research pursuits in the area of vignette complexity. Different methods for setting the complexity of a vignette can be implemented and simply loaded in place of each other here for evaluation. For example, the complexity could be defined as easily as popping up a GUI element to ask for a value. However, it also could include a task and sub-task review of the vignette itself that defines parameters of a complexity formula [57].

Plug-in for Automated Scenario Generation

Finally, the Generator plug-in handles all the automated generation functions. Here, FL-systems (or Shape Grammars) are used to select baselines and vignettes for addition to the scenario. This plug-in reads and processes the rule system and sends data to the Scenario Editor and Logic System plug-ins based upon the scenario facets selected. Note that the advantages of the messaging system in use here. The generator plug-in

sends the exact same messages that would be sent if the user were performing the selection and requirements satisfaction step manually.

COGS

COGS is the first application built upon PYTHAGORAS. It provides a scenario generation system for Fire Support Teams (FiST) which coordinate indirect fire and close-air support against targets. COGS itself uses the PYTHAGORAS core and its set of "core" plug-ins.

Figure 16 shows an example of COGS in use. The steps to creating a scenario are listed in the bottom left and are "checked off" as each step is completed. The scenario facets (baselines and vignettes) for the chosen training objective are shown on the left-hand side, the facet tree of the current scenario appears in the middle, and the requirements that need definition are shown on the right-hand side.

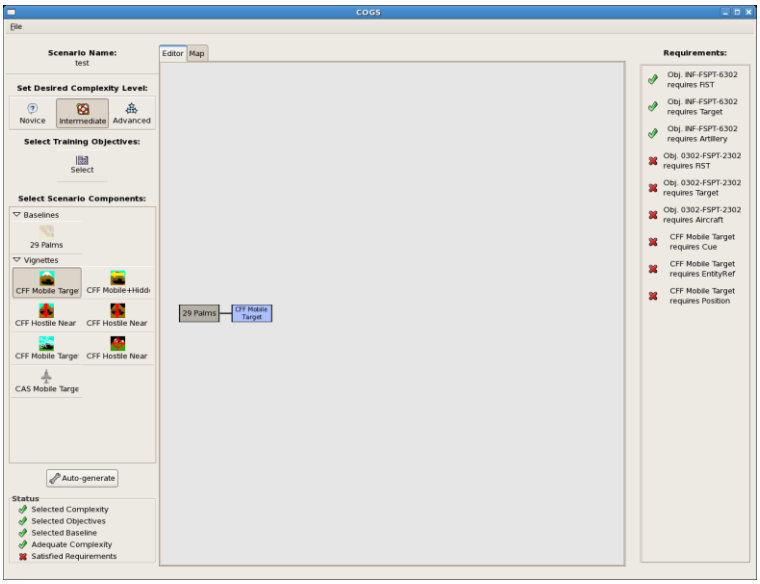


Figure 16: An Example of COGS

COGS provides a good example of the PYTHAGORAS engine. However, the configuration for each of plug-ins is specific to FiST exercises and this configuration is essentially what makes COGS what it is. The configuration file for the Facet Library in COGS has its own list of training objectives, baselines and vignettes. The "requirements," defined by these facets and satisfied by the Logic System in manual mode and the Generator in automatic mode, are the low-level parameters for the FiST domain. For example, "entity type" and "position" are two such requirements.

Does It Work?

COGS is an automated scenario generation system that creates scenarios based around Fire Support Team training objectives. However, while it creates scenarios, they may not be correct or provide training value. An analysis of the scenarios is needed.

CHAPTER SEVEN:
A TURING TEST FOR SCENARIOS

In order to evaluate the scenario generation system, a review by subject matter experts was created. The goal was to create an unbiased comparison between human-generated scenarios and those created by the scenario generation system.

The Turing Test

Turing posed whether computers could perform well in the *imitation game* (a game where two hidden players, one male and one female, are interrogated through only written communication by a third player, who must determine which is the male and which is the female) [58]. In the imitation game, player A intentionally tries to fool the interrogator while player B tries to help. Turing wondered whether a computer could be programmed to play the role of player A. This question has become a key concept in the area of artificial intelligence.

Over time this question has generalized into an interpretation where one of the two players is a computer and one is a human, and the interrogator must identify them accordingly (again, only using written communication). Note that the computer must only sufficiently imitate a human; not necessarily actually think. This thought experiment is now commonly called the Turing Test.

A Scenario Turing Test

Given the goal of the scenario generation system is to produce scenarios of sufficient quality, an evaluation was performed to verify its performance. A Turing Test

approach was used. Given a training objective and complexity level desired, a human subject matter expert creates a scenario. Then, the scenario generation system also creates a scenario for the same training objective and complexity. These two scenarios are then presented to separate, and independent, subject matter experts for review and analysis.

While the goal of this Scenario Turing Test is to have the automated system be indistinguishable from human subject matter experts, additional analysis was also performed. Questions were posed that evaluated the quality of the scenarios (both human-created and system-created) and also that probed at the conceptual understanding of the automated system itself.

For each scenario pair the reviewers were asked whether one of the pair was easily identifiable as created by a human. If so, the reviewer was then asked to identify it and give a measure of level of confidence in that identification. The reviewer was then asked to give an overall assessment (grade) for each of the scenarios in the pair.

The last element of studying the quality of the scenarios asked the reviewers to identify the strongest and weakest points for each scenario. Any omissions were also to be listed and how each scenario might be improved. Finally, the reviewers were asked if any of the omissions might indicate a weakness in how it was generated.

To assess the ability for the automated system to generate relevant scenarios, the reviewers were asked for their feedback on the model of baselines and vignettes. This included how this model may or may not correspond with the practice of professionals in their field. Delving deeper, the reviewers were also asked to give their thoughts on the

vignettes and their representation as a set of triggers and adaptations, including how well it can capture the important features needed in their field.

Expert Review

In the review here, two training objectives were identified. Given the example domain of Fire Support Teams, one objective primarily based upon Indirect Fire (IDF) was identified and also one upon Close Air Support (CAS). Specifically, these were:

1. Integrating, coordinating and de-conflicting close air support, indirect fires and maneuver to attack selected targets.
2. Using doctrinal control procedures successfully to coordinate and control attacks from CAS platforms on a visually marked target.

Both "novice" and "expert" complexity level scenarios were produced for each training objective. This resulted in four pairs of scenarios being evaluated in a 2x2 study. For the human-produced scenarios, scenarios that were recently added to the new Instructional Support System (ISS) of the U.S. Marines Deployable Virtual Training Environment (DVTE) were used. These scenarios have limited distribution to date and the SMEs had not yet seen them. The scenario generation system then was used to produce corresponding scenarios; the output was then re-plotted in the Joint Semi-Automated Forces (JSAF) application so that the map displays would match the human-produced ones.

The four scenario pairs were randomized and presented to five, independent, subject matter experts as a multi-page questionnaire. These experts include a Sergeant who regularly performs these IDF and CAS tasks within the U.S. military, a Lieutenant

Colonel and two Majors who are instructors (at two different locations) within the U.S. military that teach these tasks, and a retired Lieutenant Colonel who is well-versed in these tasks. Of the five, four returned the document (one of the Majors did not).

Analysis

The four subject matter experts performed a thorough review, which can be examined from various directions. As a simple measurement, each reviewer was asked to, literally, grade each scenario. Looking at the data as a whole, the human-generated scenarios resulted in a "grade point average" (GPA) of 2.625 (between a C+ and a B-). This is somewhat surprising since they were based on scenarios in use today; however, the result may be more based on the write-up of the scenarios than the scenario themselves (discussed below). Similarly, the computer-generated scenarios resulted in a GPA of 2.375 (also between a C+ and B-). While lower than the human-generated scenarios, it is within a half grade. More so, given the reasons offered by the reviewers, this difference can likely be reduced.

Looking at the results in the 2x2 study arrangement provides some additional details (see Table 2). The IDF-Novice condition had a much greater spread in the GPA measurements (3.667 for human vs. 2.333 for computer) while the others were much closer. Concerns about the computer-generated scenarios were expressed about the aircraft missing ordnance and sensor details, the lack of a ground maneuver element and the relatively few targets. In contrast, the human scenario contained the ground maneuver element and used the fire elements well in support of that ground maneuver element.

Table 2. GPA Results of 2x2 Study.

	IDF	**CAS**
Novice	*Human:* 3.667 *Computer:* 2.333	*Human:* 2.000 *Computer:* 2.000
Expert	*Human:* 3.083 *Computer:* 3.167	*Human:* 1.750 *Computer:* 2.000

In evaluating the automated system qualitatively, the reviewers most noted that it lacked a ground maneuver element as a part of the scenarios, particularly regarding the Indirect Fire scenarios. While the scenarios generated by the automated system do lack this element, it is largely due to the author's lack of military expertise and not the system itself. It is a straight-forward matter to add creation of this entity to the rules. Doing so will allow the automated system to provide the lacking ground maneuver element.

Regarding the Close Air Support scenarios, both the human-generated and computer-generated scenarios received low marks (GPA of 1.875 for the human-generation scenarios; 2.0 for the computer-generated). In both cases, this had little to do with the placement of the elements, but in the lack of information on sensors and ordnance. The reviewers indicated that both are critical to proper scenario execution as it drives what actions the trainee and can perform (or not perform). For example, an aircraft with laser-guided bombs makes the use of indirect fire unnecessary. Similar to the missing ground maneuver element, additional rules can provide the ordnance and sensors to the appropriate entities. Ultimately, while the computer-generated scenarios do perform as well, or better, than the human-generated scenarios, both sets need improvement.

It is interesting to note that the computer-generated expert scenarios perform better than the corresponding human ones (albeit the scores are very close). The reason is likely the perception that the computer-generated scenarios provided more options to the trainees as far as approaches to take in the exercise. That is likely desirable for an expert-level scenario, but perhaps not for a novice scenario. It very well may be related to an increased complexity as well (where more tasks or events would possibly lead to more options).

Feedback from the reviewers on the automated system approach focused more on suggestions for how the process could be performed rather than on the system itself. This is likely due to their expertise in training and their vision for the goal of offering the best training possible. Comments fall into two categories. First, a more precise call-out of the specific training objective (T&R event in the U.S. Marines) was suggested, including the training *goals*. For example, is the goal to conduct sequential or simultaneous actions? Once this is understood, the elements of the scenario will flow. The automated system uses this technique conceptually but it may need to be made more explicit.

Related to the first category, the second focuses on the ordnance and sensor capabilities of aircraft (already alluded to earlier). Given this domain (Fire Support Teams), the ordnance and sensor capability can drive the scenario much more than any sort of geographic concerns (geography is still a secondary concern, though). It is interesting that both the human and computer scenarios did not make these elements explicit. Since they do not necessarily affect the entity placement, it may have simply been overlooked. However, it is clear that it must be explicit. This leads to a future

research item: not only generating the scenario, but also the write-up of the scenario, complete with training objectives and training goals.

Interestingly, the active-duty military reviewer that was lowest in rank thought more highly, qualitatively, of the computer-generated scenarios and felt they provided a good variety of options (as opposed to only allowing a single course of action). The instructors were less satisfied; the retired Lieutenant Colonel was most critical and focused on command-and-control concerns. The lower rank reviewers were also active certified Joint Terminal Attack Controllers (JTACs) as compared to those focused on instruction.

A final analysis of the scenarios concerns the Scenario Turing Test. Each reviewer was questioned as to which scenario within the pair was human-generated. Across all scenarios, the reviewers correctly chose the human-generated scenario approximately 75% of the time. However, the reason given all but a few times was on the lack of a maneuver element. This is correctable with some additional rules in the automated system. The one other reason identified concerned the write-up of the scenario itself (the phrase "providing over watch" was used in one single description and this alerted a single reviewer).

If the data is analyzed within the 2x2 study arrangement, a number of interesting results are available as well (see Table 3). The CAS scenarios were all identified correctly and with relatively high confidence levels for the most part. Based upon comments, the reviewers indicated real world range specifics as the primary factor in their identification. With improved terminal functions in the automated system (i.e.,

using better metrics for determining positions of entities), these specifics can be improved.

Table 3. Scenario Turing Test Results from 2x2 Study.

	IDF	**CAS**
Novice	*% Correct:* 66% *Avg. Confidence:* 82% *O/U*: 0.15	*% Correct:* 100% *Avg. Confidence:* 63% *O/U*: -0.38
Expert	*% Correct:* 33% *Avg. Confidence:* 63% *O/U*: 0.30	*% Correct:* 100% *Avg. Confidence:* 85% *O/U*: -0.15

Within the Indirect Fire scenarios, the ability to identify the scenario as being produced by a human vs. computer appears to follow the GPA grades as well. In the IDF-Novice condition, the human-generated scenario scores much higher but it is also identified at high confidence levels. In the IDF-Expert condition, the confidence levels are down and the computer-generated scenario outscores the human one.

Weber and Brewer looked at the issue of calibrating confidence and accuracy data [59]. One metric suggested in their work is an over/underconfidence metric that attempts to measure the reviewer's response with more or less confidence than the accuracy of their response dictates (it is defined as the difference between mean confidence and mean accuracy). The metric ranges from -1 (meaning complete underconfidence) to +1 (meaning complete overconfidence).

Looking at the O/U results in Table 3, a few trends exist. The identifications of the IDF scenarios were judged with slightly overconfidence while the CAS ones were slightly under. This may be likely due to the IDF scenarios missing ground maneuver

elements on the system-generated scenarios while both sets of CAS scenarios had issues identified. Therefore, there were more obvious signs to identify the IDF scenarios (although the metric does show a slight overconfidence as well). The CAS scenarios were identified with underconfidence which may show the decision coming down to more of a guess (albeit an educated one). Some of the comments connected with the measures indicate this as well. Overall, the metric is fairly reasonable; a score of zero being perfect, the reviewers got within 0.38 (absolute value) in the worst case.

While the global look at the data shows the automated approach to perform satisfactorily, looking at the 2x2 study provides some interesting results. Furthermore, evidence at the possibilities of the approach begins to show. Some scenarios were satisfactory with the reviewers and outscored the corresponding human ones. However, others show the lacking elements of the current rules and how they need to be improved.

Summary

The Scenario Turing Test provides a compelling review of the scenarios generated by the automated system. While the reviewers were not fooled in many cases about which scenarios were human-generated, the causes expressed are easily addressable. While the number of reviewers was limited, the grades assigned to each set of scenarios are competitive, illustrating that an automated approach to generate relevant scenarios has potential. In addition, the reviewers provided very important feedback (some of which also applies to the human-generated scenarios) that will help drive future scenario generation effort.

CHAPTER EIGHT:
CONCLUSION AND DISCUSSION

This dissertation explored the notion of automatic scenario generation. In most cases, current training tends to re-use a small library of existing libraries over and over again. The goal in this work was to create, using procedural techniques, qualitatively similar, yet still different, scenarios.

Contributions

Six major contributions were presented that move scenario generation and training forward.

1. A conceptual model of scenarios built around training objectives (and learning objectives), complexity, baselines and vignettes was created. The model allows for elements of the scenarios to be conceptualized and built into "building blocks" for the scenario.
2. A computational model to represent scenarios and scenario facets, built around XML, was also developed. Having a concrete representation of the conceptual model is necessary in order for a computer to have any chance of actually creating a scenario.
3. Procedural modeling techniques, including Functional L-systems, were shown to be appropriate and effective for scenario generation. The addition of terminal functions gives a computational increase in power that is well-suited to the decisions that need to be made by such a system. Parameters can be set and requirements satisfied. The parallel nature of

FL-systems is useful, but can also cause some issues during the vignette selection stage.

4. A generic engine for scenario creation, PYTHAGORAS, was built. The use of a plug-in architecture for the engine allows the relatively simple creation of other scenario generation systems for other domains. In addition, common aspects of scenario generation systems can be shared and re-used.
5. A first system, COGS, was built on top of the engine to explore the automatic creation of scenarios for Fire Support Teams. The system support both manual and automatic methods, which allows instructors to override the automated system, if desired. COGS allowed the exploration of the basic concepts and exercised the concepts above to illustrate they also work in practice.
6. A scenario "Turing Test" was created and used to analyze the scenarios automatically created by the system and, ultimately, the system itself. Being able to create scenarios at all is not enough. The scenarios must be on par with human-created scenarios and be acceptable by subject matter experts. The test asked reviewers to compare human-generated scenarios with system-generated scenarios with the goal of them being indistinguishable.

Review

How does this work compare to previous works and how well does it satisfy the approach for scenario-based training? MSDL used an XML approach but it was very much tied to military scenarios. The approach taken in representing the scenario facets in this thesis generalizes to multiple domains (military and civilian). By restricting the computational model to more generic concepts (e.g., "Entity") that have parameters rather than a more specific tag (e.g., "Tank"), other domains for training are possible.

The approach taken in this work also leverages the best lessons learned from past work. The building blocks (scenario facets) follow a similar approach taken by RRLOE and ISAT, allowing for pre-approval of concrete items by subject matter experts (which simply will enhance acceptance and use). In addition, the approach allows for a model of scenario complexity that is both concrete and manageable. Each facet contributes to the total scenario complexity and can be measured accordingly.

Regarding leveraging the training domain (such as in the work by Pffefferman), the work described here does not make direct use of such knowledge. However, doing so is a better approach in that the domain knowledge is leveraged in the rule authoring within the FL-systems rather than deeply within the system itself. The rule system provides an abstract layer above the software for representing and using such intimate knowledge. This further generalizes the software approach taken.

Variety of scenarios is provided through randomization, similar to the approach by Di Domenica et al. By including random probabilities within the rule definitions of the FL-system, various scenarios can be created. However, qualitatively equivalent rules

support the need for creating qualitatively similar scenarios (while still providing for variety). The parallel nature of FL-systems also allows for the consideration of multiple vignettes (further supporting variety).

In order to support improved training, the domain ontology approach of FEAST is leveraged into learning objectives stored with the training objectives. The learning objectives are truly the tasks being trained and tracking such objectives (and potentially including metrics to measure performance of them) is important to support improved adaptive training. The approach taken in the XML files employed here allows for learning objectives for various training domains (both military and civilian) to be stored flexibly and leveraged into trainee profile data for future considerations in training tasks.

Interactive storytelling focuses on driving events during an exercise to gain a particular experience for the user. While this is closer to during-exercise scenario adaptation, the trigger-based approach within the vignettes allows for this flexibility in a pre-planned sense. Triggers support both pre-conditions and persistent pre-conditions. Ultimately, however, the approaches used in interactive storytelling will be most valuable in work concerning dynamic scenario adaptation.

The use of Functional L-systems provides a system with the necessary expressive power for evaluating scenario complexity, tracking parameters necessary for selection of scenario baselines and vignettes, and satisfying their requirements. The use of terminal functions, in particular, allows higher-level reasoning at each stage, including checking the scenario itself and looking up aspects of the trainee's profile. Indeed, this additional computational capability can provide additional expressive power to past procedural

modeling work as well. For example, the Parish and Müller CityEngine work could leverage terminal functions as opposed to global and local constraint functions. As with all approaches, however, some authoring (in this case, rules and terminal functions) is necessary.

Regarding the components leading to improved scenario-based training, the approach taken in this work satisfies four of them and supports the fifth. The vignettes, themselves, store the embedded triggers necessary while the training objectives link in the clearly-defined goals (it should be noted, however, that these goals should be expressed within the mission brief as well). As alluded to previously, the randomness of the FL-system provides the necessary approach to providing a variety of qualitatively similar scenarios. In addition, complexity is supported through tracking it across the scenario as within each scenario facet. Regarding psychological fidelity, the FL-system allows for the creation of realistic scenarios although this is dependent on the rule author as well as the simulators actually in use.

Closing the Loop

Recall that experts make decisions by leveraging a repository of experiences and use that collection to compare situations, which suggests that expertise depends upon exposure to a varied set of experiences [10]. Multiple, varied scenarios help trainees generalize their understanding and to be able to adapt it to new situations [8]. Varied scenarios allow trainees to try different courses of action within a single scenario and also to practice an intended course of action across different scenarios [9]. In addition,

scaffolding theory promotes learning by providing supports initially, which are then slowly removed as trainees develop learning strategies on their own [60].

Due to these notions, when creating an automatic scenario generator, the use of what was learned in previous exercises is important as a basis for the next scenario. For example, if a trainee makes a particular mistake, the next scenario may want to focus more on that task, or it may want to provide additional support for that training goal.

This approach "closes" the loop on the training sequence and creates an adaptive automatic scenario generator. The results of the After Action Review (AAR) can be fed into the scenario generation system and could result in alterations to the rules used by the procedural modeling system. Figure 17 shows the new training sequence with the dashed line representing the "closing of the loop" in data flow.

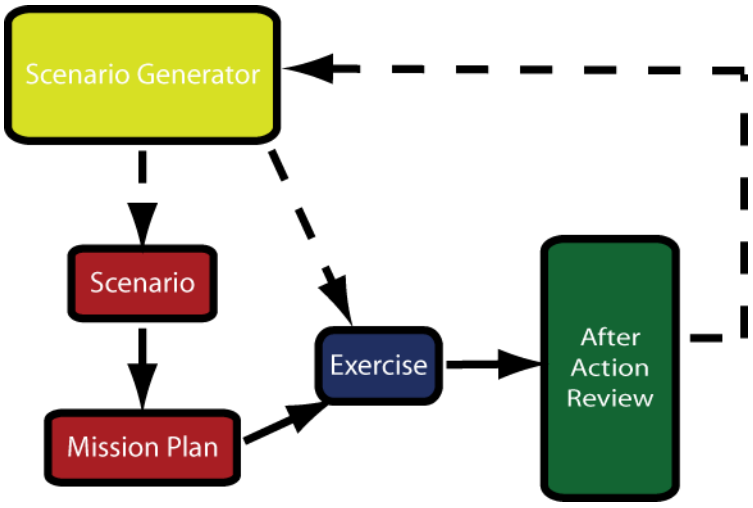


Figure 17: Training Sequence with Automatic Scenario Generation.

The automatic scenario generator now feeds the exercise with the database, entity placement and entity scripting. It also generates the scenario that is given to the trainee(s) so that a plan can be developed. The scenario generator is adaptive based on the data from the after action review that is fed into the trainee profile.

Additional Testing

While the system presented in this dissertation has a scholarly basis and has shown potential, additional testing should still be performed. The initial expert review was focused on feedback of the basic approach so it had limited participation. However, the Scenario Turing Test can be repeated using a larger audience with the initial issues addressed (lacking ground maneuver element, ordnance and sensors). In addition, the scenario size itself (4 types of scenarios; IDF vs. CAS and Novice vs. Expert) could be expanded as well. There are a multitude of possible training objectives and a larger quantity of complexity levels could be used.

A number of other interesting alterations are also possible. For example, using scenarios created by novices may provide useful results by illustrating important issues that may be common mistakes. Review by experts from another area might also provide an interesting alternative perspective.

Other Scenario Elements

This work has focused on scenario generation using simple selection of baselines and vignettes (and satisfying each facet's requirements). There are actually a large number of elements of a scenario including the terrain, buildings, object placement and

behaviors. Output from after action review can also drastically help drive the scenario generation for training process. In this section, each is reviewed as future explorations for automatic scenario generation. These elements could be subjects of many research efforts; moreover, each can have a direct impact on scenario generation and training and, therefore, the topics are very ripe for such pursuits.

Terrain

The generation of terrain could also use a procedural approach and work exists that have used such an approach [42][61][62][63][64]. The key element will be the necessary control to drive the generation as needed. An urban scenario might need a relatively level area for a town and city and will likely be near a river. However, a "call for fire" scenario would likely be away from population centers (although urban "close air support" is becoming an area of interest). Roads and other culture are also a consideration.

Buildings

When it comes to building exteriors, the use of shape grammars is very effective and provides good control. One issue, however, is in the generation of building interiors. Only a few works in this area have been published and none have the control necessary for an automatic scenario generator [65][66].

Object Placement

Objects within a scenario also need to be generated. They can be placed throughout the terrain and also represent furniture inside buildings. Scenarios built

around empty rooms are not effective training for many skills. However, when procedurally placing furniture, some concept of the room being built is required to be understood by the rules being used. In a living room, the couch should face the television and not face right up against the wall, for example. In addition, the concept of proper spacing also needs to be incorporated (you do not want the couch completely preventing people from getting to the other half of the room).

Object Generation

A related notion for objects is in object generation. In other words, procedural generation of objects could also be performed. Within a building, the furniture itself could be procedurally generated rather than a model library used. This would allow objects to be created that fit into a given culture.

Behaviors

While entity placement has its issues, scripting the computer-generated entities will be challenging on its own. This element has largely been ignored in this work. However, a number of behaviors can be procedurally suggested (such as a civilian attacking unexpectedly or maybe falling ill suddenly); feeding them to the system simulating those entities will be an issue, though. The scripting could be generated in an XML-based file that can be run through a translator to an appropriate simulation system (e.g. agent-based system).

Textual Description

The final step in the automatic scenario generation system is a textual description of the scenario suitable for distribution to the trainee(s). While this may seem a bit out of place, it is the final step in having an automated scenario system for training. Some form of template can likely be used in which the system can fill in necessary information.

After Action Review Analysis

While not an element to be generated, a final piece that could be added to improve the scenario generation system is to better use analysis from previous exercises to drive generation of a scenario. The current system relies on scenario complexity to drive the creation of a scenario. It is assumed that the trainee's past performance will be used in selecting the requested complexity. However, the system could be better tuned. If a military infantry squad routinely has poor rear security, the scenario could be adjusted to help train the unit to overcome such a deficiency (perhaps by altering the opposition entity placement accordingly).

As mentioned at the start of the chapter, this analysis and its resulting data is what "closes the loop" on the training cycle. By completing this feedback loop, training systems improve along with the trainees. They adapt as the trainee progresses.

Adaptive Training

Adaptive training avoids the "one size fits all" model that typically exists. Scenarios can be created that fulfill a specific trainee's needs. This dissertation starts down the path to creating a computational approach to adaptive training. Scenarios,

adapted to the trainee(s), are built using the procedural Functional L-systems and based upon training objectives and complexity. Additional elements such as those mentioned in this chapter can be added.

Improving complexity measures will further add to better adaptive training. While the concept of "complexity" is more objective than "difficulty," scoring each baseline and vignette to assign them complexity values is not a trivial activity. The number of sub-tasks within the activity is a factor; however, a notion of sub-task coordination is also one. An activity with many sub-tasks required to be completed in parallel is likely more complex than one with sub-tasks performed serially. However, cannot an "expert" load balance better than a "novice?" Clearly, additional study on complexity is necessary.

In addition to scenario generation, adapting the scenario during the training exercise will further push forward intelligent, adaptive training. Whether due to performance (good or bad) or functional problems (e.g., getting the aircraft shot down), scenarios can adapt to enhance the effectiveness of the training for the trainees.

There is a very old notion that you should not train specifically for the test [1]. Pre-exercise scenario generation and during-exercise scenario adaptation are steps to address that notion.

APPENDIX A:
SCENARIO TURING TEST QUESTIONNAIRE

Reviewer: _____

Thank you for agreeing to review scenarios! In this document, four pairs of scenarios are presented. Within each pairing, one is created by a subject-matter expert and one is created by a computer system. They are not identified in any way, however (e.g. you will not be told which is created by the subject-matter expert and which is created by a computer system).

The computer system uses a notion of a scenario created from a "baseline" and a set of "vignettes." The baseline includes a terrain selection and assumes essentially perfect environmental conditions (clear skies, high noon). The vignettes are then selected to add complexity to the scenario until the scenario reaches a desired level (novice, intermediate, advanced). For example, a vignette could add an additional target, an enemy air defense or alter the time-of-day to nighttime.

For this review, you will be presented with two scenarios of a similar complexity that both should address the given training objective. Questions regarding the two scenarios are then posed and we greatly appreciate your responses! Finally, at the very end we ask a couple of overall conceptual questions and we would also appreciate your response to these.

Please answer each question by entering your reply into the box after each question (you can either edit directly within Microsoft Word, or feel free to print the document and handwrite your answers). Your responses will be kept anonymous to all except for Mr. Glenn Martin, Senior Research Scientist & Lab Director at the University of Central Florida's Institute for Simulation & Training, who will be receiving the responses.
When you are done, please either e-mail the completed document to martin@ist.ucf.edu or fax it to Mr. Glenn Martin at (407) 882-1319. Again, many thanks for taking your time and helping out! It really does help us make better training tools!

Scenario A1

Training Objective: Integration, coordination and de-confliction of close air support, indirect fires and maneuver to attack selected targets.

Task: Develop and execute a company-level fire support plan integrating IDF, fixed-wing CAS and rotary-wing CAS.

Instructions: Once the scenario starts, the FiST will conduct its priority of work. The objective is to develop and/or execute a fire support plan that supports the ground scheme of maneuver, integrating all indirect and aviation fires. Suppression of enemy air defenses (SEAD) should be employed when appropriate.

Scenario:

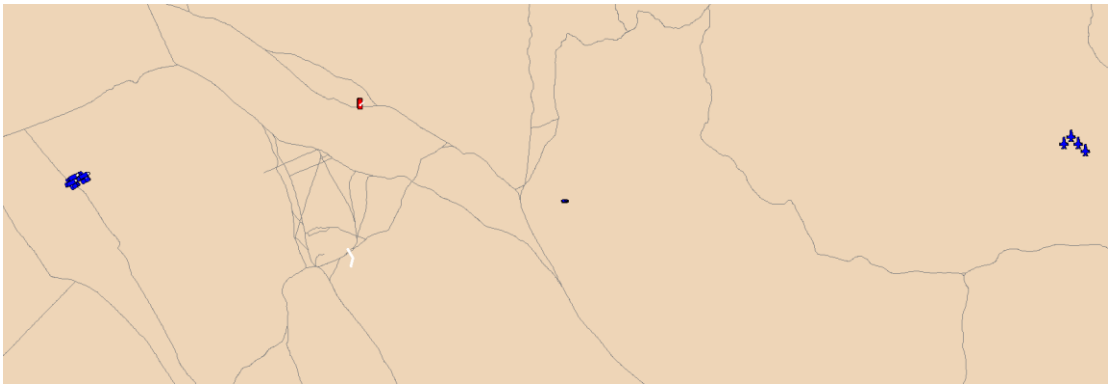
Situation: The Company is conducting a movement to contact up the Quackenbush and has identified an enemy Mech to its front.

Friendly Forces:

FiST: NU 744 107
Artillery: A Battery, NU 596 114
Air Support: Section of F/A-18s with 1xGBU 16 and 3xMk 83 per aircraft

Enemy Forces:

BMP-2: vicinity NU 682 137
Enemy Air Defense: ZSU 23/4 co-located with Armor



Scenario A2

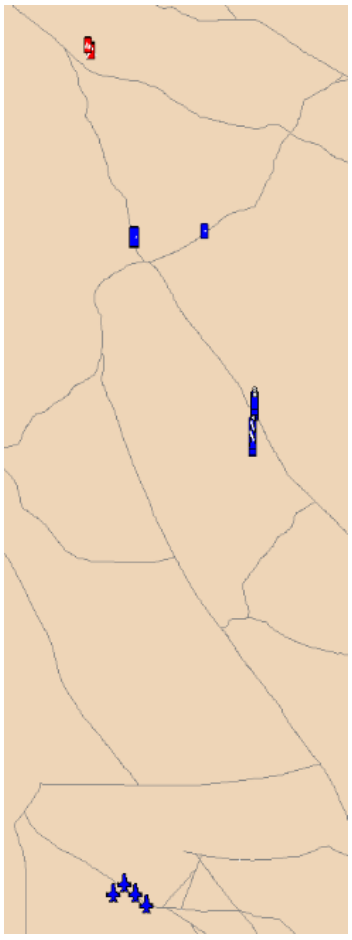
Training Objective: Integration, coordination and de-confliction of close air support, indirect fires and maneuver to attack selected targets.

Task: Develop and execute a company-level fire support plan integrating IDF, fixed-wing CAS and rotary-wing CAS.

Instructions: Once the scenario starts, the FiST will conduct its priority of work. The objective is to develop and/or execute a fire support plan that supports the ground scheme of maneuver, integrating all indirect and aviation fires. Suppression of enemy air defenses (SEAD) should be employed when appropriate.

Scenario:

Situation: The Company is conducting a movement to contact up the Quackenbush and has identified an enemy Mech platoon to its front.



Friendly Forces:

FiST: NU 669 092
Artillery: A Battery, NU 691 061
81mm Mortars: NU 681 094
Company Lead Trace: NU 667 093
Air Support: Section of F/A-18s with 1xGBU 16 and 3xMk 83 per aircraft

Enemy Forces:

Armor Platoon (3xBMP 1/AT-3): vicinity NU 658 130
Enemy Air Defenses: SA-14s co-located with Armor Platoon

Questions Regarding Scenarios A1 & A2:

Please discuss your thoughts on the pairs of scenarios that you reviewed.

1. As we informed you at the start, one of each pair of scenarios was generated by a human, and one by our system. In each case, was one of them easily identified as the human-generated scenario? If so, which one? What is your level of confidence in your identification (e. g. 90% sure; 99% sure; where 50% would mean you feel that you're totally guessing).

2. What is your overall assessment of the relative quality of the two scenarios in each pair? E. g. "I would give A1 an A-, and A2 a D+". If you prefer a numeric scale, then use A=4.0, B=3.0, C=2.0, D=1.0 and F=0.

3. For each scenario, what are its strongest and weakest points? Were there any obvious omissions that seemed to you to clearly indicate some weakness in the process by which it was generated? What were those omissions and how could the scenario be improved?

Scenario B1

Training Objective: Integration, coordination and de-confliction of close air support, indirect fires and maneuver to attack selected targets.

Task: Develop and execute a company-level fire support plan integrating IDF, fixed-wing CAS and rotary-wing CAS.

Instructions: Once the scenario starts, the FiST will conduct its priority of work. The objective is to develop and/or execute a fire support plan that supports the ground scheme of maneuver, integrating all indirect and aviation fires. Suppression of enemy air defenses (SEAD) should be employed when appropriate.

Scenario:

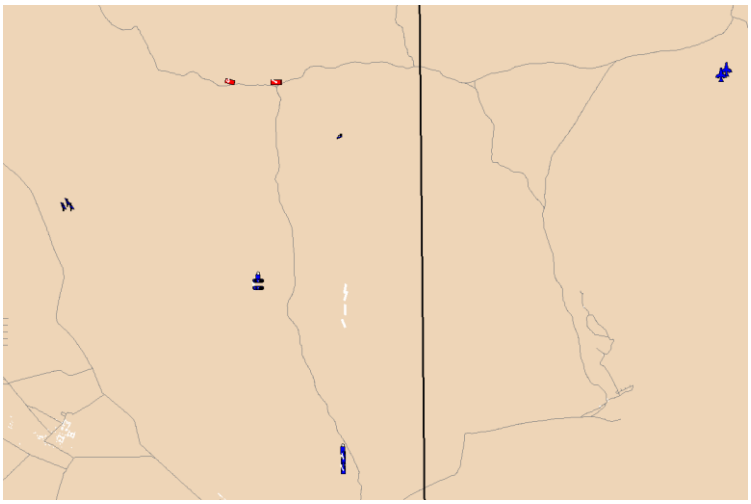
Situation: The Company is conducting an attack up the Delta corridor.

Friendly Forces:

FiST: NU 888 066
Artillery: A Battery, NT 890 945
81mm Mortars: NU 858 011
Air Support: Section of AH-1Ws holding at CP ROME with 2xHellfire, 2xTOW rockets and guns (per aircraft). Section of AV-8Bs holding at CP HONDA with 1xGBU-12 and 3xMk-82s

Enemy Forces:

Two mechanized platoons (6 BMP-2s): vicinity NU 865 087
Enemy Air Defense: ZSU 23/4 located vicinity NU 847 087



Scenario B2

Training Objective: Integration, coordination and de-confliction of close air support, indirect fires and maneuver to attack selected targets.

Task: Develop and execute a company-level fire support plan integrating IDF, fixed-wing CAS and rotary-wing CAS.

Instructions: Once the scenario starts, the FiST will conduct its priority of work. The objective is to develop and/or execute a fire support plan that supports the ground scheme of maneuver, integrating all indirect and aviation fires. Suppression of enemy air defenses (SEAD) should be employed when appropriate.

Scenario:

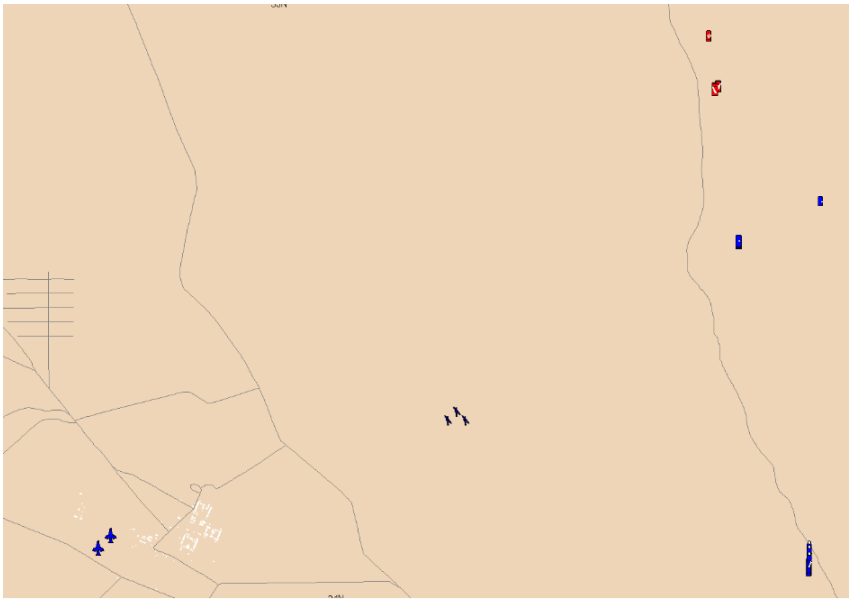
Situation: The Company is conducting an attack up the Delta corridor.

Friendly Forces:

FiST: NT 867 997
Artillery: A Battery, NT 890 950
81mm Mortars: NU 892 012
Company Lead Trace: NU 878 005
Air Support: Section of AH-1Ws holding at CP ATHENS with 2xHellfire, 2xTOW rockets and guns (per aircraft). Section of AV-8Bs holding at CP MAZDA with 1xGBU-12 and 3xMk-82s

Enemy Forces:

Two mechanized platoons (6 BMP-1s with AT-3s): vicinity NU 874 031
Enemy Air Defense: SA-13 located vicinity NU 873 040



Questions Regarding Scenarios B1 & B2:

Please discuss your thoughts on the pairs of scenarios that you reviewed.

1. As we informed you at the start, one of each pair of scenarios was generated by a human, and one by our system. In each case, was one of them easily identified as the human-generated scenario? If so, which one? What is your level of confidence in your identification (e. g. 90% sure; 99% sure; where 50% would mean you feel that you're totally guessing).

2. What is your overall assessment of the relative quality of the two scenarios in each pair? E. g. "I would give A1 an A-, and A2 a D+". If you prefer a numeric scale, then use A=4.0, B=3.0, C=2.0, D=1.0 and F=0.

3. For each scenario, what are its strongest and weakest points? Were there any obvious omissions that seemed to you to clearly indicate some weakness in the process by which it was generated? What were those omissions and how could the scenario be improved?

Scenario C1

Training Objective: Using doctrinal control procedures successfully coordinate and control attacks from CAS platforms on a visually marked target.

Task: Conduct terminal attack control with simulated fixed-wing aircraft in a permissive environment on visually marked targets.

Instructions: Control a simulated section of fixed-wing aircraft in a permissive threat environment. Simulated indirect marking rounds shall be used. Two Type I terminal attack controls required for completion.

Scenario:

Situation: The Company has selected targets to be taken out with air power in the Quackenbush area. Only Type I control is authorized.

Friendly Forces:

FiST: NU 642 116
Artillery: A Battery, NU 649 067
81mm Mortars: NU 649 097
Air Support: Section of FA-18Cs (call sign "Lightning 01 and Lightning 02") is located in vicinity of IP Ford

Enemy Forces:

2 BTR-80s: vicinity
NU 676 115

Scenario C2

Training Objective: Using doctrinal control procedures successfully coordinate and control attacks from CAS platforms on a visually marked target.

Task: Conduct terminal attack control with simulated fixed-wing aircraft in a permissive environment on visually marked targets.

Instructions: Control a simulated section of fixed-wing aircraft in a permissive threat environment. Simulated indirect marking rounds shall be used. Two Type I terminal attack controls required for completion.

Scenario:

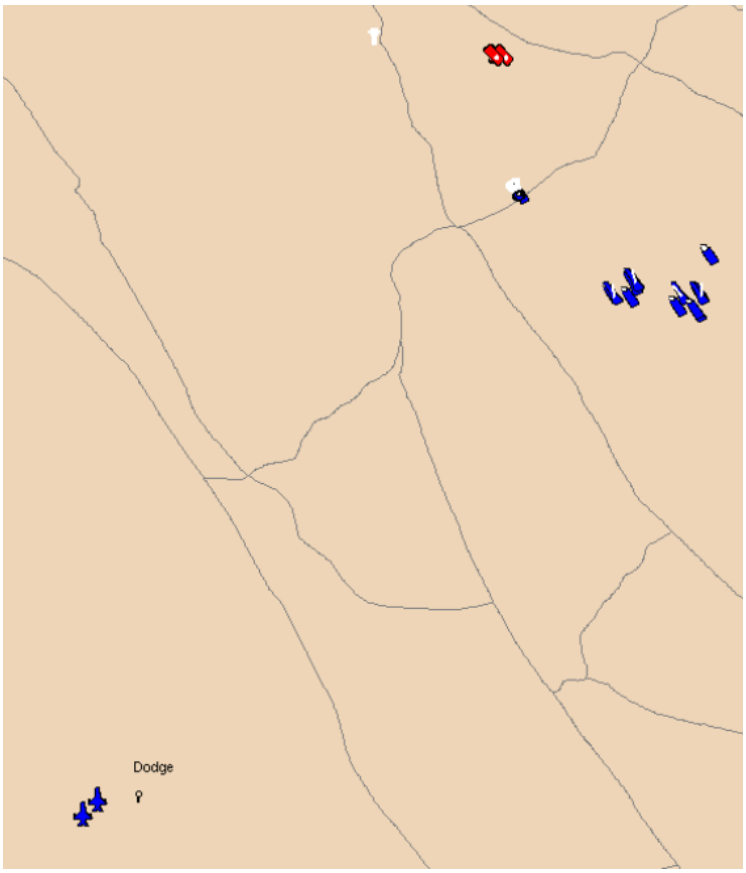
Situation: The Company has selected targets to be taken out with air power in the Quackenbush area. Only Type I control is authorized.

Friendly Forces:

FiST: NU 672 092
Artillery: A Battery, NU 707 075
81mm Mortars: NU 679 093
Air Support: Section of FA-18Cs (call sign "Lightning 01 and Lightning 02") is located in vicinity of IP Dodge

Enemy Forces:

1 BTR-80: vicinity NU 676 115
1 BTR-80 with Dismounted Infantry: vicinity NU 675 114



Questions Regarding Scenarios C1 & C2:

Please discuss your thoughts on the pairs of scenarios that you reviewed.

1. As we informed you at the start, one of each pair of scenarios was generated by a human, and one by our system. In each case, was one of them easily identified as the human-generated scenario? If so, which one? What is your level of confidence in your identification (e. g. 90% sure; 99% sure; where 50% would mean you feel that you're totally guessing).

2. What is your overall assessment of the relative quality of the two scenarios in each pair? E. g. "I would give A1 an A-, and A2 a D+". If you prefer a numeric scale, then use A=4.0, B=3.0, C=2.0, D=1.0 and F=0.

3. For each scenario, what are its strongest and weakest points? Were there any obvious omissions that seemed to you to clearly indicate some weakness in the process by which it was generated? What were those omissions and how could the scenario be improved?

Scenario D1

Training Objective: Using doctrinal control procedures successfully coordinate and control attacks from CAS platforms on a visually marked target.

Task: Conduct terminal attack control with simulated aircraft in a restrictive environment on a marked target while employing interrupted or non-standard SEAD.

Instructions: Control a simulated section of fixed-wing and/or rotary-wing aircraft in a restrictive threat environment. Coordinate interrupted or non-standard SEAD with a surface indirect fire asset. Two Type I terminal attack controls required for completion.

Scenario:

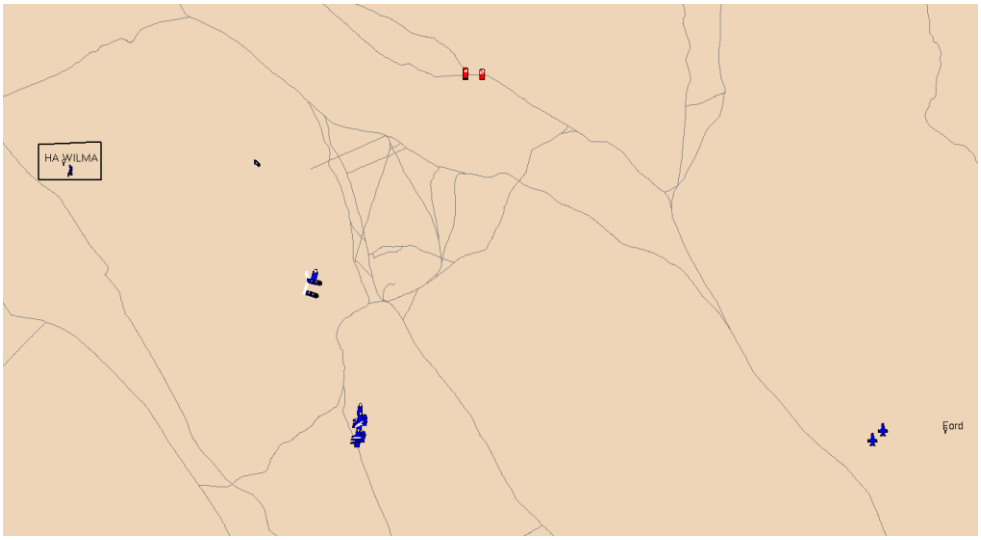
Situation: The Company has selected targets to be taken out with air power in the Quackenbush area. Only Type I control is authorized.

Friendly Forces:

FiST: NU 631 117
Artillery: A Battery, NU 663 060
81mm Mortars: NU 653 091
Air Support: Section of FA-18Cs (call sign "Lightning 01 and Lightning 02") is located in vicinity of IP Ford, and 1 AH-1W (call sign "Rattlesnake 01") is located in HA Wilma.

Enemy Forces:

1 BTR-80 Platoon: located on road vicinity NU 685 145
1 ZSU 23/4: located near road vicinity NU 685 143



Scenario D2

Training Objective: Using doctrinal control procedures successfully coordinate and control attacks from CAS platforms on a visually marked target.

Task: Conduct terminal attack control with simulated aircraft in a restrictive environment on a marked target while employing interrupted or non-standard SEAD.

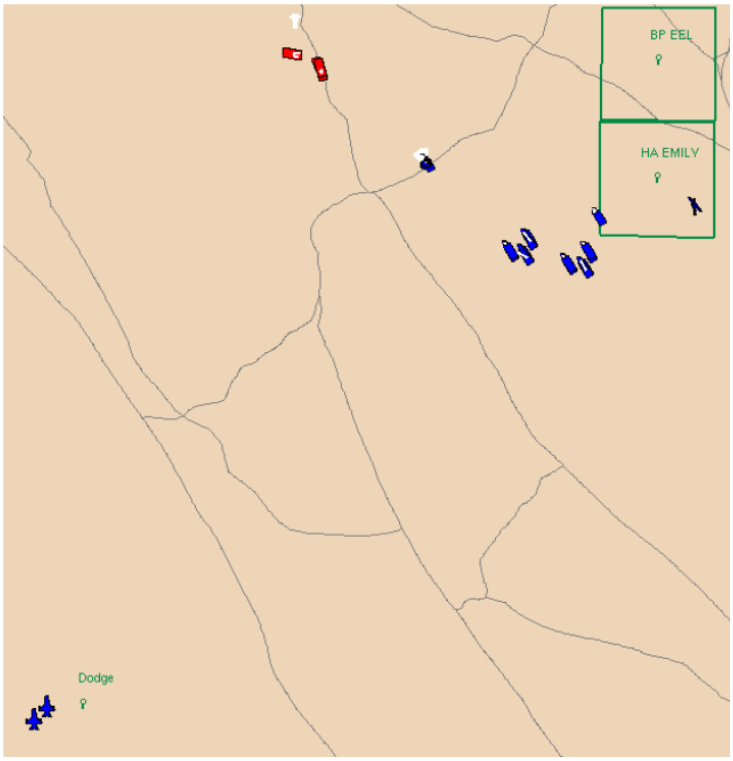
Instructions: Control a simulated section of fixed-wing and/or rotary-wing aircraft in a restrictive threat environment. Coordinate interrupted or non-standard SEAD with a surface indirect fire asset. Two Type I terminal attack controls required for completion.

Scenario:

Situation: The Company has selected targets to be taken out with air power in the Quackenbush area. Only Type I control is authorized.

Friendly Forces:

FiST: NU 672 092
Artillery: A Battery, NU 707 075
81mm Mortars: NU 679 093
Air Support: Section of FA-18Cs (call sign "Lightning 01 and Lightning 02") is located in vicinity of IP Dodge, and 1 AH-1W (call sign "Viper 01") is located in HA Emily.



Enemy Forces:

1 BTR-80 Platoon: located on road vicinity NU 660 109
1 ZSU 23/4: located on hill (providing over watch) vicinity NU 665 112

Questions Regarding Scenarios D1 & D2:

Please discuss your thoughts on the pairs of scenarios that you reviewed.

1. As we informed you at the start, one of each pair of scenarios was generated by a human, and one by our system. In each case, was one of them easily identified as the human-generated scenario? If so, which one? What is your level of confidence in your identification (e. g. 90% sure; 99% sure; where 50% would mean you feel that you're totally guessing).

2. What is your overall assessment of the relative quality of the two scenarios in each pair? E. g. "I would give A1 an A-, and A2 a D+". If you prefer a numeric scale, then use A=4.0, B=3.0, C=2.0, D=1.0 and F=0.

3. For each scenario, what are its strongest and weakest points? Were there any obvious omissions that seemed to you to clearly indicate some weakness in the process by which it was generated? What were those omissions and how could the scenario be improved?

Final Questions:

That's the end of the scenario pairs. Please provide some thoughts on the system approach overall.

1. Please discuss your thoughts on the scenario generation model of baselines and vignettes. In what ways does this model correspond with, or differ from, the practice of professionals who generate scenarios? In what ways could this model be improved?

2. Please discuss your thoughts on the vignette representation of sets of triggers and adaptations. Does this representational system accurately and completely capture the corresponding features that are needed for top quality scenario generation? In what ways could our representational system be improved?

That's It!

That's the end of the scenarios and questions! Again, many thanks for taking the time to help out! As mentioned earlier, your responses will be kept anonymous. Please either e-mail the completed document to martin@ist.ucf.edu or fax it to Mr. Glenn Martin at (407) 882-1319. Thanks again!

APPENDIX B:
SCENARIO TURING TEST RAW DATA

Five subject matter experts were asked to participate in the review and agreed. Ultimately, four of the reviewers returned the questionnaire. Four pairs of scenarios were given; both novice and expert Indirect Fire scenarios and novice and expert Close Air Support scenarios. Presentation within the pairs of scenarios was randomized.

Reviewer	Scenario A1	Scenario A2	Scenario B1	Scenario B2	Scenario C1	Scenario C2	Scenario D1	Scenario D2
SME 1	Computer	Human	Computer	Human	Computer	Human	Computer	Human
SME 2	Human	Computer	Human	Computer	Human	Computer	Human	Computer
SME 3	Computer	Human	Computer	Human	Computer	Human	Computer	Human
SME 4	Computer	Human	Computer	Human	Computer	Human	Computer	Human
	Novice IDF		*Expert IDF*		*Novice CAS*		*Expert CAS*	

Scenario Questions:

1. As we informed you at the start, one of each pair of scenarios was generated by a human, and one by our system. In each case, was one of them easily identified as the human-generated scenario? If so, which one? What is your level of confidence in your identification (e. g. 90% sure; 99% sure; where 50% would mean you feel that you're totally guessing).

Scenario A1 & A2:
SME 1: The second scenario was generated by a human. I am 80% confident. I think this is because the second scenario more closely resembles what actually takes place at this range due to the range layout / regulations.
SME 2: The one I would identify as a human creation would be scenario A2. My level of confidence in this is 85%.
SME 3: Scenario A1 was computer generated. 80% sure.
SME 4: Can't tell which is computer of which is human.

Scenario B1 & B2:
SME 1: Scenario 1 was generated by a human with a 60% confidence due again to adherence to real-world range specifics.
SME 2: B1 is computer generated and B2 is human generated. Not entirely easily identifiable. I feel 70% confident in my ID.
SME 3: Scenario B1 was computer generated. 60% sure.
SME 4: Can't tell which is computer of which is human.

Scenario C1 & C2:
SME 1: Scenario 2 was generated by a human with an 80% certainty as, again, this resembled very closely what actually takes place on the range during live training.
SME 2: I cannot ID which one is computer or human generated. My guess is C1.
SME 3: Scenario C1 was computer generated. 85% sure.
SME 4: Can't tell which is computer of which is human.

Scenario D1 & D2:
SME 1: Scenario 2 was generated by a human with 90% certainty. The "providing overwatch" comment gave it away.
SME 2: D1 is human generated and D2 is computer generated. I'm about 90% sure.
SME 3: Scenario D1 was computer generated. 75% sure.
SME 4: Can't tell which is computer of which is human.

2. What is your overall assessment of the relative quality of the two scenarios in each pair? E. g. "I would give A1 an A-, and A2 a D+". If you prefer a numeric scale, then use A=4.0, B=3.0, C=2.0, D=1.0 and F=0.

Scenario A1 & A2:
SME 1: The first scenario would get a B- and the second scenario a A-. The second scenario had a maneuver element in it, while the first did not.
SME 2: I would give A1 an "A", and A2 a "C".
SME 3: A1=C+ A2=B+
SME 4: Not answered.

Scenario B1 & B2:
SME 1: Both scenarios would rate a B+.
SME 2: B1 I give a B-, and B2 gets a B+. B1 has more relative tactical employment of armor and ADA, but B2 presents more of a challenge as far as FiST decisions.
SME 3: B1=B B2=B+
SME 4: Not answered.

Scenario C1 & C2:
SME 1: D for both scenarios.
SME 2: C1 gets a C, and C2 gets a B-.
SME 3: C1=C+ C2=B
SME 4: Not answered.

Scenario D1 & D2:
SME 1: D for both as no ordnance or sensors were listed.
SME 2: D1 gets a C and D2 gets a B.
SME 3: D1=C D2=C+
SME 4: Not answered.

3. For each scenario, what are its strongest and weakest points? Were there any obvious omissions that seemed to you to clearly indicate some weakness in the process by which it was generated? What were those omissions and how could the scenario be improved?

Scenario A1 & A2:
SME 1: The first scenario had no maneuver element position addressed. A specific T&R event listed would be required to accurately assess the quality of the scenario, for example TAC-OAS-2008. Aircraft sensors were not listed (Litening pod, ATFLIR, etc.).
SME 2: For scenario A1, the strong point is that it provides a good scenario for use of fires in support of the maneuver element. The weak point is that it doesn't necessarily match the right ADA asset to a mechanized platoon. Usually a mechanized platoon will have a ZSU 23-4, though MANPAD's (SA-14) is possible as well.
For scenario A2, the strong point is it provides a thinking challenge in a way to attack with air. The weak point is it is only 2 vehicles, both of with are easily destructible due to proximity with artillery assets. Nothing really needed as far as excess coordination of fires in the scenario.
SME 3: A1: Layout of friendly pos was atypical. Enemy forces were between FiST and IDF assets. No mention of friendly forces other than FiST and IDF.
A2: More logical scenario than A1. Lead trace of company given.
For both scenarios, more details of air support would help. Is A/C targeting pod capable? Loadout is unrealistic. Recommend mix of LGB, JDAM, and gun for fixed wing. For example, F-18 with 2xGBU-12, 1XGBU-38, gun, and LPOD.
SME 4: Missing too much planning information to provide useful training scenarios. There is a large amount of basic data missing from the depictions in both cases.

Scenario B1 & B2:
SME 1: Again the maneuver lead trace was omitted from one of the scenarios. The aircraft and ordnance on station at the time would mean that the FAC could prosecute all targets without having to use IDF. Aircraft Sensors were not listed.
SME 2: B1: Strength- Well employed enemy tactical situation. Armor up front for infantry and ADA in back to pick off aircraft attempting to attack. Weakness- SA-13 is not a very heavy threat for FW or even RW aircraft at the right distance, especially with PGM's.
B2: Strength- ADA presents more of a threat to aircraft, especially RW. Requires the FiST to decide either to destroy the ZSU, or work around it through SEAD. All would depend on commander's guidance and actual combat scenario. Weakness: The spacing of armor and the ADA threat is a little much, making use of SEAD too easy of an option, so as not to waste too much time or firepower.
SME 3: Similar to scenario A.
B1: No mention of friendly forces other than FiST and IDF.
A2: Lead trace of company given.
SME 4: Missing too much planning information to provide useful training scenarios. There is a large amount of basic data missing from the depictions in both cases.

Scenario C1 & C2:
SME 1: These scenarios lacked critical details that are required for making appropriate decisions. No sensor capabilities were listed, nor was the type of ordnance listed. These are required as they drive the tactics to be used.
SME 2: The only major difference is C2 has the strong point of having a realistic IP. Otherwise both scenarios do not have much of a challenge in way, except in a basic training scenario. With that in mind, I think it is an ok scenario, but more information on ordnance and aircraft systems on board would be beneficial.
SME 3: Both scenarios need aircraft details; ordnance, pod capability.
SME 4: Missing too much planning information to provide useful training scenarios. There is a large amount of basic data missing from the depictions in both cases

Scenario D1 & D2:
SME 1: Without knowing the ordnance to be employed, it is not possible to truly grade a scenario as it is an incomplete scenario. The capabilities of the aircraft drive the scenario more than the geographic location of things more often than not.
SME 2: D1: Strength- Close proximity fight, requiring more detailed integration with the maneuver element. Weakness- all points seem relatively close, leaving aircraft little time for maneuver into final attack cone, which would be constricting due to proximity of friendly forces.
D2: Strength- allows for more FS options and aircraft tactics. Weakness: at 5 kilometers, the target may be hard to make out and attack properly. Would have to rely mostly on aircraft for BDA and adjustment of fires.
Overall weak point: Helicoptors do not like to fly solo. If the single helo in both scenarios is FAC(A) capable, then it makes sense. Otherwise, he should have a wingman.
SME 3: Both scenarios need aircraft details; ordnance, pod capability.
SME 4: Missing too much planning information to provide useful training scenarios. There is a large amount of basic data missing from the depictions in both cases

System Questions:

1. Please discuss your thoughts on the scenario generation model of baselines and vignettes. In what ways does this model correspond with, or differ from, the practice of professionals who generate scenarios? In what ways could this model be improved?

SME 1: A specific T&R event should be listed. The event to be conducted will drive the placement of things on the battlefield as well as the capabilities that I want the aircraft to have (or not have) to force the FAC under instruction into doing what I want to see. For example, if I want the FAC to use interrupted suppression on a ZSU-23-4, I will make sure that the FW aircraft do not have any Laser-guided bombs. This is because if the aircraft checked in with a GBU-12, it could just drop the bomb on the ZSU-23-4 from an altitude sanctuary and he may not employ SEAD. It would be a correct tactical decision, but it would not meet my training goal of having him employ SEAD with CAS fires.
SME 2: The scenarios are very similar to what we would come up with for our own personnel to train with. Depending on their level of skill, we may also add ROE and have them go through the dilemma of figuring that out as well. My best suggestion is to look at some military personnel's scenarios and copy/ alter them to fit into the different scenarios you need.
SME 3: All scenarios are basic and accomplish basic requirements. Ordnance specifics are the most lacking in all scenarios. The ordnance and sensor capability drive execution more than any other aspect of the mission and must be realistic. Also, commander's intent is a key element not covered in these scenarios. Each scenario should have a defined training goal. Once that goal is determined, ordnance and commander's intent can be tailored to meet training requirements.
SME 4: Since conflicts are confusing any of the situations presented can happen; that's just life. The ground T&Rs don't possess the details you need to evaluate performance. Unfortunately, those documents are the official source for performance standards.

2. Please discuss your thoughts on the vignette representation of sets of triggers and adaptations. Does this representational system accurately and completely capture the corresponding features that are needed for top quality scenario generation? In what ways could our representational system be improved?

SME 1: Again, the aircraft capabilities piece is the critical missing piece. More specifics into what learning point the instructor wants to make—is it conducting CAS and SEAD or is it setting up combined attacks (sequential/simultaneous)? This needs to be the starting point from which the elements of the scenario flow.
SME 2: Symbols are good. Standard enough that most military personnel will understand them.
SME 3: In addition to the above, geography must be considered in the development of the scenarios. Location where personnel would or would not be located, terrain masking for ground personnel and RW assets, etc. This is secondary to what is stated in question 1. Once training objectives are determined, enemy, threat and commanders intent established, and aircraft ordnance, caps and ROE are defined, where units are placed on a map are less important.
SME 4: As you can imagine this causes a great deal of anxiety in many organizations. For instance, you need a base of fire for many tactical activities, yet (unless something changed recently) the details how to execute or evaluate the base of fire don't exist in the T&R manuals. Since training systems fundamentally offer the opportunity to "measure something and provide feedback in a plausible environment" so to speak, we routinely come up short when attempting to use the T&R as the primary source in many cases.

In this case we need to use TTECG's FiST Handbook for performance details on fire planning. The T&Rs use to just say, "brief fire plan" or "build fire plan in accordance with commander's guidance" or something like that. You can't produce a training device focusing on fire plans with only that level of guidance available.

If the newer T&R manuals possess more of the details needed, that will be great.

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