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PINELAND: A WARGAMING PLATFORM FOR INFLUENCE

by

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13. ABSTRACT (maximum 200 words)

The Department of Defense has invested heavily in modeling and simulation technology to provide valuable and cost-effective training and wargaming. Existing wargaming platforms, however, are focused largely on kinetic effects and conventional operations. Here, I present the Pineland wargaming platform I developed, intended to fill this gap. The platform provides a robust, user-friendly solution to supporting scenario generation, management, and training-audience evaluation for influence operations, irregular warfare, and other lines of effort that go beyond conventional kinetic operations. As part of this, I present the conceptual background and implementation details for a system that leverages social identity theory for the automated generation and "white cell" management of a robust scenario for wargaming operations in the information environment, to include detailed demographic, cultural, and political data and diffusion. I further discuss the implementation of an artificial intelligence system capable of handling thousands of actors in both the physical, network, and cognitive layers, with an accompanying user-friendly editor and presentation system. I conclude with a discussion of how the platform bridges an influence-operations gap in defense-oriented wargaming platforms, and how the Army and Marine Corps might use the program to enhance training for influence specialists, commanders, and technical researchers.

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PINELAND: A WARGAMING PLATFORM FOR INFLUENCE

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The Department of Defense has invested heavily in modeling and simulation technology to provide valuable and cost-effective training and wargaming. Existing wargaming platforms, however, are focused largely on kinetic effects and conventional operations. Here, I present the Pineland wargaming platform I developed, intended to fill this gap. The platform provides a robust, user-friendly solution to supporting scenario generation, management, and training-audience evaluation for influence operations, irregular warfare, and other lines of effort that go beyond conventional kinetic operations. As part of this, I present the conceptual background and implementation details for a system that leverages social identity theory for the automated generation and "white cell" management of a robust scenario for wargaming operations in the information environment, to include detailed demographic, cultural, and political data and diffusion. I further discuss the implementation of an artificial intelligence system capable of handling thousands of actors in both the physical, network, and cognitive layers, with an accompanying user-friendly editor and presentation system. I conclude with a discussion of how the platform bridges an influence-operations gap in defense-oriented wargaming platforms, and how the Army and Marine Corps might use the program to enhance training for influence specialists, commanders, and technical researchers.

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List of Acronyms and Abbreviations

AI	Artificial Intelligence
CnS	Command and Staff
COMMSTRAT	Communication Strategy and Operations
DIME	Diplomatic, Informational, Military, and Economic
DIS	Distributed Interactive Simulation
DoD	Department of Defense
EW	Electronic Warfare
EWS	Expeditionary Warfare School
IE	Information Environment
IRCs	Information-Related Capabilities
JDN	Joint Doctrine Note
JP	Joint Publication
JSON	JavaScript Object Notation
OIE	Operations in the Information Environment
MAGTF	Marine Air-Ground Task Force
MOPC	MAGTF Operations in the Information Environment Practitioner Course
MOS	Military Occupational Specialty
MOVES	Modeling, Virtual Environments, and Simulation
NPS	Naval Postgraduate School

PME	Professional Military Education
PSOM	Peace Support Operations Model
PSYOP	Psychological Operations
SIT	Social Identity Theory
STORM	Synthetic Theater Operations Research Model
SVG	Scalable Vector Graphics

Executive Summary

What Pineland is and why it matters

The Department of Defense has invested heavily in modeling, simulation, and wargaming technology to provide more effective training at a lower cost to its troops. Existing wargaming platforms, however, are focused largely on kinetic effects and conventional operations; as a result, practitioners of influence operations and irregular warfare are not able to leverage the benefits provided by modeling and simulation technology to the same extent as their peers in the traditional combat arms.

The Pineland wargame platform that I developed, detailed here, is intended to fill this gap and provide a viable training tool for military practitioners of operations intended to produce effects in the cognitive domain. The platform is of particular relevance to the Army and Marine Corps, who are both undergoing significant force redesign with an eye toward deterrence and strategic competition. Such a platform allows the services' personnel to wargame psychological operations, civil affairs missions, and public affairs concerns, and to do so in a fashion that is cost-effective, requires little additional manpower, and leverages existing software and hardware.

Broader findings

In terms of research, the central question of this work—whether it is possible to create a wargaming platform that addresses operations in the information environment, beyond what existing defense platforms allow—is answered in the affirmative here.

More generally, the development of this platform indicates that such a tailored wargaming platform is possible to create with personnel organic to the Army or Marine Corps, and that development itself can come with little additional cost in both software and hardware, potentially enhancing the services' push for increased wargaming in training and education, as well as developing troops' proficiency in wargaming design. An additional finding of interest is that open source, off-the-shelf gaming software is now at a point where it can provide the display, input, and network functionality required to build credible wargaming

tools for military applications, potentially realizing a cost savings for the Army and Marine Corps as they seek to develop their own wargaming and simulation centers and capabilities.

Improvements on the existing state of the art in defense-focused wargaming

A number of key technical features allow Pineland to bridge this gap, and represent advances over existing wargaming platforms available to the Department of Defense:

- The automated generation and "white cell" management of a robust scenario for wargaming operations in the information environment, to include detailed demographic, cultural, and political data.
- The implementation of an artificial intelligence (AI) system capable of handling thousands of actors in both the physical and cognitive domains, with an accompanying user-friendly editor and presentation layer.
- The implementation of a scalable model leveraging social identity theory to simulate the diffusion of knowledge, attitudes, and behaviors across populations.

Recommendations for integration and applications

The Pineland platform is promising for a variety of use cases. In particular, I recommend further work in testing the platform's integration with the following three areas:

- **"White cell" support for influence specialist training**. Pineland is explicitly geared toward providing a user-friendly scenario management tool for courses such as the Army's Psychological Operations school. Specific needs expressed by Psychological Operations training staff are explicitly addressed in Pineland, including automating the modeling of message propagation, generating synthetic internet traffic, and performing other scenario support work that would otherwise require an instructor to manage whiteboards, maps, and spreadsheets instead of evaluating and mentoring students.
- **Service or joint professional military education**. Pineland's relatively high-level view of the information environment and ease of use for both training audiences and training staff, along with its price tag of zero and limited hardware requirements, make it potentially useful in presenting the basic concepts of operations in the information environment to non-specialist audiences. Schools such as the Marine Corps' Com-

mand and Staff course, or the Army's Captain's Career Course, which already include a module on operations in the information environment as part of a broader exposure to various warfighting functions and fields, could leverage Pineland to augment their existing lectures and discussions with interactive wargaming against thinking opponents.

- **Technical skills training in computer science and related fields**. As a consequence of Pineland's usability-centered architecture and open-source software stack, the platform provides an accessible foundation for training skills in machine learning and agent-based approaches to artificial intelligence. Users can experiment with algorithms for agent-based behavior using a combination of an existing Python-based scripting environment and a graphical utility system, instead of needing to configure an environment and either build or adapt a wargaming environment.

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CHAPTER 1: Introduction and Overview of Existing Platforms

1.1 Psychological Operations Training and Needs for Simulation Platforms

As a Marine Corps Operations in the Information Environment (OIE) practitioner and student in both the Defense Analysis and Modeling, Virtual Environments, and Simulation (MOVES) departments at the U.S. Naval Postgraduate School (NPS), I was approached in late 2021 by former instructors at the U.S. Army Psychological Operations (PSYOP) school to explore the creation of a training platform for OIE. Their motivation was, in part, to help address staffing issues and a lack of existing wargaming and simulation platforms that included depth in OIE, particularly the use of influence Information-Related Capabilities (IRCs).[1]

A site visit to the PSYOP school in early 2022, including attendance at the culminating exercise of both the enlisted and officer PSYOP training courses[2] and interviews with the school's senior staff, further illuminated the scope of the problem.

In these interviews and observations, the following points came up repeatedly:

- The growing emphasis on U.S. strategic competition with both the People's Republic of China and Russia, as well as the Marine Corps' standing up of their own PSYOP elements, have led to increased demand for OIE training without a corresponding growth in PSYOP training staff.
- This staffing issue is exacerbated by the heavy "white cell" work required of training exercises focused on OIE, where instructors must manually represent the knowledge, attitudes, and behaviors of adversary forces, civilians in the area of operations, U.S.

[1]While much can (and has) been written on the conceptual differences between a "model" and a "simulation," I use the term "model" throughout to denote an abstract representation of reality in general, and "simulation" to indicate a model reified in mathematics, natural language, computer programming, etc.

[2]Unlike many Military Occupational Specialty (MOS) schools, where the curricula for enlisted and officer students are separate, the PSYOP school has substantial overlap and an integrated culminating exercise between its enlisted and officer training audiences.

and foreign diplomatic staff, and other actors. While this is capably provided by role-players for face-to-face interactions; indirect representations of a population (social media, TV broadcasts, etc.) require extensive bookkeeping on the part of the staff and repetitive calculations and data presentation. Often, this representation is far from real-time and requires a substantial amount of time and coordination on whiteboards and spreadsheets to credibly represent a coherent Information Environment (IE) to the training audience.

- A platform for aiding in the generation and presentation of OIE-focused scenarios is greatly desired by training staff; however, the industry solutions they were exploring at the time of the visit focused primarily on "technical" OIE, with impressive functions for representing computer networks, the effects of Electronic Warfare (EW), and utility grids, but without similarly robust representation of demography and culture.
- A need exists for service members in fields outside IRCs to have a general awareness of the IE and how to integrate other forms of action with information effects, but the only training tools available for them in these areas exists at dedicated schools that most units do not send appreciable numbers of their troops to.

This echoes my own operational experience as part of III Marine Expeditionary Force in Okinawa, Japan, from 2018-2021, where substantial appetite was expressed by operational-level commanders and staffs (battalion, regimental, and division-level) for OIE training and planning aids. This demand was not met by a corresponding ability to illustrate OIE concepts interactively, as the use of sand-table wargames, map studies, and similar training aids typically allow for when it comes to physical fires and maneuver.

In order to further clarify this problem and begin exploring a path to a solution, a number of factors needed consideration. Accordingly, I present the following survey of concepts and existing work in the field:

- The current doctrinal conception of OIE that these needs are nested within, including:
  - The Diplomatic, Informational, Military, and Economic (DIME) model of national power and the levels of military operations
  - The information environment and its layers
  - The situation of OIE practitioners within the above models

- A survey of existing Department of Defense (DoD), academic, and commercial wargaming platforms

1.2 National Power and the Information Environment

1.2.1 National Power

For practitioners of OIE, the broader context for their actions is the overarching exercise of national power. This concept of national power is perhaps best viewed through the lens of the DIME model, formalized by the DoD in Joint Doctrine Note (JDN) 1-18, "Strategy." (United States Department of Defense 2018)

In this model, national power is exercised through four primary instruments:

- **Diplomatic power**: Diplomacy, conceptualized by JDN 1-18, consists of engagements between nations, "generally to secure some form of agreement that allows the conflicting parties to coexist peacefully" (United States Department of Defense 2018).
- **Informational power**: This instrument of national power centers around "creating, exploiting, and disrupting knowledge" (United States Department of Defense 2018). While it might be tempting to think of this being the primary concern of OIE practitioners, it is important to note that information is a prerequisite for the other arms of national power, and thus OIE can be considered more broadly within the context of DIME than simply related to informational power alone.
- **Military power**: Echoing Clausewitz, JDN 1-18 defines this as "the use of force by one party in an attempt to impose its will on another" (United States Department of Defense 2018). As laid out by the Marine Corps in its foundational doctrine, for example, the exercise of military power can be conceptualized as occurring at strategic, operational, and tactical levels, as depicted in Figure 1.1. These levels are typically formulated as:
  - **Strategic**: Focused on the attainment of political objectives using the establishment of goals, "assigning forces, providing assets, and imposing conditions on the use of force in theaters of war" (United States Marine Corps 1997).
  - **Tactical**: The technical application of maneuvering forces and fires.

  - **Operational**: Linking the strategic and tactical levels, the operational level seeks to transform tactical results into strategic effects (United States Marine Corps 1997).
- **Economic power**: This is succinctly put by the JDN as "furthering or constraining others' prosperity" (United States Department of Defense 2018).

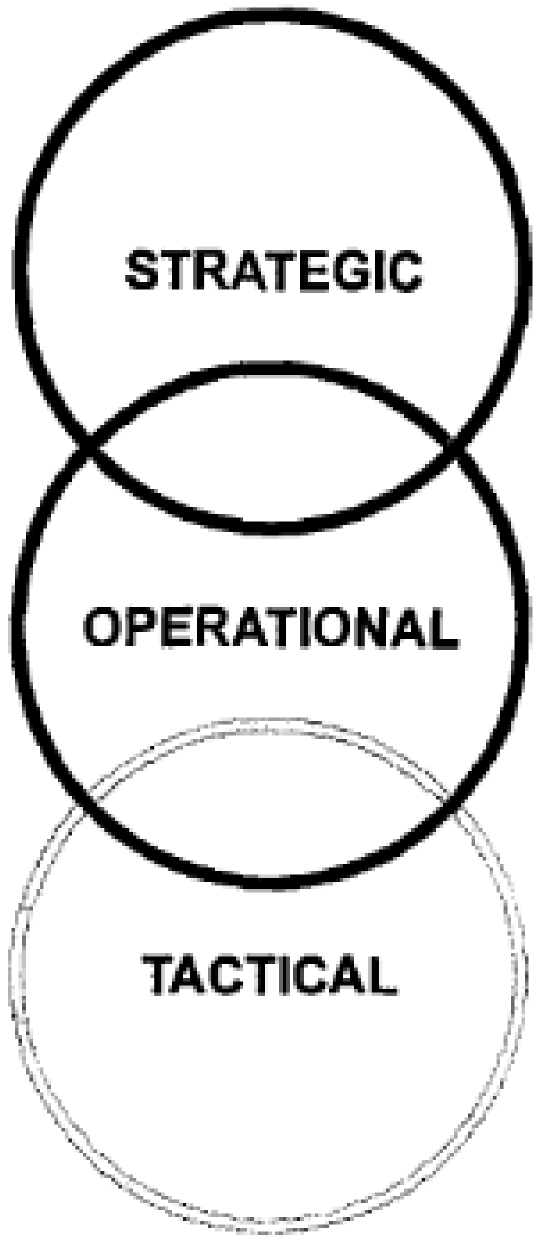

Figure 1.1. Levels of war per Marine Corps doctrine. Source: United States Marine Corps (1997).

1.2.2 The Information Environment

All of these forms of power are exercised in an environment characterized not only by its physical properties like geography and climate, but by the human context. This is the IE, the complex system of tangible and intangible factors decision-makers—especially those exercising national power—operate in.

This conception of the IE is realized in U.S. military doctrine through Joint Publication (JP) 3-13, "Operations in the Information Environment." In this conception, the IE consists of overlapping physical, informational, and cognitive layers, as depicted in Figure 1.2 from United States Department of Defense (2014).

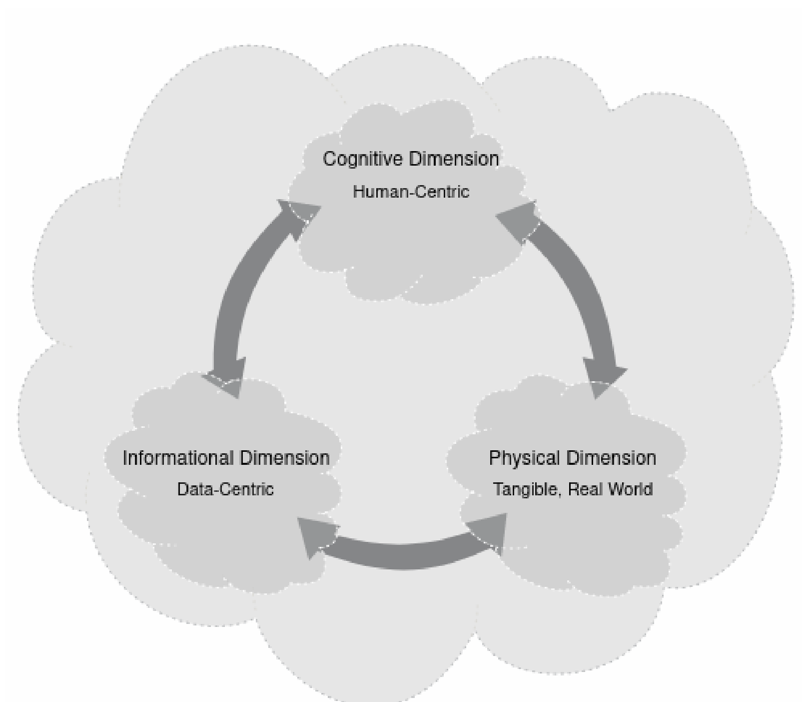

Figure 1.2. Doctrinal view of the IE. Source: United States Department of Defense (2014).

These layers, in brief, are composed of the following elements:

- **Physical layer**: The geography, structures, and physical presence of forces, populations, and units in space and time.

- **Informational layer**: The human and technological networks and means by which information is transmitted and received.
- **Cognitive layer**: The cultural, psychological, and social context of a given environment, including the knowledge, attitudes, and behaviors of actors within it.

1.2.3 The Scope of Military IRCs

According to this doctrinal understanding, *all* military decision-makers operate in the IE, although specific IRCs are often the focus of effort. While an exhaustive examination of U.S. IRCs is out of scope for this discussion, one can segment them broadly into two categories despite their substantial overlap in effects:

- "Technical" IRCs, whose effects are most prominent on the informational layer, even if they have aims and effects on other layers. Often highly technical in nature, these IRCs include such capabilities as cyber operations, EW, and space operations.
- "Influence" IRCs, whose effects are most prominent on the cognitive layer and whose aim is typically to directly influence the knowledge, attitudes, and behaviors of human groups. These IRCs include such capabilities as PSYOP, Civil Affairs, and Public Affairs.

In line with the the original impetus for the project, I focus here on "influence" IRCs; hereafter, references to OIE practitioners should be understood to primarily indicate those whose efforts are focused on the cognitive layer of the IE.

Typically, these capabilities seek to use tactical actions to achieve strategic effects, while often remaining operational in echelon. Marine Corps Communication Strategy and Operations (COMMSTRAT) units, for instance, are situated at the division level and are attached to battalion or lower elements on an ad-hoc basis. Similarly, Army PSYOP teams do not typically have an organic presence within brigade combat teams or similar maneuver formations, and typically liaise with Embassy staff and component commanders under the combatant commander for a geographic area.

Of note, this focus does not map neatly to many existing DoD wargaming products, which often assume a relatively close correspondence between the size and structure of a unit and the level at which it is intended to produce effects.

1.3 A Brief Survey of Existing Simulations

To aid in answering the question of what exists already, I present an overview of the following three general categories of simulations:

1. Simulations developed by the **military** directly, whether for training, planning, or acquisition purposes.
2. Simulations developed by **academia**, often for research purposes.
3. Simulations developed by the **private sector**, often for purposes other than training, education or research (e.g., entertainment or film production).

These categories are rarely, if ever, discrete in practice. Many military simulations have their genesis in commercial video games, and many technologies developed in one area have transitioned into the use of the other two, as noted by Hill and Miller (2017).

By nature of their profession, the most immediately available simulations to OIE practitioners will be those from the first category: military simulations.

1.3.1 Military Simulations

Simulation has an extensive history within the military, as discussed by Hill and Miller (2017) in their overview of the subject. From early board games to "sand table" games providing a tactical or operational level view of conflicts for commanders to examine, the simulation of direct, kinetic combat for the purposes of training is well-established within the military domain. In an intriguing parallel to modern OIE, Hill and Miller note that emerging domains of conflict have often been set aside in favor of simulating conventional, on-the-ground fighting — most notably with the exclusion of air power from many interwar-era wargames in use by the U.S. Army (Hill and Miller 2017, p. 4).

This focus on simulating combat operations took on new life in the early 20th century more generally, with abstract mathematical models such as the Lanchester equations attempting to provide insight into the outcome of conflicts. The use of these mathematical models grew substantially during and immediately after the Second World War, with the concurrent rise of computing capability opening up new approaches and appetites within the nascent DoD for conflict simulations (Hill and Miller 2017) .

Today, the DoD modeling and simulation space is expansive, with Hill and Miller presenting an array of systems currently in use across the entire spectrum of military activity (Figure 1.3).

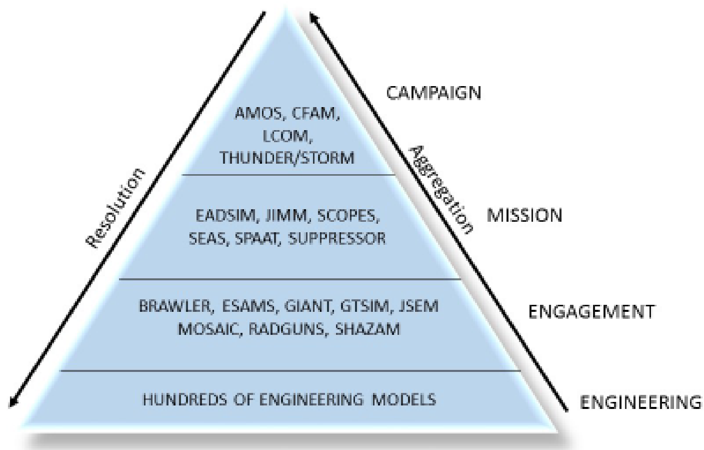

Figure 1.3. A taxonomy of DoD simulations. Source: Hill and Miller (2017).

A look at four in particular illustrates both the strengths and the shortfalls of DoD models for training OIE practitioners:

- The "Combined Arms Analysis Tool for the 21st Century" tool, hereafter referred to as the Combat XXI platform.[3]
- The "Synthetic Theater Operations Research Model (STORM)" platform for theater-level operations.
- The "Peace Support Operations Model (PSOM)" and "Athena" platforms for counterinsurgency analysis.

Combat XXI

Combat XXI , described in its U.S. Army user guide as a platform for "joint, high-resolution, closed-form, stochastic, discrete event, entity level structure analytical simulation," is an exemplar of the DoD approach to modeling and simulation (United States Army 2014). The system, intended for brigade-level and below combat simulation for ground forces, could

[3]This is often stylized as "COMBATXXI" in DoD literature.

be understood more a platform to create simulations, with "all aspects of the model input and output [needing to be] built and managed by the user" (United States Army Training and Doctrine Command Analysis Center 2015, p. 2).

The assessments of Army researchers examining Combat XXI for integration with a broader training plan illustrate the strengths and weaknesses of the platform:

- Combat XXI can be run on relatively limited hardware, requiring only two gigabytes of memory and a current Java runtime environment. (United States Army Training and Doctrine Command Analysis Center 2015, p. 9)
- Combat XXI provides functionality to represent terrain, units, behaviors, and force structures in a fashion that must be implemented by the user. (United States Army Training and Doctrine Command Analysis Center 2015, p. 10)
- Combat XXI explicitly models a unit's physical performance and characteristics, its configuration and physical mobility, as well as its communication network. In other words, Combat XXI provides explicit support for the physical layer of the IE as conceptualized by the DoD, with aspects of the informational layer modeled.
- The typical Combat XXI installation comes with source code, allowing developers to correct errors and implement new functionality where it isn't present be default, as noted in (United States Army Training and Doctrine Command Analysis Center 2015, p. 9).
- The limited distribution of Combat XXI , requiring an official request to the director of the Army's Training and Doctrine Command Analysis Center, limits the availability of the platform to researchers and training staffs that may be attempting to experiment with limited lead times (United States Army Training and Doctrine Command Analysis Center 2015, p. 9).
- The time frame between deciding Combat XXI as a potential training aid to running a particular scenario is estimated to be around seven months for the Army researchers, with a 1-3 month lead time between the creation of Combat XXI scenario and its actual execution. In contrast, other simulations examined by the Army team had an entire lead time between decision and scenario execution of no more than two months (United States Army Training and Doctrine Command Analysis Center 2015, p. 60).

As noted above, Combat XXI provides functionality "out of the box" for modeling the physical and information layers of the IE in some detail. Combat XXI has played host to a variety of approaches for modeling aspects of the cognitive layer of the IE as well.

Perhaps most interestingly for OIE practitioners, Army researcher Casey Connors at the Army's Training and Doctrine Analysis Center, along with others from NPS, implemented a tactical-level crowd dynamic simulation in Combat XXI , depicted in Figure 1.4. Connors' model explicitly included aspects of the cognitive environment, including demography and discrete attitudes (e.g., "aggressive, passive, random" attitudes of soldiers in a crowd environment). However, Connors' report also acknowledged the difficulty of integrating a cognitive model with Combat XXI , requiring a separate crowd dynamics model operating outside of Combat XXI . The report also noted that models that would account for "various regional[,] cutlural [sic], and political environments" remained a valuable subject for continued development (Connors et al. 2017, p. 20).

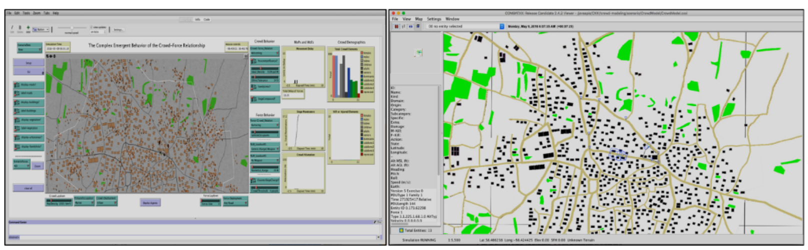

Figure 1.4. Connors' crowd dynamics model in the Combat XXI system, illustrating the platform's interface, level of detail, and tactical focus. Source: Connors et al. (2017).

The STORM Platform

STORM platform provides a theater-level planning aid for DoD decision-makers; like Combat XXI , it is a stochastic model, described by Navy researcher Christian Seymour as a "pillar of campaign analysis" within the DoD (Seymour 2014).

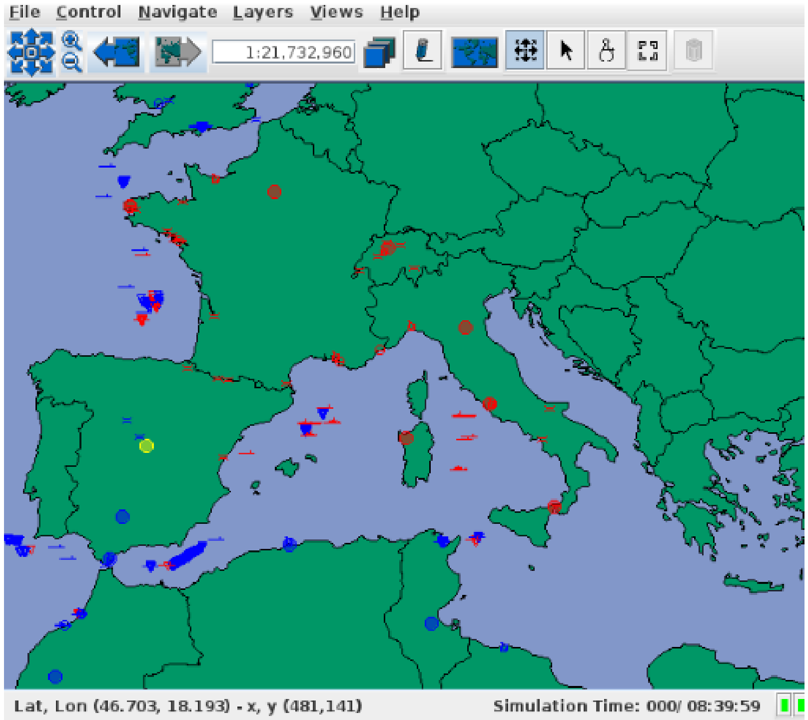

Figure 1.5. Representative screenshot of STORM user interface. Source: Seymour (2014).

Seymour is quick to acknowledge the complexity of the platform, with its thousand-page user's manual and separate volumes of programming reference for the implementation of new features and scenarios (Seymour 2014, p. xv). Running the scenario is not interactive, with a single runthrough capable of lasting up to twelve hours, with days of post-processing required to make sense of the data. Furthermore, scenario development may take up to a year, making direct use of STORM unsuitable for a training environment based on grounds of time alone (Seymour 2014, p. 2).

Other notable DoD models, such as the Joint Warfare System (JWARS), are also focused at the campaign level; while potentially valuable for informing training on theater OIE, this strategic-level focus limits their ability for direct use in a training curriculum aimed at operational-level OIE practitioners. The Marine Corps' Marine Air-Ground Task Force Tactical Warfare Simulation (MTWS), conversely, focuses largely on tactical-level effects and is geared primarily towards modeling kinetic actions and their supporting logistics

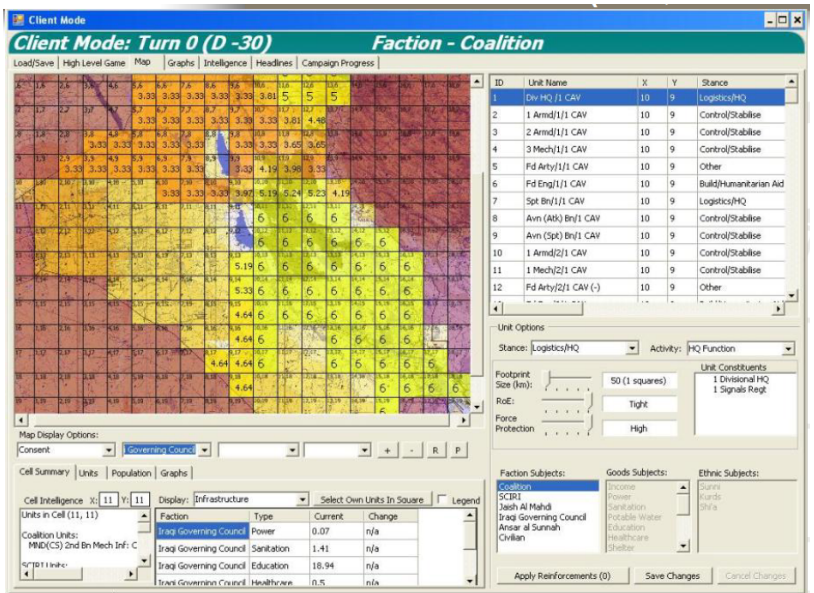

Figure 1.6. Representative PSOM screenshot. Source: Appleget (2011)

efforts. Like many of the other systems noted above, MTWS is intended to provide a degree of flexibility to its end users, with scenarios able to be defined and ran using a number of interfaces common to other DoD platforms.

PSOM

PSOM,[4] in comparison to Combat XXI and STORM, *does* attempt to focus on intangibles. This platform, explicitly intended by its developers to include economic, social, and political factors, came about from British developers seeking to model the then-ongoing counterinsurgency campaign in Iraq (Body and Marston 2010).

PSOM models geography with a grid populated by various populations with changeable opinions, and actors within the scenario who can possess a variety of different "stances" (i.e., having aggressive rules of engagement, a more cautious approach to the use of force, etc.). Various metrics, including perception of the population on security and consent of the population towards assorted actors, serve as the primary outputs from PSOM, with the inputs being stances, forces, and the capabilities of these forces. A representative view of how this information is presented to the user is provided as Figure 1.6

[4]Often pronounced "possum."

With a time scale of months and years and a campaign-level view of the environment, PSOM encapsulates the complexities of the IE with far more potential than many other defense-focused models. However, a number of issues persist with its ability to model OIE effectively. In a review of the system's capabilities, Marlin (2009) notes a number of remaining challenges, including:

- The lack of impact differing units and capabilities can have on the outcome of a given situation, making it challenging to use PSOM to explore and educate about force generation, structure, and deployment of certain capabilities
- An inability to model uncertainties in irregular warfare
- An extreme dependence on manually inputting population data and their encoded assumptions, which, in Marlin's analysis, will often dominate the results of the platform's simulations

Additionally, in many ways PSOM represents a tool tailored to the needs of the era, with unit-level considerations of firepower, casualty counts, and force protection stances providing the driving force, and the resulting effects in the cognitive layer of the IE ultimately presented to the user. More granular approaches to messaging, including deliberate appeal to specific populations, and situations of strategic competition rather than some level of ongoing armed conflict are largely outside the scope of PSOM.

In his analysis, Marlin aptly summarizes these observations by noting that PSOM "should be used for its original purpose," with the system having potential as "a high-level staff and leader training tool and as a planning aid for... stability operations" (Marlin 2009, p. xxii).

Athena

A similar system from the United States occupies largely the same niche in modeling counterinsurgency operations as PSOM. Athena, developed by the California Institute of Technology for the DoD, takes a similar approach with actors in a segmented environment (albeit by neighborhoods, districts, and so on, compared to PSOM's grids). Distinct from PSOM, however, Athena models explicit relationships of communication and interaction between actors on an individual level, with support, influence, and control embedded in these connections. Interestingly, Athena computes affinities between entities through these relationships, represented as an abstract score along each actor-to-actor relationship link (Duquette et al. 2015).[5]

Athena goes beyond PSOM in its consideration of the cognitive environment in a number of ways. Chiefly, individual actors have a number of beliefs; the emphasis each actor places on these beliefs, and their position on them, will dictate their affinity with other units. Units may also have explicit needs (for safety, food, etc.) This affords Athena a greater granularity in depicting the IE

Interaction within Athena takes the form of differing tactics per actor; these tactics range from repairing infrastructure, to combat, to demobilizing forces. The end result of the simulation is a range of outcomes in the economy within the scenario and the physical disposition of actors.

Despite this depth, Athena, like PSOM, possesses a number of characteristics which may make it questionable for use as an OIE training tool:

- A lack of granularity in specific actions taken to affect the cognitive layer of the IE, such as directed messaging, time-limited propaganda.
- Little affordance on the presentation layer for translating attitudes to the user in a way that can be analyzed in a broader training scope; e.g., for key PSYOP tasks like target audience analysis.
- Specialized knowledge required for setup, deployment, and troubleshooting, along with a heavy reliance on manual generation and management for scenarios.
- A lack of active development, compounded by the fact that Athena's primary programming language, Tcl, is becoming increasingly niche in its user base. This may threaten the extensibility afforded to those seeking to develop novel tactics or actors for use within Athena.

DoD Simulations: Some Broad Observations

DoD simulations, exemplified by Combat XXI and STORM, offer a number of possible advantages for OIE practitioners. Notably, these simulations:

[5]These relationships form a complete graph, which may raise the specter of a combinatorial explosion when it comes to scaling scenarios.

- Are products of the DoD, and are thus accessible to many training staffs at little to no up-front cost. This is a double-edged sword, with updates and bugfixes to the platform potentially requiring the navigation of military bureaucracy to push out to the user base.[6]
- Have extensive bodies of supporting literature and research, as well as exhaustive supporting documentation to aid their use and the development of new scenarios.
- Allow trainers to combine inputs from squad-level or lower tactical engagements up to theater-level combat, even if these simulations are not used directly.
- May include explicit focus on multiple layers of the IE and certain forms of conflict below the threshold of large-scale combat operations.

However, these simulations also come with notable disadvantages for use in a modern training environment:

- The need for manual scenario generation requires operators who are familiar with the platform and its often-extensive supporting literature. Furthermore, scenario generation is often encumbered by long lead times.
- The platforms are often focused heavily on the military aspect of DIME and the physical layer of the IE. Where they include the informational and cognitive layers, this representation is often an adjunct to the physical layer and does not represent the cognitive layer on an operational scale.
- The platforms themselves are not necessarily intuitive for a training audience without a technical background; especially for a training audience with sharply limited time and an already broad curriculum, as in many Professional Military Education (PME) schools.
- The often-specific focus of OIE-related concerns onto counterinsurgency and stability operations in particular, limiting their utility for other types of operation (e.g., competition in a space not characterized by violence).

These broader tendencies often create a feedback loop with wargaming participants, further limiting their utility to effectively communicate OIE concepts. Abitbol (2020), in a discus-

[6] Also of note, the Distributed Interactive Simulation (DIS) protocol, originated for and in wide use by the DoD for its simulations, does not include explicit support for the cognitive layer of the IE, although it does have support for elements of the informational layer in the realm of EW and communications. (IEEE Standards Association 2002).

sion of the existing DoD approaches to wargaming influence, makes a number of pointed observations about existing DoD wargaming platforms and approaches:

- Players tend to consider the IE in terms of the physical environment alone, "equat[ing] the exertion of cognitive influence with holding physical territory."
- Wargaming platforms often closely align with idiosyncratic service doctrines, lacking the flexibility to allow players to explore multi-service approaches to OIE.
- Players often attribute the complexity of understanding OIE to the complex abstractions of wargaming interfaces, rather than the inherent nature of the domain.
- "Participants often cannot describe the process of selecting target audiences," with no feedback inherent to the system, or easily afforded by wargaming staff through it, modeling the diversity of approaches and results in an environment with heterogeneous target audiences.

1.3.2 Simulation Approaches From Academia

Models of conflict have long been a concern for academia[7] as well as the military, as demonstrated in the overview presented by Kress (2012).

In much the same way that modeling of the physical layer of the IE burgeoned with growing computing power and new mathematical tools in the first half of the 20th century, modeling concepts of deterrence and strategic interaction became a richer field of study in the same time frame. Kress cites the rise of game-theoretical approaches, including French mathematician Émile Borel's "Colonel Blotto" game, as examples of academics beginning to examine operational-level military challenges. Questions of broader strategic deterrence, and non-kinetic actions, also began to emerge alongside game theory in the postwar era, albeit often with a nexus to the very kinetic (potential) effects of nuclear weapons (Kress 2012).

As acknowledged by Kress, modeling the cognitive dimension of conflict is inherently a difficult process, with concepts such as fear, confidence, and persuasion not lending themselves as easily to quantitative models as physical combat. The rise in interest in

[7]Here, I use "academia" not simply in the sense of traditional educational/research institutions, but more broadly to indicate the sum of private-sector organizations whose primary business is the accumulation, presentation, and sale of knowledge and analysis.

Western democracies of combating terrorism and non-state violent groups has sparked a surge of interest in these intangible concepts, with the relevant models often explicitly including what would be called in the cognitive layer of the IE in DoD parlance.

This view of conflict is typified by Ivan Arreguin-Toft's model of strategic interaction, an attempt to model the strategic outcomes of conflicts between asymmetric actors (Arreguin-Toft 2005). This model moves beyond directly kinetic actions, instead concerning itself with the overall decision-making approach of actors in conflict. This model, then, tackles the cognitive layer of the IE at the strategic level. While compelling, this strategic focus also represents a weakness in the model's applicability to operational-level thinkers. Operational and tactical-level elements of the "M" in DIME, as well as states of competition that haven't boiled over into overt conflict, are outside the scope of Arreguin-Toft's model.

The model of insurgent/counter-insurgent competition presented by Kress (Figure 1.7) leans heavily on the language of behavioral economics and centers itself around cognitive effects. Indeed, Kress notes, these more recent academic models "can be used for identifying key individuals whose absence will destabilize an adversary network in a manner analogous to the way in which advertisers target likely buyers" (Kress 2012, p. 5).

This dovetails neatly with current U.S. military doctrine regarding the IE—compare Kress's presentation with the presentation of target audiences in JP 3-13, as reproduced in Figure 1.8. The model Kress presents can be understood as dealing largely in the cognitive layer, nested within the broader IE construct.

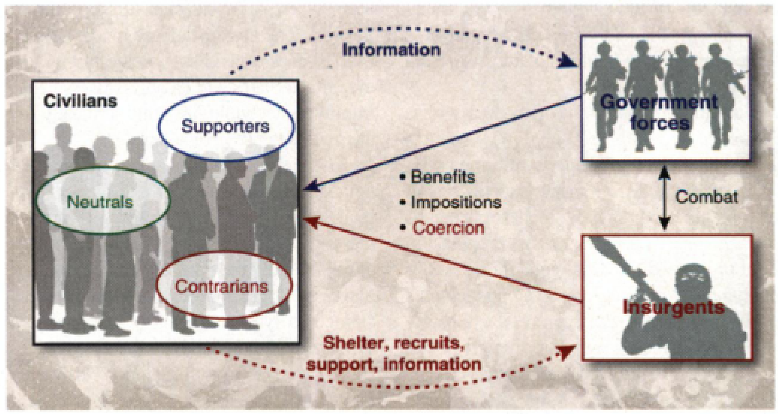

Figure 1.7. Kress's presentation of an insurgency/counter-insurgency warfare model. Compare with the doctrinal model of the IE as presented in JP 3-13. Source: Kress (2012).

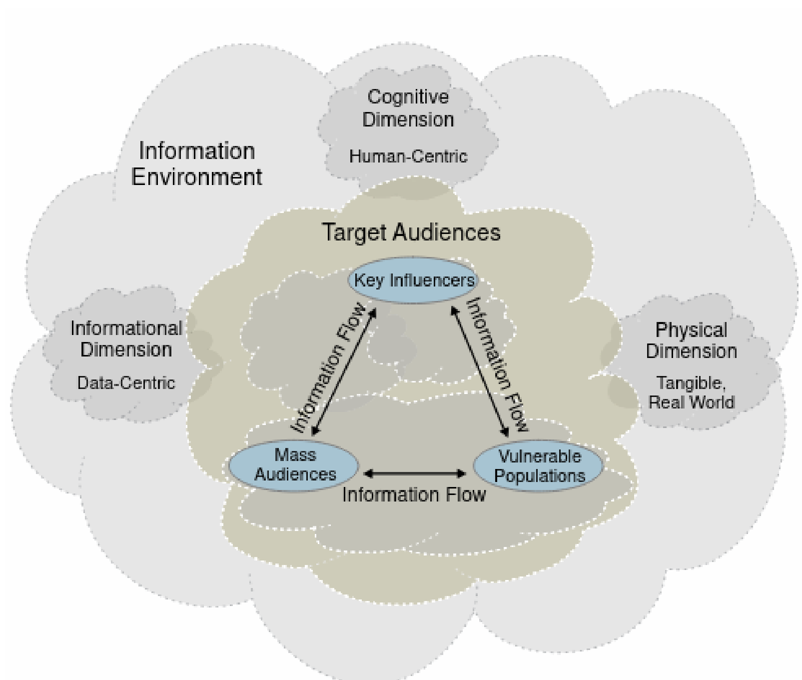

Figure 1.8. Doctrinal presentation of target audiences situated in the IE. Compare with Kress's model in Figure 1.7. Source: United States Department of Defense (2014).

It is this focus on the cognitive space where much academic research outstrips that conducted "in-house" within the DoD. For a closer examination of the types of benefits and limitations afforded by these types of models, we will examine two in particular:

1. The RAND corporation's "Will to Fight" model.
2. Australian researchers Dave and Amy Ormrod's "Persuasion Game."

RAND's "Will to Fight" Model

Billed as a "a flexible, scalable model of will to fight that can be applied to any ground combat unit," RAND's model represents an attempt to distill the complexities of human motivation into a coherent theoretical framework, and the resulting report includes a discussion of an attempt to integrate this cognitive model into an existing Army simulation at the tactical level (Connable et al. 2018). In examining this model, I first note the following points:

- The RAND corporation, while a private-sector enterprise, is emblematic of many academic efforts in the study of conflict. Often contracted by the DoD and other public-sector actors, the models of RAND and similar organizations could be considered a middle ground between those developed "in house" by the military and those created by private sector entities with private clients and purposes.
- The vagaries of human knowledge, attitudes, and behaviors are extraordinarily different, perhaps impossible, to quantify precisely. While the Will to Fight model attempts to provide a useful taxonomy for examining cognitive factors, like *any* cognitive model, it must be understood in the vein of statistician George Box's quip of "all models are wrong; some models are useful" (Box 1979) .

Interestingly, the Will to Fight report leads with an acknowledgment of the weakness of existing military simulations at incorporating the cognitive layer of the IE, noting that "most U.S. military war games and simulations... either do not include will to fight or include only minor proxies of will to fight" (Connable et al. 2018, p. 15).

Conceptually, RAND's answer to this is an individual-level model, examining cognitive effects from the perspective of motivational, cultural, and capability factors. (Connable et al. 2018, p. 17). However, RAND's model does acknowledge the effect of operational and strategic-level factors on cognitive, tactical-level effects, from societal trust and ethnic cohesion to a state's civil-military relations (Connable et al. 2018, p. 20). The overall model is presented in a wheel diagram, reproduced here as Figure 1.9. The report's authors explicitly address the simplification inherent in such a model, stating their contention that a model "in which factors are understood and a few well-substantiated general links are suggested[,] is both more realistic and sufficiently grounded in empirical research to give it practical credibility" (Connable et al. 2018, p. 22).

The report stops short of providing specific recommendations for how to integrate such a model into training and education, or which model to use, but does suggest that academic approaches might serve as a useful foundation for a military training effort in cognitively-focused OIE.

The simulation using the Will to Fight model leveraged the Army's existing "Infantry Warrior Simulation" platform, and modeled an individual's will to fight by introducing a delay to an individual soldier's reloading and firing process within the simulation. Like many DoD simulations, this instantation of the Will to Fight model exists at the tactical level, dealing with the movement and fire of individual forces; the RAND simulation did not examine effects above the platoon level. Indeed, the report's authors acknowledge this is a matter of deliberate scoping, denoting their model as a "tactical-operational" model (Connable et al. 2018, p. 16).

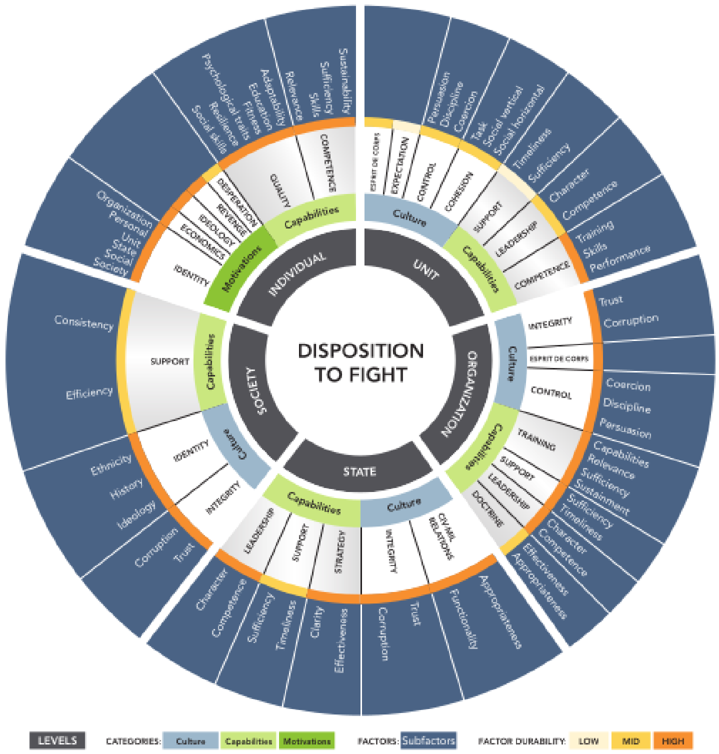

Figure 1.9. RAND's "Will to Fight" model. Source: Connable et al. (2018).

Similarly, like most DoD simulations, this approach primarily focused on the military component of DIME, examining the cognitive layer primarily as an adjunct to the physical layer (i.e., physical destruction or preservation of a unit in a squad or platoon-level engagement).

While RAND's approach is an intriguing look at the cognitive layer on the tactical level, other academic approaches have attempted to center the "I" in DIME in an operational-level look. Castillo (2014), for instance, steps beyond RAND's model and presents a theory of military cohesion centered in the cognitive layer, with cohesion among forces examined primarily in terms of the interplay between social, psychological, political, and behavioral forces within a military culture.

However, the most notable approach to translating theory into wargaming is perhaps the "Persuasion Game."

The Persuasion Game

Published in 2020, *The Persuasion Game* is an explicit attempt from academia to marry the "structured and quantitative strengths" of traditional military wargames with a flexible focus on influence (Ormrod et al. 2020, p. 30). Intriguingly, and in a departure from those models discussed previously, the authors of this approach explicitly disavow a presumption of kinetic conflict, instead using a mix of off-the-shelf simulation platforms and an active, robust team of exercise controllers to realize an interactive wargame of strategic competition, exemplified by the representative view reproduced here as Figure 1.10. This wargame was not so much a codified system as a single exercise, in the vein of early tabletop wargames discussed by Hill and Miller (2017).

Figure 1.10. Representative view of the "Persuasion Game." Source: Ormrod et al. (2020).

The entire conduct of the wargame took place over five days, including a review period. () Intriguingly, this is comparable in length to the culminating exercise at the Army PSYOP school, potentially indicating a congruence of time frames and training goals. The Persuasion Game's model may lend itself well to this sort of highly formalized education in a less resource-constrained environment, where access to skilled instructors is achievable.

Furthermore, the Persuasion Game's conception of the information environment closely aligns with many of the lenses through which DoD doctrine views it. The game explicitly utilizes the same "PMESII" (Political, Military, Economic, Social, Infrastructure, Information) and "ASCOPE" (Areas, Structures, Capabilities, Organizations, People, Events) mnemonics for understanding human landscapes that doctrine presents, as well as expanding on these concepts to include news media, law enforcement, and intelligence activities in the IE. (Ormrod et al. 2020)

The wargame centered around a manually-constructed fictitious landscape, as depicted in Figure 1.11.

Figure 1.11. Wargame landscape from the "Persuasion Game." Source: Ormrod et al. (2020).

While the authors caution that their wargame remains a proof-of-concept, the use of a vivid depiction of the IE, a focus on competition beyond kinetic conflict, and the use of supporting simulations to visualize the scenario make it an appealing candidate for modeling future approaches off of.

To facilitate this appeal, however, the game required numerous teams of support staff, including:

- A team of experts facilitating the overall conduct of the wargame
- Technical experts to manage the supporting simulations and visualizations
- A media and simulation team providing inputs to the exercise participants
- Intelligence, population, and economy-focused content-creation teams providing exercise inputs
- Adjudicators for the sequence and flow of player turns

This emphasis on staffing poses a problem to such a model's ability to meet the needs of the Army PSYOP school and similar organizations. Ultimately, while the Persuasion Game approach is ready-made to be a part of a training program and has an innovative focus, it possesses many of the same strengths and weaknesses as other academic models.

Academic Models: Some Broad Observations

Both the Persuasion Game and RAND's Will to Fight model, although very different in character, typify some of the inherent strengths of academic approaches to modeling OIE, especially in comparison to traditional DoD models:

- These approaches from academia tend to address high-level questions of strategic interaction, decision-making, and the impact of strategic factors across multiple levels of warfare.
- Academic approaches often represent viewpoints from outside the DoD, potentially avoiding cultural biases towards kinetic action that may be present in military leadership.
- Some approaches from academia (e.g., the Persuasion Game) avoid attempting to be a high-fidelity simulation of phenomena that are difficult to quantify, instead seeking to act as wargames that may generate valuable insights.

However, both approaches examined here suffer from a number of weaknesses that may not make them suitable candidates for basing a training platform off of, including the following:

- The Persuasion Game's wargaming approach required extensive staff and manual work to update its IE model, sacrificing economy for depth.

- Simulations like RAND's implementation of their Will to Fight Model often remain focused on kinetic action at the tactical level, making them an inappropriate fit to directly integrate into training for operational-level, non-kinetic actors.
- The Will to Fight model in particular, with its agent-based nature at the individual level, may not scale well to the regional scale of planning exercises used at military schools like the Army PSYOP school or the Marine Corps' MAGTF Operations in the Information Environment Practitioner Course (MOPC), and are not necessarily intuitive to operate or highly interactive.

At this point, with the strengths and weaknesses of both DoD and academic approaches in mind, we can productively examine what the private-sector world might offer.

1.3.3 Private Sector Simulations

Commercial wargames for entertainment, as a genre, are immensely popular, and are arguably one of the most robust entertainment sectors in the world. Not simply an enjoyable way to spend time, many of these games have led to genuine advances in real-time simulation, as in the use of the "behavior tree" concept for Artificial Intelligence (AI) making the transition from its creation for *Halo 2* to use in real-world robotics. (Colledanchise and Ögren 2017)

As discussed by Westera et al. (2020), many of the simulation techniques used in these platforms depart dramatically from those pioneered by government or academia due to differing priorities and the tendency of game developers to emphasize scalable approaches over novel but less-performant or riskier options.[8] These game-based approaches have often, however, fed back into military simulations in particular, with Czech game studio Bohemia Interactive's "ARMA" series of games sharing notable development effort with their "VBS" series of tactical-level military simulators (Westera et al. 2020, p. 352).[9]

[8]While the authors attribute this to a reticence by game developers to "embrace advanced AI," they also acknowledge that many academic approaches have "[failed]... to live up to their promises of enabling expert systems" (Westera et al. 2020, p. 352).

[9]Anecdotally, the use of games for training directly is widespread in the U.S. military at a level not often captured by the literature, due to ad-hoc and improvised use of games for training at the small-unit level. I have observed battalion- and company-level use of the ARMA 3 game, with a staff of one enterprising lance corporal, to visualize tactical wargames and to train forward observers. Often, these efforts are not shared above the unit due to non-standard use of issued computer equipment or a stated desire to avoid dealing

Figure 1.12. Stellaris's use of the DIME model. Source: Paradox Interactive (2016).

The space of commercial war games crosses all levels of military operations, and often utilizes all elements of the DIME paradigm to present players with a sense of challenge. Commercial games like *Stellaris* or the Civilization series, both of which position players as the heads of national or supranational organizations, naturally incorporate questions of deterrence and strategic interaction, although the spatial and time scales at hand (in the case of *Stellaris*, both of quite literally universal proportions) makes adapting such a platform to PME a difficult prospect. To their credit, both games/series explicitly allow players to advance their national interests through means other than kinetic action, representing a departure from the combat-focused view of platforms developed by the DoD. Despite their abstraction and often fantastical setting, many commercial wargames realize the DIME model explicitly, as in *Stellaris* (Figure 1.12).

Modeling influence operations in particular remains a niche subset of commercial simulations, and has often been constrained to the abstract strategic space. Little Red Dog Games' *Precipice* (Figure 1.13) is one such narratively coherent approach to simulating questions of strategic deterrence in the commercial games space. The game, a strategy offering with a Cold War backdrop, allows players the option of using various diplomatic, informational, military, and economic measures to thwart their rival superpowers' ambitions. However, the

with military bureaucracy. The institutional factors in these barriers to innovation would be fertile ground for further research.

game remains so abstract in its details that it would be difficult to draw meaningful insights from even a robust sampling of playthroughs, let alone attempt to divine any actionable insights for the real world from it (Little Red Dog Games 2019).

Figure 1.13. Representative screenshot from *Precipice* advertising material. Source: Little Red Dog Games (2019).

In many ways, *Precipice* is emblematic of both the strengths and weaknesses of many commercial wargames. It is accessible, easy to pick up for a novice or an experienced user, and requires no external support or specialized hardware, in stark contrast to many of the other approaches examined above. It also generates thought-provoking scenarios (albeit from a limited pool of possibilities) and expresses the DIME model in particular in a way that is interactive and memorable.

However, like many other commercial approaches, the game is in many ways incompatible with a potential training use case, at least directly. The same ease of use and low barrier to entry limit its depth, and the lower resources available to its developer compared to many DoD and academic entities introduce often-steep tradeoffs between fidelity and conservation of development time. Conversely, games like *Stellaris* have substantial development resources available and target audiences less constrained by hardware resources, making it difficult to map a potential development path from such private-sector offerings onto those possible within the defense space.

The cultural aspect of using commercial games for training may also be important to consider. Many DoD approaches have the "look and feel" of real-world command and control systems, with low-resolution graphics and simple symbology. Departing from this visual language toward one that emphasizes more visual fidelity or a more cohesive aesthetic may introduce a cognitive barrier for training audiences unwilling to be perceived as "playing games at work." This cultural aspect is a potentially valuable avenue for further study.

The landscape of simulations is constantly expanding; however, this survey provides a look into both the state of OIE-related simulation and the design influences behind this project as a whole.

With lessons learned from military, academic, and commercial approaches to simulating OIE in mind, I now turn to how these lessons informed the design of a platform to address the identified need.

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CHAPTER 2: Concepts of Competition and Design Considerations

Bearing in mind lessons learned from previous approaches to modeling OIE for wargaming, I now present both the conceptual underpinnings of the Pineland project, and the resulting design decisions that informed its technical development.

2.1 Representing the Cognitive Landscape through Social Identity Theory

The need to abstract the complex nature of human opinion, belief, and behavior to facilitate all of the above is a core issue for Pineland and one amply recognized by existing work in the field. Not every form of interaction is necessarily relevant to the types of scenarios Pineland presents, however—an individual's preference in food, favorite style of music, and so on may be indicative of their cultural identity, but represent a level of fidelity not necessary for the aims of a platform focused on operational-level wargaming. However, the notion of identity itself points to a conceptual framework for representing the cognitive environment in Pineland .

Social Identity Theory (SIT), as formulated by sociologist Henri Tajfel, posits that human identity is a function of overlapping identities, often ones that lend themselves to in-group/out-group distinctions (Tajfel and Turner 1986). For instance, a population engaged in Ireland's tumultuous period of resistance to British rule might be categorized by their self-conception as Catholics and Irish, often in a coincident fashion. However, populations within these groups might be further highlighted as having a strong male or female identity, loyalty to a particular town, and so on, with identities not necessarily being disjoint.

SIT also favors the development of a wargaming product due to the extensive body of research tying it explicitly to conflict and competition. Ward (2017), for instance, provides a model for applying SIT to international relations in general, and inter-state competition in particular. Citing such examples as pre-WWII Japanese militarism and pre-WWI international competition, Ward notes the utility of SIT in modeling state aims, and more particularly, the effect of mass social identity on goal-setting by political decision-makers.

Even more directly, Althaus and Coe (2011) use SIT to model popular support for war. Intriguingly, social identity here is quantified in part by popular opinion, and change in social identity is considered as a function not simply of the "tone and content" of messaging, but of the existing identities and the relative salience of each identity on the part of the subject.

This conceptual framework provides a useful structure to conceptualize population dynamics for Pineland , contextualized in the broader IE. For example:

- A population living in a region whose identity relative to the governing body is strongly negative may represent a population with a lack of loyalty, or one in open rebellion, to the governing body.
- An ethnically-diverse population in a city with low identity with their own ethnic group and a high identity with the ruling body might represent a well-integrated minority ensconced in the social structure, whereas the opposite situation might indicate a stigmatized minority. This tracks with observations from Maliepaard and Phalet (2012) on the integration and tension experienced by Dutch Muslim populations as a function of their social "in-group" identity with non-Muslim, ethnically Dutch neighbors.
- A population whose identity with a particular ethnic group is high may be more reluctant to believe negative reports or rumors concerning the ethnic group, and they may be predisposed to believe positive ones.
- A foreign aid recipient may identify more with the donor state, signifying some pan-national identity of "the free world," "the glorious proletariat struggle," etc. In this way, social identity theory presents a model not just of static identities, but of reciprocity between populations up to the national level, as noted by Doosje and Haslam (2005).

2.1.1 Applying Theory to Wargaming

Importantly for wargaming, the social identity approach lends itself well to modeling with quantified abstractions. For instance, identities can be modeled as values on a scale from completely regarding an identity as an out-group one, to completely regarding the identity as an in-group one. While this is undoubtedly simplistic, affording one axis of expression for identity, a population can be modeled as a vector of such identities to expand the representation space considerably.

For operations short of large-scale combat operations, social identity theory offers a way to model human interactions in a fashion that can be readily understood and manipulated in a way that highlights key questions that must be considered for OIE practitioners. Namely:

- What potential audiences exist in an area?
- Who are these audiences—does their self-conception match categories defined by governments and outside organizations?
- How does the target audience relate to other actors in the information environment?
- What predispositions do these potential target audiences have?

The application of quantitative techniques in social identity theory to conflict is by no means novel, and in many cases closely parallel common wargaming abstractions. Gallagher (1989), for instance, examines the conflict in Northern Ireland through the allocation of abstract resource points to others known only to experimental subjects as an aggregate of binary social identities, and finds meaningful correlation with real-world phenomena. Interestingly, Gallagher finds differing modes of interaction depending on whether the subject identifies with a majority or a minority identity, suggesting that social identities may have an asymmetric effect with regards to conflict.[10]

In sum, modeling the cognitive layer of the information environment in Pineland using social identity theory is both broadly understandable, and technologically feasible. This does not necessarily provide the highest fidelity possible; however, it follows from the purpose of the platform to provide exposure to OIE principles and to get a training audience asking relevant questions.

2.2 Platform Design Considerations

Synthesizing both the needs identified in research, the conceptual approach identified, and the resources available, I scoped the development of the Pineland platform to align with the following criteria:

[10]The Gallagher model is reflected in Pineland in part with the representation of ethnic and political identity described in Section 3.2.1.

- The geographic space of a Pineland scenario is operational in scope, where population interactions, unit movements, etc. are represented in the aggregate, not on an individual level. The scale should support multiple nations within the scenario space, yet be scalable to intra-national operations. This replicates the regional setting of the PSYOP culminating exercise, which is highly similar to the Persuasion Game's map (depicted in Figure 1.11) from Ormrod et al. (2020). (An example of a similarly-scaled scenario from Pineland is presented as Figure 2.1.)
- Human and technological networks must be accounted for and represented in a way that preserves both their relationship to, and distinction from, physical topology, following the observations of Abitbol (2020).
- Factors should be abstracted to the greatest level that allows disparate factors to remain identifiable; the platform should not require the training audience to have a deep understanding of the inner workings of factors (logistics, artillery fire, etc.) that they are not being trained for. An idea like "funding," for example, is preferable to forcing the training audience to contend with the entire budgeting process, in the interest of keeping the focus on OIE.
- Actors/units within the scenario should be scaled to the typical level they operate independently at, balanced with the scale at which the effects of multiple such actors are meaningfully distinct. For example, an infantry battalion, an Army Special Forces team, a PSYOP detachment, a shipbuilding business in a port, or a carrier strike group might all be represented by a single unit ach within the scenario.
- Limited kinetic actions should be within the scope of the scenario, but attempting to model ongoing large-scale combat operations is outside the scope of Pineland 's intent and may be better suited to existing DoD platforms. Similarly, a state of perfect peace is outside the scope of both reality and Pineland as a project.
- Competition between heterogeneous actors must be modeled—that is, units, organizations, and individuals with different aims and different means of achieving their aims. This loosely follows the theoretical work from McCormick and Owen (1999) in modeling competition across multiple domains, not simply the military-on-military competition characterizing many, perhaps most, extant wargames.
- Time scales should be artificially compressed, where the movement of troops, material, etc. and the development of social and economic currents proceeds quickly enough to illustrate their effects.

- The platform should support scenarios that allow for meaningful choices with degrees of success and failure, yet not be so divergent that comparative wargaming is impossible. If a training space does not allow for meaningfully different choices in a single scenario, the ability of users to experiment and learn from failures, compare approaches, and otherwise stimulate thought may be curtailed. Similarly, a scenario with an infinite possibility space may be just as unproductive, leading users to experiment with approaches not easily mapped to reality or to become apathetic in the face of overwhelming and hard-to-contextualize information.
- The conceptual language of navigating space, managing resources, and assigning actors employed in Pineland should mirror commercial gaming space. Leveraging the existing cultural capital of these platforms and marrying it with the existing conceptual language of the military offers a plausible path to creating a high-engagement platform with a low barrier of entry for the training audience.

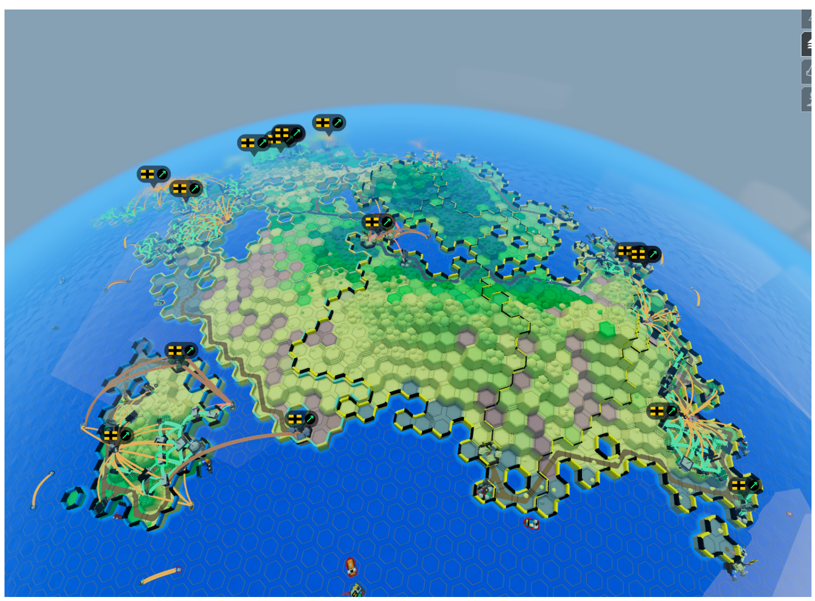

Figure 2.1. Example Pineland scenario

With a conceptual framework in place, development of Pineland was possible. In the next chapter, I turn from conceptual factors to technical ones that enabled Pineland to meet this design.

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CHAPTER 3: Detailed Platform Description

Here, I present the technical constraints that informed the development of the Pineland platform, as well as an overview of the platform itself. An exhaustive description of the platform would run counter to the intent to provide it as a standalone product capable of usage on its own terms. As a result, the following discussion focuses on those technical details that are of particular interest to realizing both a solution to the needs identified in Chapter 1 and the conceptual underpinnings discussed in Chapter 2.

3.1 Technical Constraints

In order to reflect the realities of creating a training platform suitable for use in an DoD environment, I placed a number of technical constraints in place prior to development, including:

- The platform must be able to be run on a computer of average power, not requiring specialized hardware, but not necessarily being capable of being run on a minimalist setup.
- To avoid the time overhead of developing with classified information, the platform itself must be developed on an unclassified machine, with unclassified data.
- To the greatest extent possible, the platform should leverage existing open-source (as in software, not as in intelligence) solutions, to permit faster development, avoid re-inventing technical wheels, and avoid licensing entanglements. Furthermore, all open-source libraries used should utilize a permissive open-source license, not a "copyleft" one (e.g., the GNU General Public License) that imposes restrictions on the use, modification, and distribution of the resulting software.
- Where network functionality exists in the platform, it must support asynchronous execution, not dependent on a reliable (or any) network connection, and must not require dedicated server hardware. This permits a more scalable platform, eases

development time required, and affords for the realities of situations with limited bandwidth.[11]
- The platform must run on Windows and Linux devices, with no mobile or Mac OS X deployment intended.

With these design and technical considerations in mind, I settled on the selection of the open-source Godot game engine to implement the presentation layer of Pineland in.

- Godot's open-source nature, allowing development to be self-supporting and not constrained by engine bugs encountered during development. In practice, this turned out to be a significant asset, with several controls only exposed via scripting by Godot replicated and altered to support functions specific to Pineland in C++.
- No cost or licensing requirements that would impair Pineland adoption by DoD entities
- An existing framework within the engine to tie platform-agnostic, high-performance C++ code to the engine without recompilation of the entire project
- A robust and easy-to-learn scripting language, allowing modifications to scenario events and unit AI to be written by end users without working knowledge of C++ or in-depth software engineering
- Low engine binary size and explicit support for older or lower-end hardware, with low start-up time
- My existing familiarity with the engine. This greatly reduced the time needed for development to reach a full pace.

In addition, I decided early on in the process that the presentation model should be one familiar to users of commercial strategy games, using the visual language and interface modalities expected by a force now largely having grown up in the era of computer games.[12]

[11] Ultimately, a client/server model was employed for multiplayer functionality as opposed to a lockstep-determinism model, in the interest of allowing one more powerful machine to act as server with more typical DoD workstations for clients on a local area network.

[12] Due to the relative ease the Godot engine affords to the process of "re-skinning" a user interface, a more staid appearance, or one more closely tailored to end user expectations, is easily achievable as future work.

3.2 Game Overview

3.2.1 The Physical Layer

Cells

Each game of Pineland takes place on an arbitrarily-sized hexagonal grid.[13] Each of these cells contains the following information:

- Basic physical properties, including water level, elevation, terrain ruggedness, vegetation cover, soil fertility, and baseline humidity and temperature. These properties are all exposed to the AI system and can be viewed by players. Differing units within the game are able to use this information to inform their decision-making and pathfinding, e.g., units on foot moving only through cells of sufficiently low ruggedness, or embassies being unable to host cultural events in areas with sufficiently low supported population density. This information is generated or loaded at scenario start and does not change throughout the lifespan of the game.[14]
- Unit dimensions supported in the cell, including land, sea surface, subsurface, air, and space dimensions. While in practice a cell always is available to air and space dimensions, and either land or sea surface, with subsurface dimensions being determined by a configurable water depth setting, support for more restrictive or less restrictive specification is included in the system. This supports situations where users may want to designate certain airspace as impassable, for instance, or use the presence of cloud cover to deny satellite sensors effective access to certain cells.
- Political information, including which national and/or sub-national entities the cell belongs to. While this information is not presently changed in any existing Pineland scenario; the underlying model allows for territory to change hands.

Units

The base element of Pineland , however, is the unit—here used, as indicated in the conceptual overview above, to represent virtually any actor or phenomena capable of having an independent impact on the scenario. While an extensible framework for creating new unit

[13]While this grid is segmented into sets of 16-by-16-cell chunks internally, this is entirely for performance purposes and is completely transparent to the end user.

[14]A description of how this information is generated is provided in Section A.4.

types is provided, the default set of units is comprised of over 200 entities ranging from cell towers to infantry units, and from tropical storms to internet "troll farms." Units are contained either within cells, to represent units with a physical presence on the map, or within other units, indicating a hierarchical relationship or the unit being physically connected to its parent unit; e.g., embarked units on a naval vessel. Each unit has a number of properties, including but not limited to the following:

- Basic identifying information, including a system-generated unique identifier, a unit name that will be displayed to system users, and a general "status" of the unit, where appropriate, to clarify what the "intent" of the unit is, not merely its observed behavior.
- Physical dimensions the unit can operate in, defined as land, sea surface, subsurface, air, and space dimensions. Support for units spanning multiple dimensions
- An arbitrary set of tags, which can signify both descriptive information visible to users, e.g., "On Fire," "Humanitarian," "Government-Owned," as well as information used in unit-level decision making, e.g., "previously seen by unit #123." This allows for scenarios to be easily constructed with new unit types that are fully interoperable with existing unit types. For instance, a scenario package focused on undersea warfare would not need to manually build compatibility with every possible undersea mine unit type, instead simply concerning itself with those subsurface units with the "mine" tag.
- A physical location and facing direction. Due to the operational focus of Pineland , the latter is specified as an enumeration of the six cell faces.
- An optional national identity
- A selection of unit behavior sets (discussed in more detail below) and actions available either to players or the AI (or both) controlling the unit. Settings for configuring the update rate of the unit are also available, to allow units such as cell towers to be completely reactive, requiring no compute time during each cycle of the simulation, or for more ponderous organizations to only react to new information in a certain time frame.
- A selection of currencies, representing resources available to the unit. These currencies can have optional set capacity limits, and support setting derivative values to model continuous change in their level without manually updating every time step.

These currencies are designed to be flexible, able to be changed in user-specific builds of Pineland with minimal effort, and include by default:

  - Money: For the purposes of Pineland , all money is considered fungible.
  - Raw materials: Representing potentially valuable resources (crude oil, unprocessed foodstuffs, etc.) that cannot be used directly in their present form.
  - Logistics: Processed materials that directly facilitate the actions of national and international actors. As Pineland is not intended to simulate logistics in the military sense in depth, a military unit's logistics in the system can be thought of as the sum of all medical supplies, ammunition, rations, etc. it needs in order to continue to provide combat power. Similarly, logistics for a protest movement can be viewed as the materials without which it cannot continue to effectively persist, not necessarily a specific good or resource directly.
  - Health: In a nod to the conceptual language of commercial video games, this represents the structural integrity of a unit, without which it ceases to exist as a coherent actor. This need not literally represent health in the medical sense, with the health of a cell tower representing its structural integrity, or the health of a military unit representing an amalgamation of its manpower and the physical condition of its men and materiel. In the example scenario, health is used as a measure of a unit's ability to continue to exist; logistics as a measure of its means to act.
  - Food: While primarily intended as a literal representation of sustenance, especially for civilian populations, this is also used as a proxy for goods necessary to sustain satisfaction in a population in the example scenario.

- A "blackboard," accessible to the AI system, to allow for arbitrary state information to be queried and stored on a per-unit basis, e.g., lists of other units of interest, internally-decided critical levels of currencies, as mentioned above, that will prompt further action, and so on.

Of note, many of these unit properties are not defined as a single variable, but as timelines charting the change of the property over time, similar to the approach described by Smith (2013). This allows for a scenario, at any point, to be viewed both forwards and backwards in time, or for a specific slice in time of the scenario to be examined in depth. Not only does this allow training audiences to examine the layers of the information environment in

Figure 3.1. A sampling of interfaces for a typical Pineland unit

depth to aid their decision-making, it provides a built-in capability for recording all training audience decisions and supplementing after-action analysis with a replay of the scenario that can be perused at leisure.

A selection of interfaces for examining units is presented in Figure 3.1.

Demography

Both cells and units have at most one population object assigned to them, representing the sum of all people in the cell or unit and tying the physical layer of the information environment to the network and cognitive layers. Each population is segmented along axes of ethnicity, age, and sex, allowing for fine-grained representation of demography. This segmentation can be manually specified along with a margin for variance, or can be completely procedurally generated as part of the scenario, using such factors as the population density and preference for sex-selective abortions of the ethnic groups represented to produce a plausible demographic breakdown.

Realizing the social identity theory aspects of the Pineland concept takes place in the population object, with each population having an arbitrary, changeable set of social identities that can be affected by scenario events, player actions, or the result of AI-controlled third parties. The process for determining starting identities relies on modeling ethnic diffusion, described in more depth in Appendix A.4. In brief, ethnicities are assigned a random origin on the land masses and a number of starting expansion factors from a configurable weighted matrix; these factors control both the means and the extent of the spread. An ethnic group with no maritime culture will not spread over water, for instance; an ethnic group with a nomadic aspect will settle in small, densely-populated pockets in areas of high population density, etc. The spread of ethnic groups is not exclusive; as a result, each cell capable of sustaining a population will have its population assigned starting ethnic identities in proportion to the strength of the ethnic group's presence in the cell.

Once national and sub-national borders are drawn as described in Appendix A.4, each population is assigned national identities. This involves a combination of where the population is located, the nature of the government, and the ethnic makeup of the population. For example:

- A population that is primarily of the minority but dominant ethnic group in a politically repressive nation will identify highly with its nation, while primarily majority populations will not, reflecting observations from scholars such as Hassan (2020). This effect is mediated by the relative size of majority and minority ethnic groups, reflecting the influence of threat perceptions on national and ethnic identities discussed by Verkuyten (2008), as well as the observations of Gallagher (1989) on the asymmetry of minority/majority interactions with respect to social identity.
- Populations in nations with highly politically open governments will tend to exhibit more variable levels of national identity, subject to the ethnic effects as described above. Those in nations with more repressive governments will exhibit a more polarized level of national identity based on both their ethnic similarity to the governing power and their overall prosperity.
- The overall in-group/out-group bias tendency of the constituent ethnic groups will affect their relationship to the state, with sharp in-group biases increasing ethnic identity and decreasing national identities for non-dominant ethnic groups, following the observations of Maliepaard and Phalet (2012) on Dutch Muslim integration.

From here, sexual identities are assigned based on the actual sexual demographics of the population, mediated by a weighted average of the constituent ethnic groups' tendencies towards misogynist or misandrist cultural biases.

Using a similar process, populations are assigned degrees of identity with foreign nations, using factors such as similarity to the foreign state's population as a whole, the relation between their nation and the foreign one, and the ethnic composition of the foreign state (e.g., a repressed minority in Country A will tend to view Country B, where their ethnic group is dominant, more positively).

3.2.2 The Network Layer

The network layer in Pineland is represented using a graph structure, with each node corresponding to a unit and each edge corresponding to a "channel," or type of information transition (e.g., television, radio, internet, etc.) possible between two units. Packets, corresponding to any type of messaging, can be pushed through these channels and produce effects in the receiving units.

The graph edges do not represent *actual* connections per se, rather their potential, and are recalculated on-the-fly based on the physical distances and transmission types available to each unit. Units are capable of both "push," "passive," and "pull" connections to the informational layer; a radio station, for instance, has push access to the network layer through radio channel, and will proactively be able to push network "packets" out. A housing development, by contrast, has only passive access to the network layer through the radio channel, able to receive packets through the radio channel but unable to transmit out. A cell tower has "pull" access through the internet channel, able to proactively connect to units with passive internet access and allow them to push packets through the internet channel.

Packets can contain an arbitrary amount of information in a key-value format similar to JavaScript Object Notation (JSON), as well as:

- Persuasive messaging attached to them
- Connotations indicating their favorability to certain identities
- Requests or advertisements for particular types of currency exchanges
- Suggestions for other unit actions to be taken in response to receipt
- Code to be executed on receiving units

The network layer is fully dynamic, with units connecting, disconnecting, and propagating packets in a fashion transparent to the end user, who need only worry about the content of packets and available connections when designing their scenario and unit AI elements. Internally, the network packets maintain one copy of the packet for graph, with propagation handled by a unique packet ID, and use an approach similar to the label propagation described by Zhu and Ghahramani (2002) to circulate packets through the network layer in a sufficiently performant fashion.

3.2.3 The Cognitive Layer

The cognitive layer in Pineland is represented through the intersection of demography and networks, with the identities of each population defining and being shaped by their actions, reactions, and movements in the physical and network layers. As described above in Section 3.2.1, each unit with a population contains an overlapping set of identities, complete with a degree of identification with each. This is abstracted as a set of timelines, with each point on the timeline representing a percentage of identification with a given identity. While this is undoubtedly abstract, and it is difficult to directly map to reality (i.e., what does identifying 50% with an identity mean?), it provides a useful abstraction that embeds social identity theory into the Pineland construct.

This information, depending on the configuration of the platform and user roles assigned, may be represented to the user as a direct view of the underlying values in the model, as an abstract "vox populi" style sampling of attitudes and statements, or using both methods.

Vox Populi

"Vox populi" mode is also intended to provide a means of generating content for training audience members to sift through, identify, and synthesize into intelligence in the course of a broader training exercise. The mode can either pipe out data in JSON format for integration with other tools in the training environment, or can be displayed directly to the user; from a given unit or selection of units, the following process is performed by the system:

1. The network connections of the selected unit(s) is sampled and the graph of all populations with some form of ability to communicated with the selected unit(s) is assembled.

2. Weightings are assigned to each unit in this graph based on the network distance and number of connections to the selected unit. A unit speaking face-to-face with the selected unit, for instance, is assigned a higher weighting than those communicating only indirectly with the selected unit via word-of-mouth rumors or the internet-based paraphrase of radio broadcasts.
3. A weighted selection of (unit, channel) pairs is drawn from this weighted graph, up to a number specified by the system configuration.
4. For each element in the list of units and channels, human-readable messages are created, using a generative grammar in a manner similar to Grasl and Economou (2010). The contents of this grammar are themselves generated in part using the open-source BLOOM language model from BigScience Workshop (2022).
5. The messages are formatted into JSON and/or formatted for display in the user interface, depending on the configuration.

Examples of the default view of these feeds, as presented inside the Pineland interface, are given as Figures 3.2 and 3.3.

Figure 3.2. "Vox Populi" view of a deteriorating situation in an isolated rural community

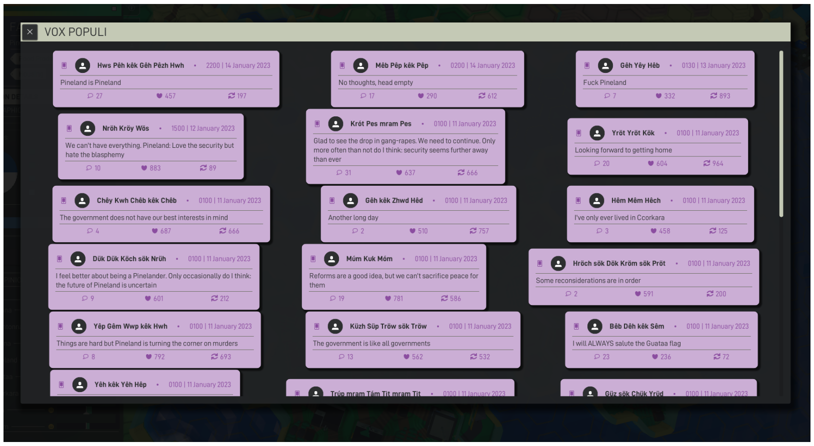

Figure 3.3. "Vox Populi" view of an internet-connected housing area with stable public identities

Changing Identities

There are two primary vehicles for populations to alter their identities:

1. Direct manipulation, usually done at the unit AI level. This is largely up to the user to define based on the desired scenario.
2. Response to packet arrivals. This is more involved and discussed in more depth below.

With respect to the latter, every unit is able to define an arbitrary number of reactions to an incoming packet as part of its AI scripting, defined in depth below. However, there are a number of mechanisms for altering identities that operate below this on the system level, allowing for most common forms of influence to be modeled in a sufficiently performant manner to support the scale of a Pineland scenario. These operations run once per unit upon first receipt of a unique network packet; repeated messaging campaigns are simply modeled as sending out copies of the desired packet.

Indirect messaging : The first of these mechanisms is the optional inclusion of connotations to any packet. These connotations indicate, in essence, a positive or negative action or event, who benefits from it, and (optionally) the originator of the action. Units will alter their identity with regard to the originator, then, based on their identity of the target(s) of the action. For instance, a packet with a positive connotation for Ethnic Group X from Country

Y may increase or decrease the identity with Country Y of the of a unit receiving the packet, depending on the unit's existing identity with both Ethnic Group X and Country Y.

This method is intended primarily for those actions which may or may not be messaging-oriented, but which have both an effect on the cognitive environment and no deliberate overt communication (speeches, broadcasts, internet posts, etc.) associated.

Direct messaging : This mechanism accounts for the direct and targeted exercise of influence in the cognitive layer. This consists of an arbitrary number of messaging campaign objects attached to a packet.

Each messaging campaign defines which channels it can spread through: for instance, a unit that is producing video content may be able to spread through internet and television, but due to the media involved may be less efficiently spread, or not spread, through radio or face-to-face-communication. The messaging campaign also includes an optional reference to the source of the messaging, which may not be the actual originator, allowing for the modeling of attributed official statements, mis-attributed memes, false advertising, and propaganda of the black, gray, and white varieties.

Each messaging campaign furthermore consists of one or more target audiences, which consist of a vector of weights per age and sex category (e.g., “18-25 year old men”) and per ethnic group. While these values can be decided by AI per-unit or manually input by players, weights are automatically recalculated from these suggestions to account for spillover effects, with a target audience of 18-25 year old men also targeting, even unintentionally and to a lesser degree, similarly-aged women and, to a lesser extent still, those outside those age and sex ranges. Similar spillover is applied for ethnic targeting, depending on whether the ethnic groups share a common language and the degree of in-group bias possessed by each.

Finally, each messaging campaign has one or more effects, consisting of the type, direction, and magnitude of desired identity change.

Resistance and change : In all cases, resistance and compounding effects to identity change include resistance configurable by system-level setting, where a more extreme identity is more amenable to further consolidation of the identity and is more resistant to change.

Quantifying the observations of Althaus and Coe (2011) in wargamable form, this is modeled as:

$$I = I(I_C, I_D, P) = I_C + (I_D - I_C) \times \text{clamp}\left(\left(\left(1 - \frac{|I_D - I_C|}{I_{\max} - I_{\min}}\right) \times \left[\begin{cases} \frac{1}{2} & \text{if } \text{sign}(I_D - I_C) > 0 \neq \text{sign}(I_C) \\ 1 & \text{otherwise} \end{cases}\right]\right)^{R_P} + R_F + \frac{P}{I_{\max}}, 0, 1\right) \times S$$

where:

- I is the actual identity value once a change applied
- I_C and I_D are the current and desired identity values, respectively
- $I_{\min}$ and $I_{\max}$ are the minimum and maximum identity values (by default, $I_{\min} = -I_{\max}$)
- R_P is a non-negative real number for the power of the resistance effect
- R_F is an arbitrary real number for the floor of the resistance effect, to allow for even a powerful resistance to result in some identity change, depending on the desired outcomes for the system use case.
- S is an abstract "similarity coefficient" $\in [0, 1]$ which can be set a number of ways depending on the effect—the Euclidean distance between identity values considered as a vector, normalized to the maximum possible such distance, a similar figure for the demographic difference, etc. This is intended to allow an out-of-the box ability for scenario creation to account for different theories of messaging resonance to be presented to the training audience.
- P is a per-unit, non-negative integer $\in [0, I_{\max}]$ indicating a "persuasiveness" of the unit in overcoming resistance, allowing for certain units to have non-demographically-related increased influence capacity.

These factors were arrived at through trial and error, allowing units to produce effects that parallel observations from social identity theory research cited in Section 2.1 with a substantial of tuning afforded to the end user.

Again, I emphasize here that Pineland is not intended to model the real world with high fidelity, and that this is an obvious abstraction. The goal is to provide those using the system with a means to demonstrate concepts in a way that stimulates valuable (and evaluable) responses and thought. While this algorithm is by no means elaborate, it allows for the modeling of messaging to account for such factors as messaging skill, resistance to change, demographic similarities affording easier transmission of messaging between groups, etc.

3.3 Simulation Flow and Unit AI

Each Pineland scenario runs until one or more nations in the scenario have achieved their victory condition, or until a specified global failure condition (e.g., the outbreak of widespread conflict) is met. Nations may reach a point where they are unable to succeed due to insufficient resources; however, in its current iteration, Pineland does not detect the case where all nations are unable to succeed, but not failure condition is present.

A Pineland scenario appears as a continuous flow to the users (although users with instructor roles may pause the simulation). Transparently to the user, however, the scenario is simulated in a cycle of steps. Each step consists of the following phases:

1. Queued manual user input, received since the last update step, is processed.
2. All unit physical positions are updated.
3. Propagation of packets through the network is calculated.
4. The effects of newly-arrived packets at units are calculated and applied.
5. Units conduct their individual decision-making and schedule their movements, actions, and network interactions for the next step.[15]

3.3.1 Unit AI

Unit AI decision-making may be made using any combination of the following techniques:

- Traditional text-based scripting
- A utility system with a user-friendly interface

For the former, units may use any number of scripts, prepared either in GDScript (the Godot engine's Python-like scripting language) or C#, executing both with an update function on

[15]In practice, this is usually conducted every N steps, not every step, for most units.

a specified interval, or in reaction to defined events (receiving network packets, currency changes, etc.)[16]

The latter method is similar, in that it uses functions called at specified intervals and in response to user actions; however, in place of traditional scripting, the system leverages a visual, node-based system developed specifically for Pineland that allows non-specialist users to quickly create and modify the behavior of various units in the scenario. This interface is depicted in Figure 3.4.

The system, built from the ground up for the Pineland platform, is at its core a utility AI system, where different behaviors are evaluated in terms of user-defined criteria, and the highest-weighted behavior is selected for execution. Each behavior takes its weighting from an arbitrary number of inputs, each consisting of a real number $\in [0, 1]$, and uses the formula from Mark and Lewis (2015) to avoid penalizing behaviors with a greater number of input values.

In a significant departure from Mark and Lewis (2015), the system only considers nodes indicating behaviors as special, using these to gather all connected nodes and construct an execution graph. Nodes coming after the behavior node in the execution graph are only executed if the behavior is selected, while nodes occurring before it in the execution graph are executed on every evaluation. Nodes may or may not produce effects, and consist of a wide variety of built-in types that allow users to simply and easily direct their units to query identities of other units, evaluate currency levels, perform network operations and transactions, and so forth. These node graphs are compiled once into memory when the first unit using them is created in the scenario, allowing for performant execution at runtime and a wide library of unit types while minimizing overhead.

In keeping with the conceptual design of the Pineland platform, there are no "special" units—units may perform operations on other units or request operations from other units, but social, political, and command hierarchies are allowed to emerge naturally from unit interactions. In the default scenario, for instance, an embassy unit disburses funding for

[16] While the Godot engine provides a functionality for a wide variety of other languages to be used, and this was used heavily for Pineland development, the use of Pineland -specific types for user-facing scripting in languages other than GDScript and C++ has not yet been tested.

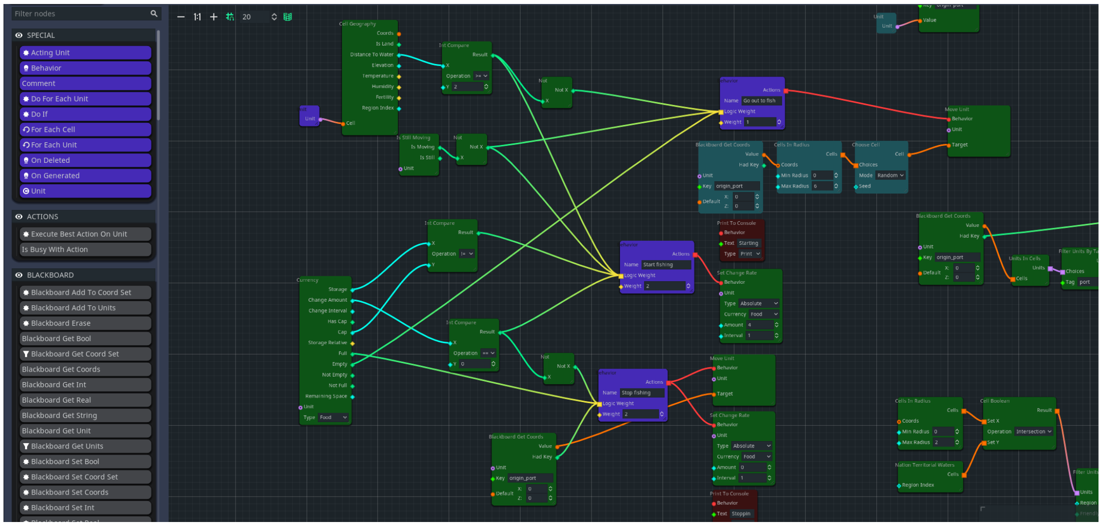

Figure 3.4. A view of the AI file for a fishing boat unit, demonstrating the use of a user-friendly, node-based interface for designing utility AI.

activities of its owning nation in the nation it is resident in, and the utility systems of various units requiring funding will construct an implicit plan of action.

Further work may allow this process to be parallelized; however, in the current state, processing of unit AI is performed sequentially in order to avoid race conditions in the state of units.

3.3.2 Victory and Defeat

While Pineland is intended to be adaptable to a wide range of training audiences, failure states for Pineland scenario are primarily intended to take a number of forms:

- The beginning of large-scale armed conflict. In the language of social identity theory as described in section 2.1, national-level identities have become so polarized that the in-group/out-group distinction escalates into violence.
- Adversary nations successfully achieving their OIE objectives in a contested third country, e.g., expulsion of the player's diplomats, the termination of a force basing agreement with the player's nation, etc. In social identity terms, one actor has successfully moved the identity of the populace far enough from the adversary identity

that the government is no longer willing to tolerate the presence of the actor with the newly-incompatible identity.

- Internal collapse of a player-supported third-party government; in this situation, one can consider the identity of being a loyal citizen has been displaced in the population by other identities that are not reconcilable.

Success, by contrast, typically entails avoiding these failure modes for a specified length of time, or may involve achieving diplomatic goals or the collapse of an adversary-supported regime. For the purposes of the default scenario, both the player and adversary nations are considered to be operating in an expeditionary fashion; that is, neither the player nor the adversary physically possesses territory on the scenario map, and their own domestic populations, governments, etc. are represented only in the most abstract sense. Other third-party "expeditionary" powers may also be present in a scenario, and are handled in a similar fashion.

Like all other aspects of the platform, further success and failure modes are able to be defined by the user and mixed with built-in and procedurally-generated content to achieve the desired goals.

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CHAPTER 4:
Applications

In its current state, Pineland is suitable for a number of applications, many of which were explicit considerations in the design and implementation processes.

4.1 Influence Training and Education

As discussed previously, existing wargaming platforms often focus on kinetic effects to the exclusion of considering the effects of informational and social phenomena. The explicit focus on modeling these phenomena in Pineland allows training audiences, many of which may not have been professionally exposed to OIE in any meaningful way, an opportunity to gain an appreciation for basic concepts and doctrine in a responsive, user-friendly environment that allows self-paced exploration, wargaming, and observation of effects. As part of a broader curriculum, Pineland can serve as both an introductory exercise as well as an interactive tool for visualizing plans and scenarios.

As developing partner force OIE capabilities becomes increasingly important for many OIE practitioners, Pineland also provides a platform for communicating key OIE concepts in a language-agnostic way, as well as providing a shared visualization of the conceptual aspects of a scenario that can be viewed from any angle, in both physical and network views, and in a fashion that allows observation of the real-world distribution of various ethnic groups and political entities.

4.1.1 Example Use Case: U.S. Marine Corps Operations in the Information Environment Practitioner's Course

MOPC, the Marine Corps' current answer to producing MOS-qualified OIE planning generalists for officers and staff non-commissioned officers, represents one possible use case for Pineland as a training tool.[17]

[17]The course, previously known as Information Operations Practitioner Course, has been selected due to my personal experience with the course.

The course is split into two parts. The first portion familiarizes students with the general concepts of the IE, its segmentation into physical, informational, and cognitive layers, and various considerations that go into developing an understanding. Presented in a lecture with PowerPoint providing accompanying graphics, this familiarization represents the first MOPC opportunity to integrate Pineland as a training tool.

Pineland provides a rich solution for familiarizing students with the IE in a way that can be stepped through and examined at their own pace, as well as being used by instructors to highlight points of interest on an overhead display. The platform natively provides a number of important features for this introductory phase:

- The ability to toggle between physical and network views, as well as to transition between the two contextually. For example, an instructor highlighting the relationship between physical and network layers can switch between viewing a key piece of infrastructure (e.g., internet exchange points, logistics nodes, etc.) in its geographical context and its network connections, many of which may be far from it geographically.
- Functionality to see a situation evolve over time, or to see the steady-state pattern of life in a scenario in terms of everything from flows of money and goods to media broadcasts.
- Features allowing existing data to be plugged into the Pineland model, allowing existing course scenarios to be brought to life in interactive fashion.

Furthermore, the platform provides features allowing a mix of pre-defined scenario content and procedurally generated content, allowing for such questions as “how does this situation change if this is a peninsula, not an island?” or “what does this same situation look like if a natural disaster wipes out fishing boats in a particular region?” to be explored in as much depth as the original scenario. This similarly allows changes to the scenario with a single click, such as simulating the impact to a local IE if key network nodes are degraded through cyber attacks, inclement weather, or other events.

The second part of MOPC, going into more detail about various information-related capabilities and culminating in a planning exercise, also represents an opportunity for Pineland to provide value to the training process. The platform allows students to wargame through courses of action, explore the rough contours of how a situation might develop in the wake of scenario injects. Much as in how instructors might use the platform to present a scenario in a level of depth not possible with traditional materials, students (or staff planners in general) can use Pineland to present their assessment of a scenario and potential courses of action, as well as play out possible outcomes, during a presentation. The abstract nature of Pineland works in its favor for this use case, with presenters able to manually add detail to a scenario where they wish to highlight particular points, and let the system fill in the remaining detail outside the area of focus.

4.2 General Professional Military Education

Within the Marine Corps, the existing Expeditionary Warfare School (EWS) and Command and Staff (CnS) military education programs for company grade and field-grade officers rely heavily on the use of wargames and scenarios. Well-developed scenarios backed by extensive supporting material, from notional intelligence reports to detailed description of adversary doctrine, are used to train burgeoning staff officers and commanders to understand the complexities of maneuver warfare. Most of the actual wargaming and training aspect, however, is left up to the skill and time of the often part-time volunteer instructors to provide, ranging from tabletop facsimiles of islands and turn-by-turn wargames to icons haphazardly strewn across spreadsheets.

Platforms like Pineland offer an opportunity for the traditional wargame approach to be presented to students at programs like EWS with far greater depth and responsiveness than that afforded by the existing approach. Especially for aspects of modern conflicts heavily driven by OIE, Pineland affords instructors the ability to have students decide on a course of action, then step through the consequences in detail before rewinding and exploring alternative possibilities. The extensive use of procedural generation also allows scenarios to be populated in depth with minimal effort on the instructors' part, simply choosing between an infinite selection of possibilities or downloading pre-built scenarios that directly model existing EWS or CnS course content.

Much as Pineland can be used in an OIE-focused training curriculum, the platform also lends itself well to general PME. The relatively basic functionality to handle combat in the platform still outstrips the often rudimentary manual wargaming present in most EWS sections, and affords instructors the opportunity to present a strong case for the impact of shaping actions on the battlefield. Questions that students in an EWS seminar might have, to which Pineland provides an out-of-the-box solution to aid instructors in answering and illustrating, include:

- How does a certain maneuver change when civilians in the area are motivated to actively provide information to the enemy?
- Which radio, TV, and internet infrastructure in an area is critical to the functioning of the civilian government, and what is the reach and audience composition of it?
- What might be the target of an enemy's attempt to degrade an ally or partner's ability to conduct stability and governance operations?
- Where can a local economy provide opportunities to lessen friendly forces' logistic signatures, and how willing is the population to cooperate with friendly forces in doing so?
- Where might refugees complicate both friendly and enemy schemes of maneuver?

With its abstract view of both informational and cognitive elements of the modern landscape of combat, Pineland also allows students who may not be OIE practitioners themselves to gain an appreciation of the effects of, if not the mechanisms behind, PSYOP, public affairs, cyber operations, and EW in shaping operations.

The example solution provided with the initial release of Pineland represents a scenario Marines looking at a position as a commander or on operational-level staffs in particular may be keenly interested in: A port call by elements of a littoral regiment-style amphibious force to an ally whose commitment is being tested by the interference of enemy fishing (and "fishing") vessels in their territorial waters and a coordinated enemy influence campaign.

4.3 Technical Training and Education

Existing programs for wargaming, modeling, and simulation, such as the Marine Corps' program at the Naval Postgraduate School, suffer from a lack of platforms that are both accessible enough for students with no technical background to learn with, and possess enough depth that more serious research and education is possible.

The Python-like GDScript interpreted language included in the Godot engine is extended in Pineland with full support for unit, landscape, and network manipulation and a robust

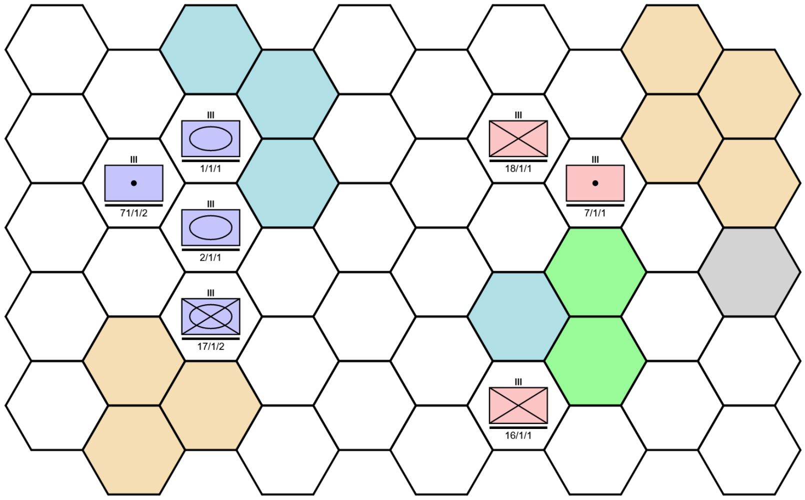

Figure 4.1. Representative screenshot from Christian Darken's "Atlatl" platform, used for training students in basic programming concepts at NPS.

error-messaging capability. The architecture of the platform affords students the possibility to experiment with writing different approaches to unit AI in a controlled, failure-tolerant environment that does not depend on a client/server architecture or any additional development software. As such, it could be considered a suitable and more fully-featured, user-friendly replacement for the in-house, in-development "Atlatl" engine developed by NPS faculty, as depicted in Figure 4.1.

For topics such as simulation interoperability, Pineland provides an out-of-the-box solution to the need for a platform with complex behavior and an easy-to-grasp language and data model for students to connect to existing, less user-friendly DoD systems. Pineland leverages the Godot engine's cross-platform components and modern, platform-agnostic C++ to provide users with an environment that is easy to install on a variety of systems in an educational setting, with no need for client/server setup, bespoke Python virtual environments, or other overhead impacting instructional time.

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CHAPTER 5:
Conclusion and Further Lines of Effort

5.1 Conclusion

Existing DoD products do not adequately meet the expressed needs of OIE practitioners for training tools, at a time when using wargaming and simulation techniques is already well-entrenched in the world of training for conventional kinetic operations.

Such products are often too specialized towards kinetic operations, require significant investment in resources beyond the means of most OIE-focused schools, or simply are not able to be integrated in an existing training pipeline without extensive technical work and education on the system itself. As a result, the staffing challenges of schools training OIE practitioners and other less conventional forces are exacerbated by an inability to leverage advances in automated training support tools.

As presented here, the Pineland platform offers a step toward solving to these challenges, providing a scalable and flexible platform for wargaming that realizes U.S. OIE doctrine and presents it in a user-friendly form on commercially-available hardware. With a focus on ease of tailoring to specific end-user requirements, Pineland provides a solid foundation for a diverse array of wargaming applications focused squarely on operations in the information environment.

5.2 Future Work

Further lines of effort for work on Pineland and integration into training pipelines could include:

- Deployment and testing with existing training pipelines.
- Testing with broader military PME courses.
- Integration of multiplayer functionality across the internet, allowing for disaggregated training sites to interact with the same Pineland scenario.

- Further integration of machine learning to display text and visual indications of sentiment, working backward from sentiment analysis techniques in order to present a higher-fidelity representation of the IE to training audiences.

APPENDIX A:
Further Implementation Notes

A.1 Application Architecture

As shown in Figure A.1, the Pineland architecture is structured such that there are three primary components:

1. The HexelGridInstance class, representing the linkage between the Godot engine's scene graph and the Pineland library.
2. The HexelWorld class, containing the model for the simulation. HexelWorld contains a number of structures within it to preserve encapsulation of function; HexelWorld's direct children include the data chunks themselves, a unit registry providing functionality to track, iterate over, and operate on all units in the simulation, and a set of atlases allowing fast retrieval of data for ethnic groups, regions, and similar entities.
3. Renderers, whether tied to a individual chunks (allowing for chunks not visible to not be rendered) or to specific unit types (i.e., all "Cell Tower" units share a same renderer).

All communication from the HexelWorld to the renderers takes place indirectly, with calls to create, destroy, or update unit representations passing into a lock-free queue within the renderer for deferred processing. This mitigates race conditions that would be prevalent with a direct-call model.

Heavy use is made of a signal/slot implementation from the EnTT library by Michele Caini and other contributors to afford this separation (Caini and other 2022).

The HexelGridInstance class is also responsible for the creation and management of a pool of worker threads that can be accessed arbitrarily by both its contained HexelWorld and various renderers. While this pool is used most heavily during scenario generation, in which many algorithms operate on chunk-by-chunk basis, it is also used at runtime to generate meshes for units and terrain, to parallelize graph algorithms on the network model, to enable pathfinding paralellization, and to conduct loading and saving. Each of these tasks

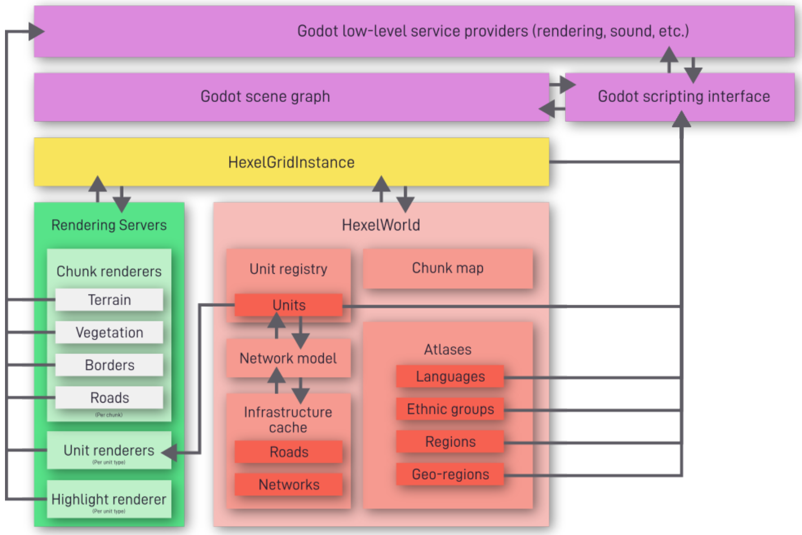

Figure A.1. High-level Pineland architecture. Note that communication between data (red) and rendering (green) is one-way, with the HexelGridInstance class (yellow) providing the interface to the Godot engine's functionality (purple).

is encapsulated in its own class agnostic to the type of executing structure, and can also be submitted to a serialized task manager for single-threaded execution in a guaranteed first-in, first-out ordering if needed.

A.1.1 Renderering

All renderers bypass the Godot engine's scene graph and instead interact directly withe the internal "servers" in Godot, essentially thin abstractions over lower-level APIs like graphics, sound, and input. This design choice was made after profiling the overhead required to instantiate thousands of units using the scene graph directly. This allows efficient batching of unit types, where the unit's flag (all of which for all regions are created at runtime and packed into a single texture dynamically), coloration, and other special visual data are represented by a four-component floating-point vector afforded by Godot to particle instances.

The version of Godot used (3.5.1) does not support dynamic batching of 3D objects; hence, the Pineland library handles its own batching, allowing for fixed-size blocks of rendered units to be allocated and deallocated in a fashion transparent to higher-level code. The batch size is designer-configurable per unit, with units commonly found in the hundreds (residential buildings, cell towers, etc.) typically having 512 or 1024 instances per batch allocated, with another batch allocated when more are requested. Instances within a batch that do not correspond to a specific unit are not rendered.

This scheme comes with tradeoffs, namely:

- Units do not have their own animations or effects, making it impossible under the current scheme to have, for instance, factories puffing smoke or tank treads rolling appropriately. Given the time constraints for development, relatively high-level view of the platform, and deliberately stylized aesthetic, this was considered acceptable.
- Viewport culling is not performed for units unless the entire batch is off-screen. Given the mobility of certain types of units and the batching being performed agnostic to unit position, this may present a waste of GPU time for larger scenarios, although thus far the benefit of batching to reduce draw calls has proved far more significant than any corresponding inefficiency.
- Units that have a substantial potential allocation of instances, but infrequent occurrence, may cause further waste. For example, swarms of missiles or drones in a more combat-oriented modification of Pineland . This can be mitigated, as has been done, by keeping batch sizes relatively low for unit types with a high potential for creation or destruction at runtime.

Most of these tradeoffs have been obviated by the upcoming Godot 4 release, which will likely provide a means to greatly reduce rendering-specific code within the Pineland library, offloading it to the engine. Code that does not interface with the scripting engine or renderers will likely require only minor modification for an engine upgrade.

Unlike visual rendering, sound uses Godot's scene graph in order to provide spatial audio, with the performance deficiency here being judged acceptable given the use of sound to enhance user experience, not to provide actionable data directly to the user. Audio source nodes are utilized under an object pool method managed by a separate thread and available to be played ad-hoc, transparent to the internal HexelWorld code. Units need only request a specific sound be played at their location from HexelWorld, which passes a signal up;

the HexelGrid class in turn accepts this signal and places it into a concurrent queue for processing by the spatial sound manager.

The meshing algorithm for rendering hex cells is inspired by Flick (2021).

A.2 Pathfinding

The abstraction of geography used in Pineland allows a number of optimizations to be made with respect to pathfinding. First, the decision was made early on to avoid having units impede each others' movement in any way. Thus, the ability of a unit to move from one cell to another is a function of the following:

- The movement type of the unit; i.e., whether it is capable of ground, sea surface, subsurface, air, or space movement. Units can have multiple movement modes to represent amphibious units.
- The terrain type of the cell moved into, i.e., land or water.
- The elevation change between cells, for land units only. Land units can only move between cells with a difference in elevation of no greater than one step.
- National borders, with units not entering hostile regions.

In a similar fashion as rendering, pathfinding is also handled independent of the world simulation proper; once units have conducted their AI passes for a tick and computed requested movement targets, their requests are passed to a pathfinding queue. This pathfinding queue uses the same lock-free concurrent queue as most of the other queues utilized in Pineland 's implementation. From here, the set of worker threads used globally by the HexelWorld instance computes pathfinding solutions in parallel before providing each respective unit with its pathfinding solution as each job finishes.

The algorithm used is vanilla A*. Profiling has not indicated that pathfinding is a performance bottleneck thus far, so only a few additional optimizations are applied. Pathfinding terminates early if the source and destination cells are not in the same geo-region (i.e., the same body of water, the same landmass, etc.) for the unit's movement type, if the source and destination cells are adjacent or the same, or if the unit cannot move into the destination cell at all (i.e., a land unit trying to move into a water cell). Additionally, the use of a unit flag constraining the unit to roads sharply narrows the search space for most civilian land vehicles. For the current iteration of Pineland , these considerations suffice to allow responsive pathfinding at scale.

Larger scenarios may well be able to be further optimized by a hierarchical pathfinding setup; however, the operational scale of Pineland means that most unit movements are constrained to a relatively small neighborhood, and those which are not, such as cargo ship port-to-port paths, can be cached on the unit level without needing to handle path caching as part of the pathfinding system proper.

A.3 Network Representation

The internal structure of the network graph is composed of a two-layer data structure.[18] The bottom layer handles graph algorithms and relationship structures, with nodes and edges represented solely as unsigned integer IDs without accompanying data save for adjacency lists, chosen due to the sparse nature of the network graph. The upper layer uses a hash map structure to map these node and edge IDs to indices in a vector of data items.

This two-layer structure was decided upon for two reasons: Firstly, the separation of data storage and graph representation enhanced maintainability and reduced development overhead by separating the need to manage memory for the data attached to nodes and edges from the representation of relationships. Second, many operations on the graph in practice did not require access to the adjacency information, instead iterating over a list of all edge data or all node data. Allowing these to be conducted without additional references and to be stored in a contiguous vector, preserving cache locality, was profiled to improved performance significantly for operations of this type. Many operations, additionally, only required adjacency information, without attached data. The performance overhead of an additional hash map lookup when querying the graph in such a way that required both adjacency information and attached data was not profiled to be significant.

A significant challenge during development of the network system was the calculation of connected components. Such calculations would need to be fully dynamic due to the constant insertion and deletion of graph edges at runtime, meaning that existing approaches like a union-find structure would not be effective. This is an active area of research, however, and

[18]Other graph structures, such as the one used to model international relations and the network of roads present in a scenario, use this implementation internally as well.

ultimately those aspects of Pineland that leverage connected components for optimization rely on calculating and caching connected components for nodes unlikely to change (e.g., stationary units in the network model) and brute-forcing dynamic units' connections with both each other and with static components.

A.4 Procedural Scenario Generation

A.4.1 Motivation and Overview

While in many cases it might be desirable to have scenarios crafted entirely by hand, whether to echo real-life events or to achieve a specific training objective, manually-generated scenarios come with a number of downsides:

- Significant time and effort may often be required on the part of scenario designers, compounded by the fact that the tools used to generate scenarios may not be familiar to designers.
- Generating the island environments of Pineland by hand, with enough complexity to pose interesting choices to the player, would require an understanding of the underlying system that would only add to the learning curve of prospective designers.
- A fully-featured program to create scenarios with enough ease to be a public interface would significantly expand the time and scope of the project. Focusing development on those aspects most germane to providing a workable wargaming environment for OIE, then developing a scenario editor tailored to those users who expressed interest in the project, was judged to be a better use of limited development time.
- During development, testing features in a variety of situations to ensure their correct implementation would necessitate development time spent creating scenarios by hand, not in the actual testing and debugging process.

For this reason, one of the foundational design choices for Pineland was to make heavy use of procedural generation, allowing scenarios to be loosely specified in terms of size, scope, and other factors, with the system generating a full scenario from the starting parameters. The system arrived at possesses a number of useful features that offer significant flexibility and the possibility of easily extending Pineland for any number of wargaming purposes:

- The system is completely deterministic. A given seed value will always produce the same scenario, when generation is performed with the same software version. Common sources of non-deterministic behavior are avoided, e.g., no floating-point calculations are used in the world generation process save for those attributes which are purely cosmetic.
- Most aspects of the system make heavy use of parallelization, allowing for faster generation on computers that support multi-threading.
- Parameters can be specified with as little detail as needed, or in enough detail that a very specific type of scenario can be created without having to hand-populate the world. Users can specify both geographic parameters from average humidity to maximum elevation, as well as human terrain data like number of ethnic groups and average friction between them. Users can also feed the generation system with hand-crafted components, such as countries, ethnic groups, and languages, to ensure that the final scenario will include the desired items.

A.4.2 The World Generation Process

To achieve the useful properties detailed above, the world generation system uses a layered approach. Multiple passes are made over the world, separated into distinct phases dealing with a layer of the simulation:

1. Geography.
2. Demography.
3. Political landscape.

A.4.3 Geography

In the first pass, the world is initialized to consist of blank cells in an $x \times z$-cell grid of the size specified by the user. For performance reasons, these cells are not stored in the world directly; rather, the world is divided into a series of square chunks, each consisting of a 16×16 block of cells and metadata associated with the chunk itself.[19] The first pass

[19]Chunk metadata largely consists of values allowing for early termination of functions that operate on a cell-wise basis; for example, each chunk stores the number of underwater cells it possesses, allowing a land unit's pathfinding process to skip the chunk entirely if it consists solely of water.

allocates a sufficient number of chunks and stores it in a hash map indexed by (x, z) chunk coordinates. Cells within the chunk are initialized to their default values.

In the second pass in this phase, land and water are determined. A set of (x, z) "tectonic seed" points with a Manhattan distance less than a specified value around the chunk are generated, using a Poisson process governed by a pseudo-random generator seeded by the world seed. From here, cells are assigned to the closest one of these tectonic seeds, effectively creating a cell-wise Voronoi diagram. A two-dimensional noise function with parameters specified by the user is then sampled, assigning these points as land or water.[20] Following this, a separate pass generates rivers between the "plates" at a user-specified rate. These border cells are identified simply by noting which cells have adjacent cells from different regions, with river generation determined by the river generation rate and a pseudo-random generator seeded by the indices of each adjoining region. From here, another pass identifies the distance to the closest water cell (for land cells) or land cell (for water cells), used for erosion and moisture diffusion modeling. Starting elevations, governed by a two-dimensional noise generator, are also applied in this step, before being attenuated towards sea level by a function mapping distances to the coastline to a $[0, 1]$ range.

Also computed in this step is a list of connected components for both land and water, enabling both the cosmetic naming of landmasses as islands and continents, but also several pathfinding optimizations during simulation (e.g., land units being able to disregard any cell not on the same landmass as a valid movement target).

Subsequent passes generate, in order, starting values for the wind, humidity and temperature values per cell, with each step informing the later values. Wind direction and strength are sampled from two-dimensional noise functions. Humidity is seeded in much the same way, with a configurable falloff function for elevation. Humidity is also modified with a simple diffusion model taking into account moisture transport from bodies of water, with the elevation and wind distance/direction from previous passes providing for rain shadows near mountains. Similarly, temperature is generated with a random noise function and then attenuated by user-configurable functions taking into account the inputs of previous passes, particularly elevation. A normalized "ruggedness" value, indicating the relative flatness of

[20]The noise function used for the various layered generators in the world generation steps are an adaptation of Perlin noise, implemented to use only fixed-point calculations for cross-platform determinism.

the terrain, is also computed in this pass, with 0 indicating a cell whose neighbors are all at the same elevation, and 1 indicating heavily corrugated terrain.[21]

A further pass applies a fertility value to each cell c, normalized into values in the $[0, 1]$ interval and computed as follows:

Here, $F(c), R(c), V(c), T(c), H(c)$ indicate the fertility, ruggedness, vegetation, temperature, and humidity of each cell, respectively, with the corresponding minimum and maximum values specified by the user taking the form of $X_{\min}, X_{\max}$. The constants used were determined experimentally to give plausible results. After this step, the cosmetic color of the cell (with no effect on the model) is assigned using vegetation and temperature as the (x, y) UV coordinates for a user-provided texture map.

A.4.4 Demography

At this point in the process, the model represents the given scenario in a state of nature absent human habitation. Human habitation is distributed with the following steps, in a similar fashion as that described by

1. Create a rough distribution of ethnic groups.
2. Use the ethnic data from the first step to determine a relative ethnic distribution in each cell, and the habitability score to determine population size.
3. Assign each cell a habitability value, constructed as described below.
4. Pick high-habitability cells as major settlements.
5. Link major settlements into a road network.
6. Create minor settlements along the road network and in a random sampling of other locations.

Ethnic Group Generation

Ethnic groups are generated by taking a user-specified distance d_{eg} between ethnic group origins and diffusion rates for methods of ethnic group spread and selecting land points at random. Points are selected until an iteration where no point can be placed within a distance

[21] An extension of this simulation platform to account for a more detailed model of maneuver warfare could easily incorporate the ruggedness and vegetation data into a measure of the visibility and mobility restrictions in a given area.

$d_{eg} \cdot \lfloor w_{eg} U(-1, 1) \rfloor$, where U is a uniform random distribution and w_{eg} is a user-supplied variance, to any other already-placed point. A modification to this process allows a point to be placed if it is on a different landmass to any existing point, allowing for the creation of islands with distinct ethnic groups.

Methods of ethnic group diffusion consist of overland diffusion, over-water diffusion, and colonial diffusion—the former two items represent the ethnic group's tendency to spread over land and water cells, while the latter is an integer indicating the maximum number of colonies an ethnic group can create. These colonies, with a number governed by this colony count multiplied by a random value seeded by the index of the ethnic-placement iteration and the world seed, simply repeat placement of a new point keyed to the same ethnic group as the previous point.

Data for each ethnic group is then generated. As a proxy for skin color, to account for inter-group interactions along these lines, each ethnic group is assigned a "melanin" score based on the baseline temperature in their origin cell. Ethnic groups are then assigned random values for ethnic tolerance and sex bias from user-configurable distributions.

A pseudo-language, following the approach of O'Leary (2016), is generated for this ethnic group. These pseudo-languages map English words to coherent "languages," where specific words in English will map to clusters of synonyms, and the pseudo-language as a whole has an internally consistent orthography, sentence structure, and syllabary. These languages have minimal additional refinement in the form of specialized genitive and definitive cases, as well as naming conventions, and like most data in the platform, can be specified ahead of time, partially-, or fully-user generated. This provides users of the system with further immersion, affording the appearance of different languages without the development effort of translation, and without giving any advantage to players who may have real-world understandings of languages they do not possess translation capability for in the simulation.

Every cell is then assigned a score for each ethnic group by a simple flood fill from the chosen points, with scores governed by the diffusion parameters mentioned above. The final score per group corresponding to the inverse distance from the group's initial origin point(s), and the scoring process is executed in parallel. Following, groups are ordered from highest to lowest scores within each cell and pruned based on the tolerance scores for each group in turn. For example, a group with the maximum tolerance score will conduct no pruning on lower-ranked groups within the same cell, and a group with the minimum will completely eliminate all other groups in the cell. This process is carried out from the most prevalent group to the least, resulting in an ethnic distribution with a diversity of human terrain, from large swathes of mono-ethnic cells to dense clusters of diverse populations.

Habitability Scoring

Habitability scoring is accomplished using the following equation:

$$\text{Hab}(c) = \sum \begin{bmatrix} w_{dw}\left(\dfrac{1}{D_w(c)}\right) \\ w_R \cdot (1 - R(c)) \\ \left(\dfrac{1 - E(c)}{E_{\max}}\right) \\ w_{nw} \cdot \left(\begin{cases} 0 \text{ if } N_{nw}(c) = 0 \\ \left(1 - \frac{N_{nw}(c)-1}{5} \text{ otherwise}\right) \end{cases}\right) \\ w_F \cdot F(c) \\ -w_F \cdot \left(\begin{cases} 1 \text{ if } T(c) \in [T_{\text{pop\_min}}, T_{\text{pop\_max}}] \\ 0 \text{ otherwise} \end{cases}\right) \end{bmatrix}$$

In addition to the above definitions, $T_{\text{pop\_min}}, T_{\text{pop\_max}}$ indicate the minimum and maximum temperatures for population specified by the user, while w_X indicates the user-specified weighting for factor X. Of particular interest is N_{nw}, the number of neighboring cells to the given cell that are underwater. The formula is intended to provide higher settlement scores to cells that have a natural protected harbor; this behavior can be configured by the relative weighting of w_{nw} and w_{dw}, the weighting of the number-of-water-neighbors and distance-to-water factors, respectively.

This scoring occurs in parallel; after it is complete, the main world generation process selects cells from the scored list in descending score order, until no cells remain that are within a user-configurable distance (with a pseudo-random variance created with a given uniform distribution by the user, seeded by the cell global coordinates' hash) seed from other major settlements. This ensures a relatively even distribution of major settlements without undue regularity, reflecting the phenomenon of human settlements to cluster in geographically-desirable locations and the relative but not exclusive prevalence of metropolitan areas without other large settlements nearby.

These settlements are then linked by roads. These are computed in order of the habitability list using an A* algorithm with a step to disregard non-like-landmass cells. The weighting and heuristic functions are both tuned to prefer using existing roads rather than creating new ones. The end result of this step could be adapted into a tactical-level wargame's means of generating settlements in and of itself—but for the operational/strategic-level focus here, further processing is done.

Additional settlements are then placed using Poisson processes in two passes, one along major roads, and one in a disc from major settlements, all governed by user-configurable parameters. Once the specified number of minor settlements have been placed, the settlement placement terminates and minor settlements are linked to the closest existing road, using a pathfinding process nearly identical to the initial road placement.

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