Tools for the Creation of Semantic Information for Modeling and Simulation

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ABSTRACT: *Current combat simulations use polygonal representations of the terrain, augmented with vector data, for terrain reasoning. Algorithms such as vehicle movement and line-of-sight use these data to determine vehicle speed and orientation, as well as for targeting and navigation. While these data provide the basic terrain representation needed for vehicle dynamics and weapon system effects, they do not provide the semantic information needed for higher level reasoning, especially for modeling of human behaviors within a combat environment. Semantic information goes beyond the physical characteristics that most terrain databases provide, and includes relationships between terrain features and how they can be used in the performance of specific combat missions. This paper will discuss current work MÄK is doing for the US Army Soldier System Center to generate semantic terrain information for the Infantry Warrior Simulation (IWARS), a constructive simulation being developed for analysis of infantry tactics and equipment. Geoprocessing models are being developed in C/JMTK to generate mobility, cover, and concealment features for use in planning and movement behaviors. Scripts for Autodesk 3ds Max are being developed to automate the generation of semantic information for building interior representations.*

1. Introduction

Under a Phase II SBIR contract with the Natick Soldier Center, MÄK Technologies is developing tools to generate semantic information for modeling and simulation systems. ESRI's ArcGIS is a component of the Commercial Joint Mapping Toolkit (C/JMTK). It is used in the modeling and simulation (M&S) terrain database generation field mostly for source data preparation, but it also provides capabilities for semantic information generation. For example, the Spatial Analyst and 3D Analyst extensions can be used to classify elevation data and create geoprocessing tools to create new features for mobility, cover, and concealment. These features can be used by combat models to change movement behaviors or in planning algorithms. Three dimensional modeling programs, such as Autodesk 3ds Max, can be used to generate geometry and attributes for movement within building interiors. This paper discusses current work MÄK is doing to generate semantic terrain information using ArcGIS and 3ds Max for simulation applications.

2. Terrain Database Representations in M&S Systems

Typical terrain databases for modeling and simulation come in two varieties – those for 3D visualization and those for computer generated forces (CGF) applications. The 3D visualization databases need to "look good", especially in relation to the real world. These databases consist of a terrain skin represented with polygons that are generated from a digital elevation model (DEM). These polygons can be based on a regular grid or based on a Triangulated Irregular Network (TIN). TINs allow databases to be load balanced, utilizing polygon budgets where they are most needed in areas of highly varying terrain. Integrated TINs take this one step further and integrate feature data into the tinning process, such as cutting roads and rivers into the terrain skin. Figure 1 is an example of the integrated TIN process.

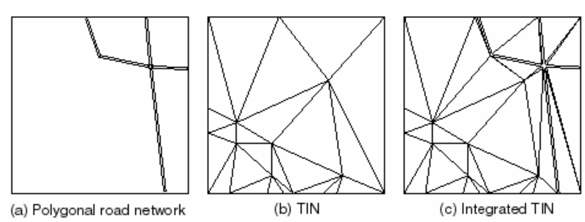

Figure 1: Road, TIN, and Integrated TIN

Along with the terrain polygons, visual databases include texture information to provide a visualization of ground and material types. These databases include 3D models for buildings, trees, and other cultural and natural point features, as well as 2D linear and area features with specific textures for roads, rivers, lakes, etc. These databases may also have aerial imagery draped over the terrain skin for a realistic visual representation.

Terrain database for CGF systems are quite different from these visual databases. While CGF systems may use their terrain information for 2D visualization, the main use is for terrain reasoning. CGF terrain contains the geometry and attribution of elevation, cultural and natural features, used for vehicle placement, movement algorithms, and line of sight. Movement algorithms include path planning, obstacle avoidance, and vehicle dynamics models, while line of sight algorithms are used for targeting and communications. CGF terrain databases have a terrain skin, similar to the 3D visualization databases, but include more attribution data instead of textures. This attribution data allows the computer models to reason about the terrain explicitly, without having to infer information. Terrain skin attribution may include soil type (including water), mobility characteristics, and vegetation characteristics.

In addition to the terrain skin, CGF terrain databases also include point, line, and area features, which are also attributed for computer reasoning. These attributes include feature type, geometric characteristics like width and height, and more semantic information like road network topology. These databases may also include 3D models associated with point features, which run the gamut from high fidelity building models with interior structure to low fidelity “overturned shoe boxes”.

Other key aspects of CGF terrain databases are compactness and spatial organization. In order to provide optimal performance, CGF terrain database are kept as compact as possible so that they can be stored in computer memory in whole, eliminating the need for costly disk access. They also include a spatial organization so that all of the terrain data around a location can be found quickly. Spatial organization schemes can be grid-based or hierarchical, like quadtrees or octtrees. [1]

3. Semantic Information for Modeling and Simulation

Terrain databases for modeling and simulation do not contain much semantic information, which a person looking at the actual terrain or a map would be able to deduce about the terrain. This includes information such as how roads can be used to cross rivers at bridges, areas of the terrain that would have mobility restrictions for different vehicle types, how depressions or elevations in the terrain could be used for cover and concealment, or how small units can navigate within urban features such as buildings and sewers. This semantic information could also be used for predicting enemy movement and locations, and is required for higher-level terrain reasoning and human behavior modeling, especially in urban environments.

We started this project by determining what semantic information is needed for M&S and what tools are available that could help generate it. We investigated existing simulation combat model requirements to determine the types of semantic information capabilities required to improve their realism and performance. We focused on dismounted infantry (DI) and vehicle combat model requirements. We worked with the combat model developers to prioritize the requirements and develop a strategy for generating and representing this semantic information. We investigated availability of source data for this information and how it can be incorporated into simulation terrain representations.

The types of semantic information needed fell into two categories – semantic information for building interiors and semantic information for cross country mobility, cover, and concealment [2]. For building interiors, MÄK is using 3D modeling tools to develop complex representations. For the other areas, we are using ArcInfo and extensions. Table 1 shows an initial list of semantic information requirements.

Table 1: Semantic Information for M&S

Point Features	Cover	Direction (N, NW, etc.) Unit Size (DI, Vehicle, Platoon, etc.) Topology (Nearest points of same type)
	Concealment	Direction (N, NW, etc.) Unit Size (DI, Vehicle, Platoon, etc.) Topology (Nearest points of same type)
	Bridges	Weight limit Overhead clearance Length Width
Linear Features	Integrated Road & River Network	Segments Intersections Crossing Points (Bridges, Fords, etc.)

	Ridge and Valley lines (see Sec. 6)	Segments Intersections Linked military crest and valley areas
	Linear Danger Areas	Examples - Roads and Trails, Rivers and Streams, Wire Obstacles Segments Type Height or depth, width Current speed and direction
Area Features	Cover (see Sec. 7)	Direction (N, NW, etc.) Cover Level (Good, Fair, Poor, etc.) Unit Size (DI, Vehicle, Platoon, etc.) Topology (Nearest areas of same type)
	Concealment (see Sec. 7)	Direction (N, NW, etc.) Concealment Level (Good, Fair, Poor, etc.) Unit Size (DI, Vehicle, Platoon, etc.) Topology (Nearest areas of same type)
	Trafficability (see Sec. 5)	Slope Soil Composition Vegetation Type Topology (Network between similar areas)
	Military Crest (see Sec. 6)	Highest elevation from which contour base can be seen without defilade Linked ridge lines
	Valleys	Linked valley lines Width and depth
	Danger Areas	An area where an entire unit can be destroyed quickly. Examples - Large field or open flat area where no cover and concealment exists, Vegetation area that does not provide cover, Minefield, Villages or urban areas. Type

4. Semantic Information in C/JMTK

ArcGIS products are used in the M&S terrain database generation field mostly for source data preparation, but they also provide capabilities for semantic information generation. One such capability is the ability to perform thematic mapping, based on source data attribution. For example, DFAD data provides feature and attribute information, but is provided as one big file with everything included. ArcView allows one to very quickly sort feature data by feature type (point, line, area), and more importantly, by feature classification (See Figure 2). Separate layers can be created for road, river, and railroad linear features, which can be retained in the terrain database generation process as thematic layers. Similar classifications can be performed for point and aerial features. This tool could also be used for semantic culling – for instance removing features that are not relevant for the combat models or level of fidelity of the simulation.

There are two ArcGIS extensions that provide additional capabilities for semantic information generation, 3D Analyst and Spatial Analyst. With these extensions, one can classify elevation data and create aerial features based on slope and aspect (direction of slope). These features can be used by combat models to change movement behaviors or in planning algorithms.

ArcInfo provides even more capabilities for semantic information generation, by adding higher-level processing, particular the ability to generate topologies within and between features. This topology information can also be retained in the terrain database generation process, providing semantic information for planning algorithms. The topology rule enforcement and editing capabilities within ArcInfo allow source data to be cleaned up prior to importation to database generation systems. Some examples include checking road networks for connectivity at intersections or overlaps that do not have an associated intersection, checking aerial features for overlapping areas that should not overlap or gaps where they should be adjacent, and checking line features that represent linear boundaries to line up with aerial features that they are associated with.

The ESRI ArcGIS products were chosen for this project because of their large number of internal spatial data processing and analysis functions, and because it is one of the components in the C/JMTK suite of tools. The Army's Battlespace Terrain Reasoning and Awareness (BTRA) program is also using this tool to develop visibility and mobility maps, and we can leverage that work as well. We are developing geoprocessing models and scripts that automate the steps needed to generate semantic data.

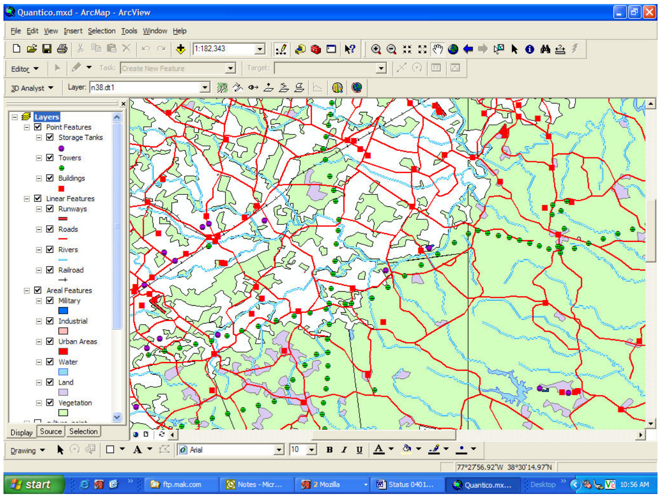

Figure 2: Thematic layers from DFAD data

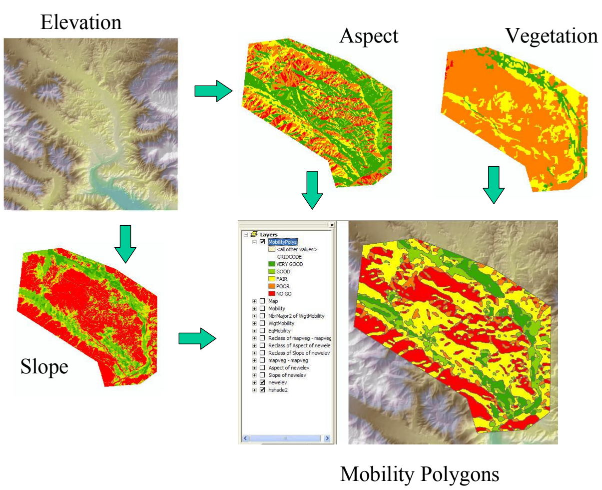

Figure 3: Mobility Map Generation using Spatial Analyst in ArcGIS

5. Mobility Feature Generation

The Spatial Analyst extension in ArcInfo was used to generate polygonal mobility features from vegetation feature and raster elevation data, to satisfy the Trafficability Area Features requirement. Three raster data sets were created representing vegetation, slope, and aspect. The vegetation data set was created by converting a vegetation layer containing polygons to a raster, which was reclassified to represent six mobility types.

The Slope tool was run on a DTED data set to create a slope layer, which was reclassified to represent six slope ranges. The Aspect tool was run on the same DTED data set to create an aspect layer, which was reclassified to represent six aspect ranges. These three layers were combined using the Raster Calculator to generate a single raster data set. Different weights were used for the three layers, with slope being the highest weight, aspect second, and vegetation being the lowest weight. The resulting raster was generalized using neighborhood statistics to eliminate very small features, and the generalized raster was converted to polygonal features. Figure 3 shows the process and the intermediate results.

We further refined this process, utilizing USGS data around the Boulder, Co area. Using ArcInfo with the Spatial Analyst and 3D Analyst extensions, the Slope tools was run to generate a slope raster, then the Reclassify tool was used to reclassify the slopes into six categories based on the standard Army slope categories from FM 5-33 Terrain Analysis [3]: 0-3%, 3-10%, 10-20%, 20-30%, 30-45%, greater than 45%. These slope areas were generalized with the Generalization tool, and reclassified again to three categories for use in the simulation – GO (0-10%), SLOW-GO (20-30%), and NO GO (greater than 30%). Finally, the Raster to Feature tool was used to generate polygons of the raster areas, which were exported as Shape files. Figure 4 shows the polygons that were generated.

These mobility polygons needed to be refined to create mobility features for the simulation. The original slope polygons had some very large areas that included many interior rings, and some of the areas had a very large number of vertices. The Aggregate Polygons and Simplify Polygons tools available in ArcInfo 9.2 were used to generalize the mobility polygons. We used the Features To Geodatabase tool to convert these areas to Shape files, which added Area and Shape Length (perimeter) attributes, and calculated the values for these fields. Figure 5 shows an image of the generalized mobility polygons in ArcInfo.

The mobility polygons needed to be mapped to a FACC code, so that MÄK's VR-Forces CGF could identify them. The mobility shape file was updated in ArcInfo to include a new attribute Mobility_Type, which was set to either "NO_GO" or "SLOW_GO". In VR-Forces, the DB170 Slope Category FACC code was used, which was mapped to the Mobility_Type attribute in the Shape file. The Colorado database with the imported mobility areas (in purple) is shown in VR-Forces in Figure 6.

The path planner in VR-Forces was modified to use these new mobility features, and the new behavior is shown in Figure 7. The view on the left shows the path planned for an M1A2 vehicle to Waypoint 3 in the Southeast. The direct route runs through the SLOW_GO and NO_GO areas, and the planned path avoids both these areas, as well as the river, since water features are included in the impassable list of the path planner. The view on the right shows the planned path from the M1A2 to Waypoint 1 in the Northeast.

The direct route again runs through the SLOW_GO and NO_GO areas, but this time the planned route goes through the SLOW_GO area, since this path is less costly than going all the way around the North of the SLOW_GO area. If the M1A2 in the left view is tasked to go to Waypoint 2, which is in the NO_GO area, the path planner warns that no route could be generated, since there is no way to avoid the NO_GO area.

When feature information is also available, we have developed a more sophisticated geoprocessing model for generating mobility features. This model uses the Union tool to merge tree areas with SLOW_GO areas based on slope. It then uses the Clip and Buffer tools to cut roads into the SLOW_GO and NO_GO areas, providing access through those areas. We also generated a tool that removes overlaps between the SLOW_GO and NO_GO areas.

Combat models in the simulations can use these mobility features for a variety of functions, ranging from simple path planning to higher level mission planning. As shown with our work with VR-Forces, these features can be used to help generate paths for individual vehicles or units. For higher level mission planning, these features could be used to predict enemy movement and identify potential choke points or kill zones.

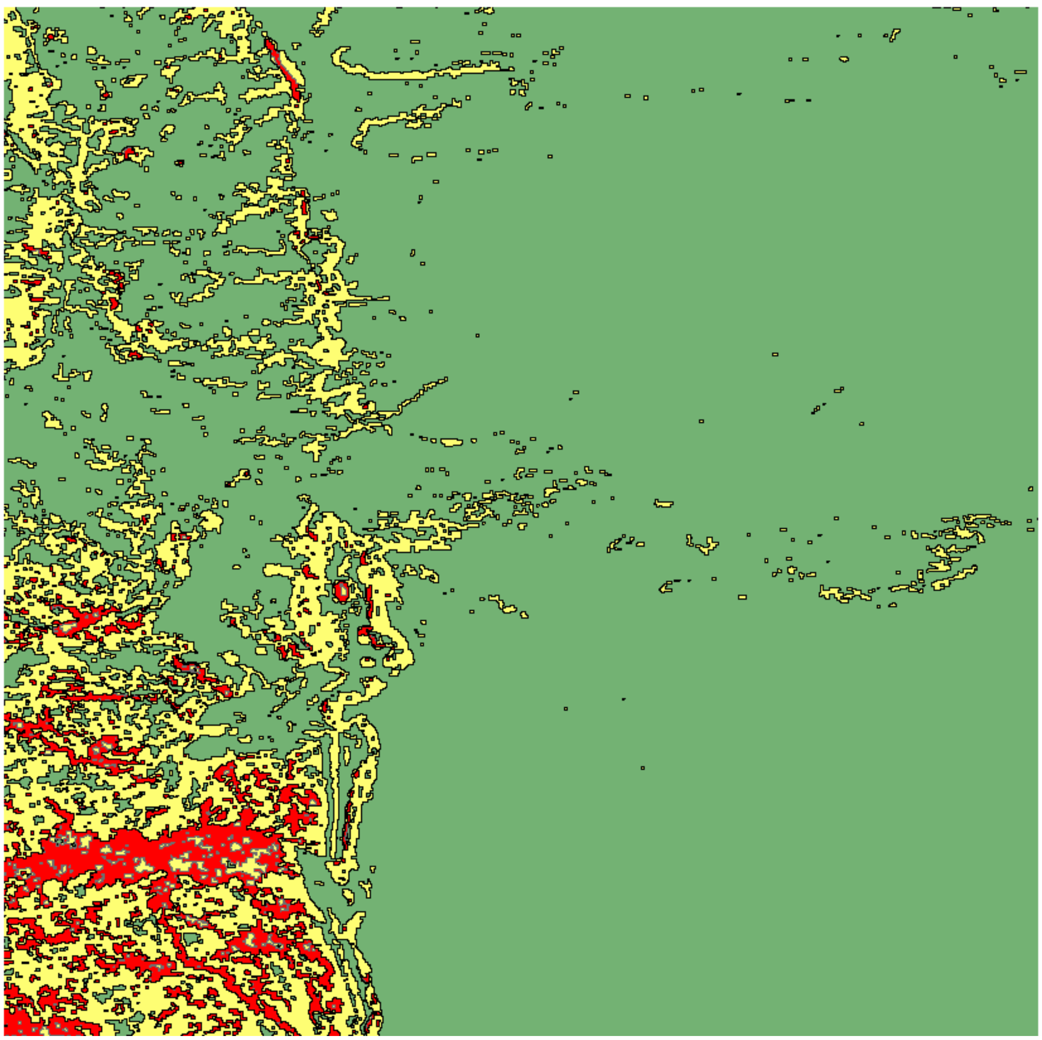

Figure 4: Slope Polygons from Colorado DEM

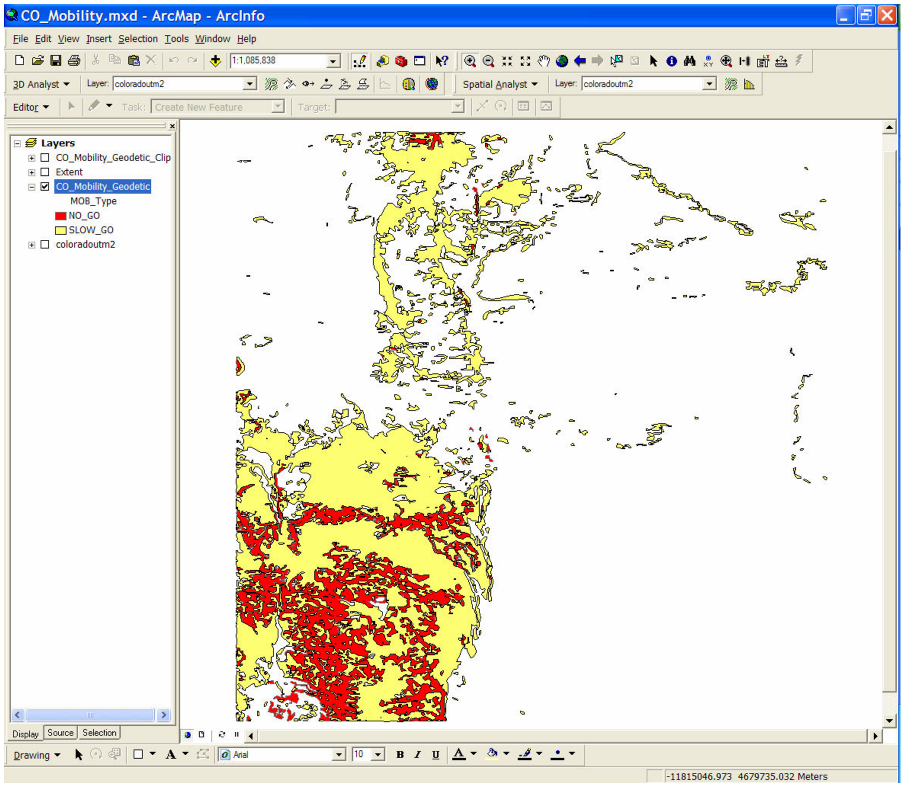

Figure 5: Generalized Mobility Areas

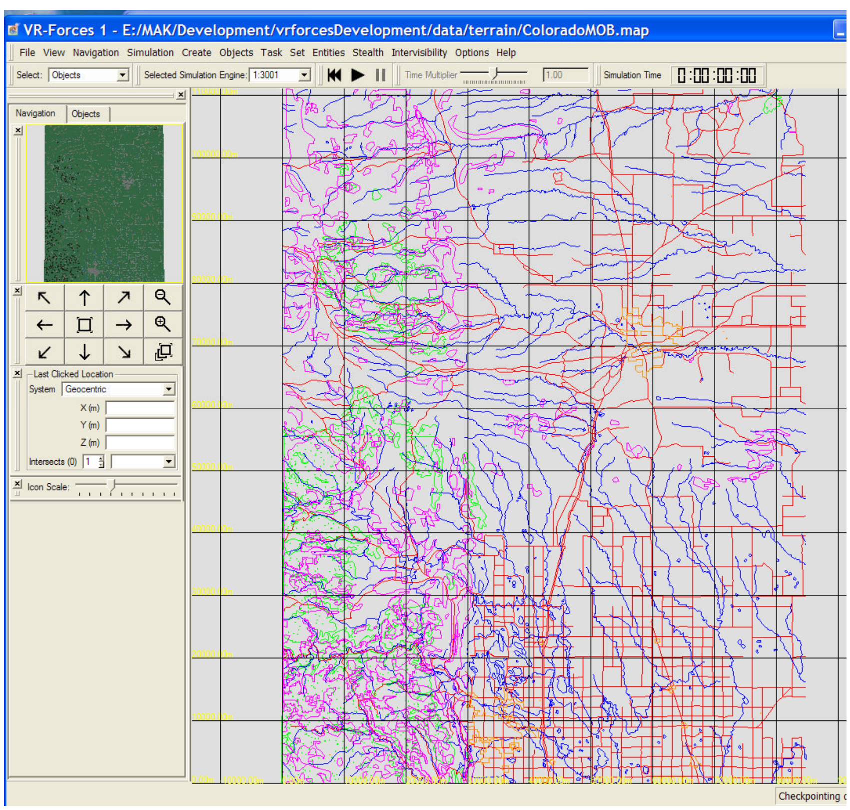

Figure 6: Colorado Database with Mobility Areas from Shape File

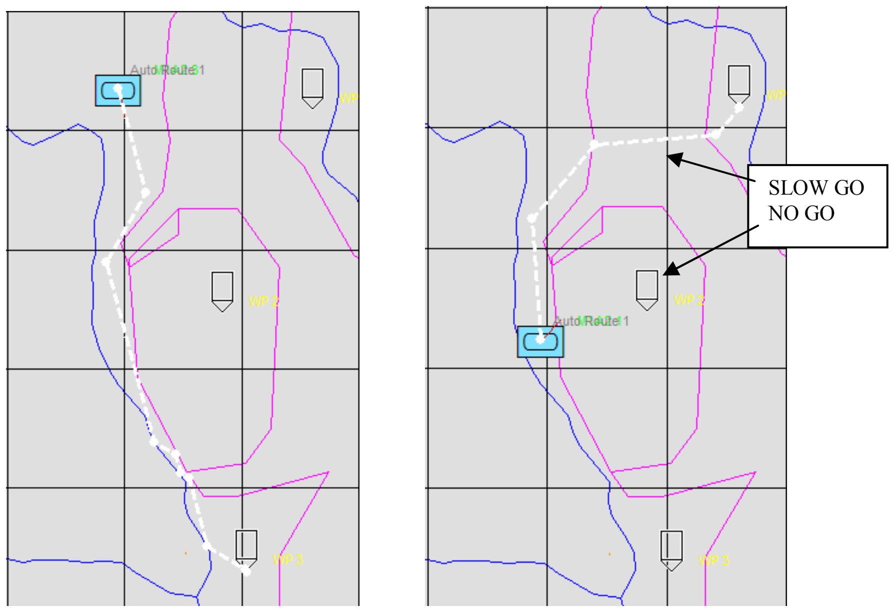

Figure 7: Mobility Areas in VR-Forces Path Planning

6. Ridge and Valley Feature Generation

In order to satisfy the Military Crest Area Feature and Ridge and Valley Lines Linear Feature requirements, we started by generating ridge and valley edge features from digital elevation models. Figure 8 shows the geoprocessing model for this process. Slope and aspect rasters are generated from the DEM, along with a raster of aspects for areas of high slope in the Slope and Aspect model. The Zero Accumulation model uses the Flow Direction and Flow Accumulation tools from the Spatial Analyst Hydrology toolbox to find all raster areas that would have zero water accumulation. The Ridgeline Features model finds the zero accumulation areas that correspond with the high slope aspect areas, which are converted to polygons and simplified. The resulting polygons represent ridge line areas. For valley edge areas, we developed a Toe In Slope model, which separates the slope raster into a raster of high slopes and a raster of low slopes. These rasters are then used to select the original elevation data from the DEM for each of these slope categories. A 3x3 Mean filter is run over each of these elevation rasters, and a Map Algebra expression finds the areas where they overlap, which corresponds to the valley edges. The Remove Overlaps model uses the Clip and Erase tools to remove overlaps between the ridge and valley edge features, and the Dissolve tool is used on each set of polygons to remove overlaps within the ridge and valley feature sets.

After this model is run, the ridge and valley edge polygons are converted back to rasters for vectorization. We are using the ArcScan vectorization editing routine to create center lines from each of the ridge and valley edge areas. The Identity routine then associates each line with the valley or ridge polygon they are contained in. Figure 9 shows the resultant ridge and valley areas and lines.

Combat models could use these ridge and valley features for generating sophisticated routes that use the underlying terrain for observation of potential enemy locations. Line of sight checks could be performed from the ridge lines to the valley lines, in order to generate routes that follow military crests. We are in the process of upgrading the tools to perform these tests.

7. Cover and Concealment Feature Generation

In order to satisfy the Cover and Concealment Feature requirements, we again used tools from the Spatial Analyst extension to generate linear features that correspond to cover and concealment, based on slope/aspect, tree areas and built up areas. For the slope/aspect features, a raster of aspect values for areas of high slope is generated. We developed a model that uses the Focal Statistics tool with a Wedge neighborhood to shift pixels in each one of the eight cardinal directions. The tool then performs a subtraction of the original raster from the shifted raster, leaving those pixels that corresponded to the edge of the aspect areas in that direction. Figure 10 shows this process for a shift in the Southwest direction. The tool then converts the resultant raster to linear features, and attributes each line with the direction that the feature provides cover and concealment from, as well as the type of feature it came from, in this case Aspect. We developed similar models for the tree areas and built up areas, but for these features roads, railroads, and trails are first cut into the tree and built up area features. The Focal Statistics tool is again run on these cut features to find the edges in the eight cardinal directions, and the resultant linear features are attributed with either Tree Area or Built Up Area accordingly. Figures 11 through 13 show the intermediate results of this process. Figure 14 shows the combined results, with aspect features in red, tree features in green, and built up area features in blue.

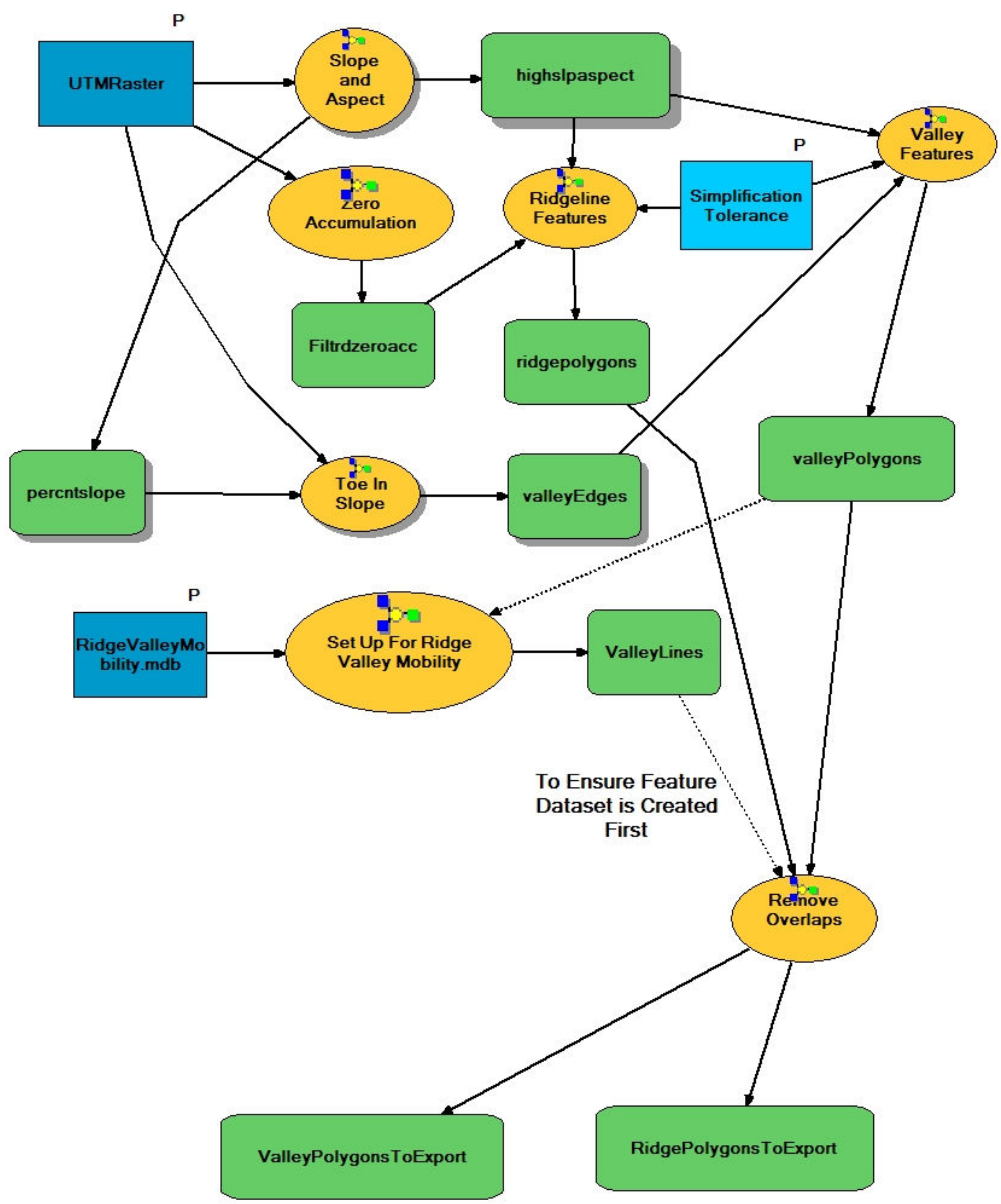

Figure 8: Ridge and Valley Model

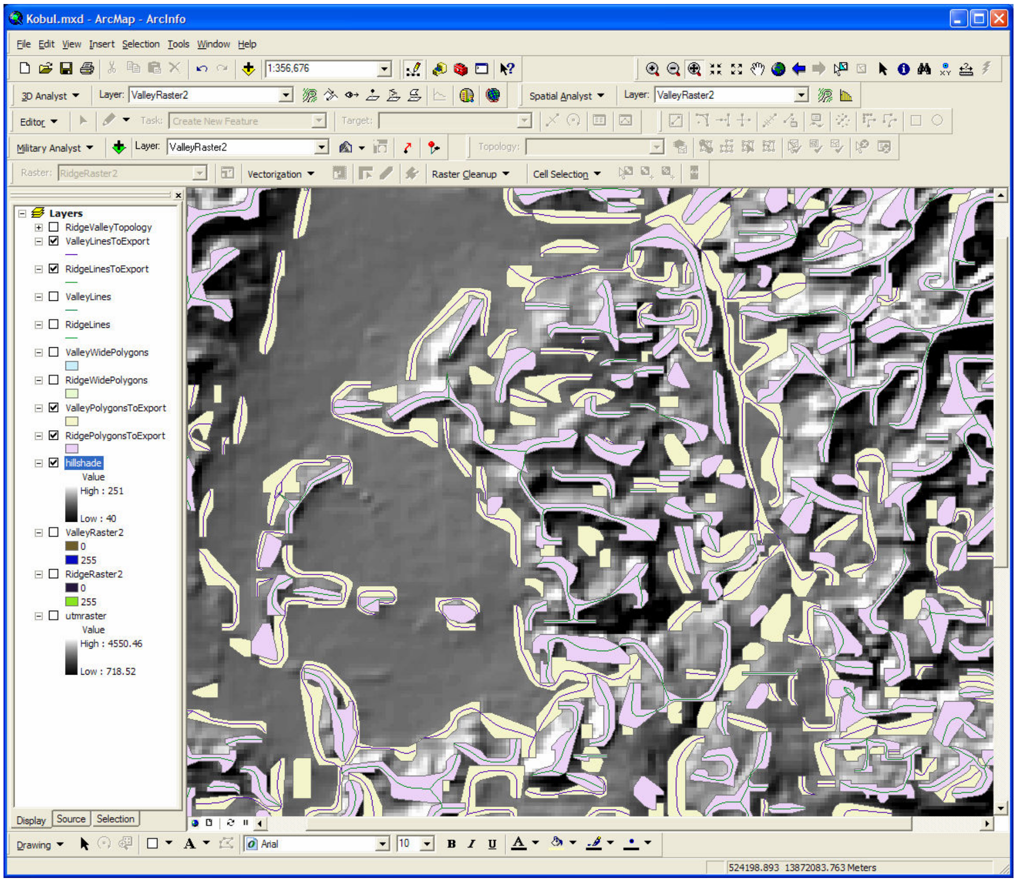

Figure 9: Ridge and Valley Edge Area and Linear Features

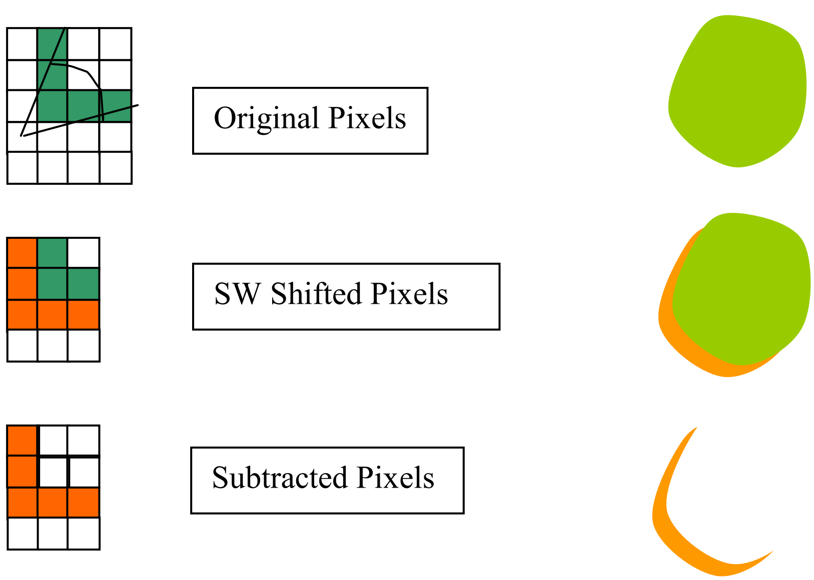

Figure 10: Focal Statistics and Subtraction to find SW Edge

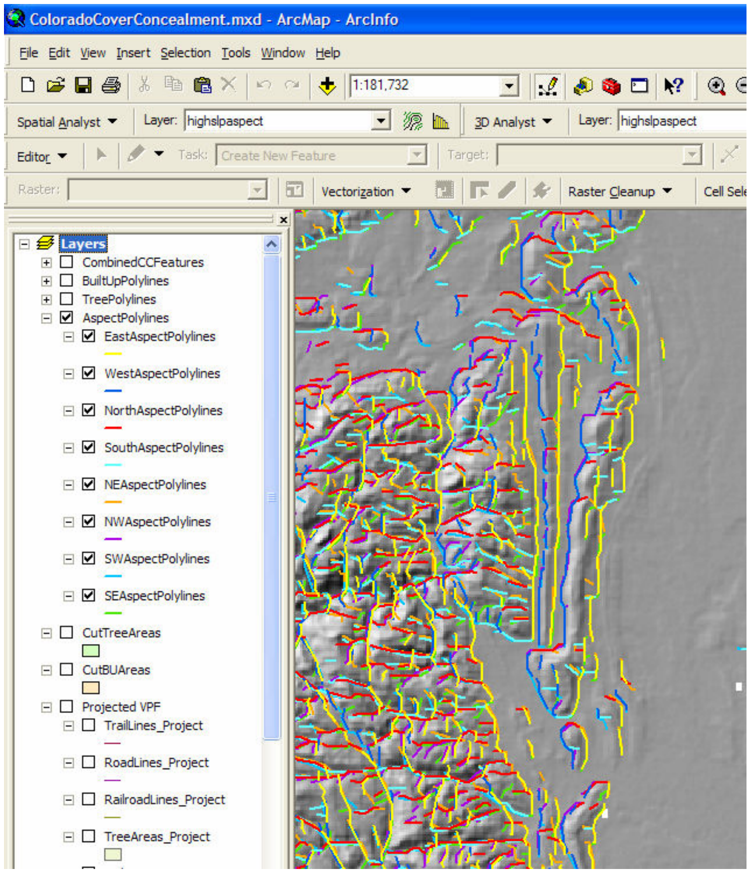

Figure 11: Concealment From Aspect

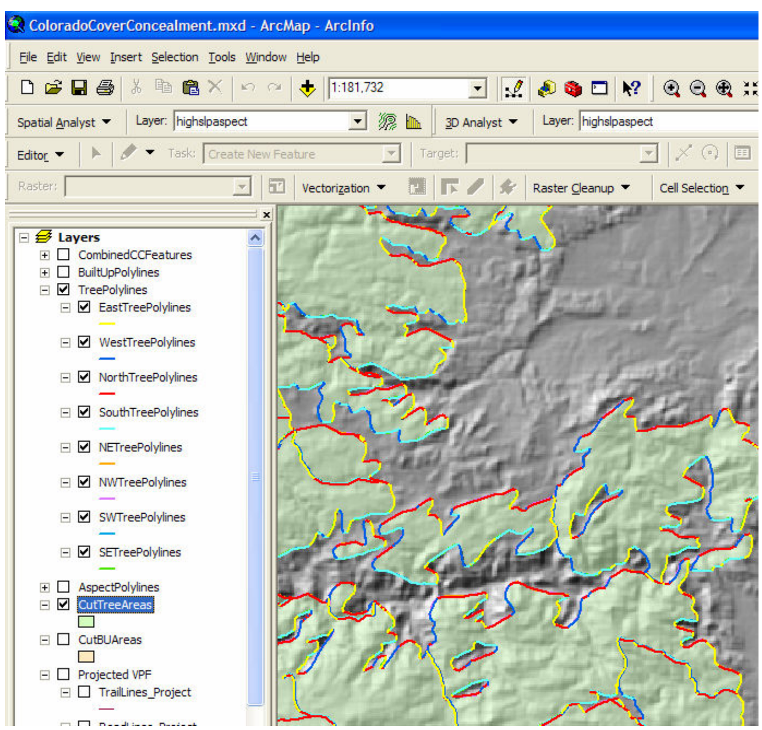

Figure 12: Concealment From Tree Areas

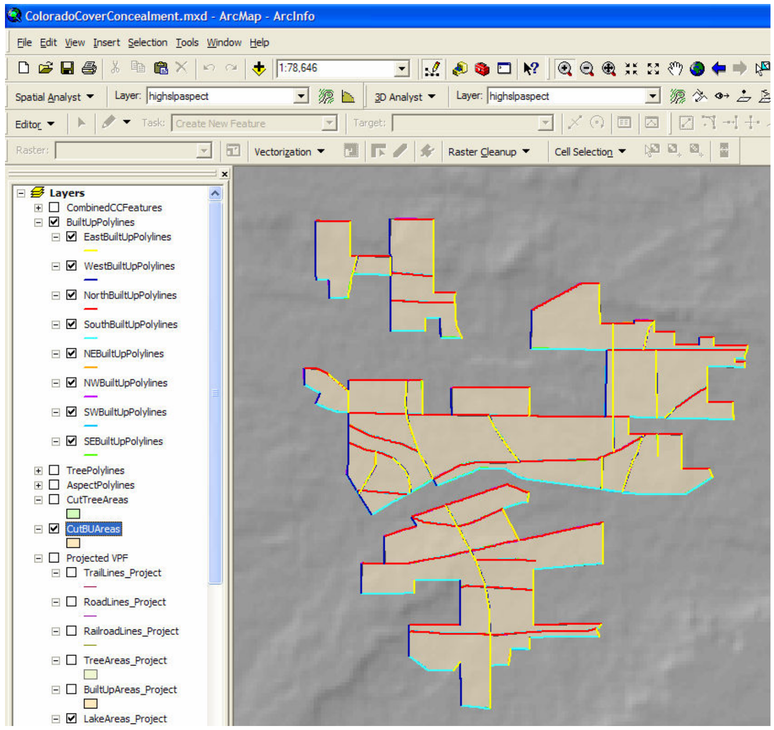

Figure 13: Concealment From Built Up Areas

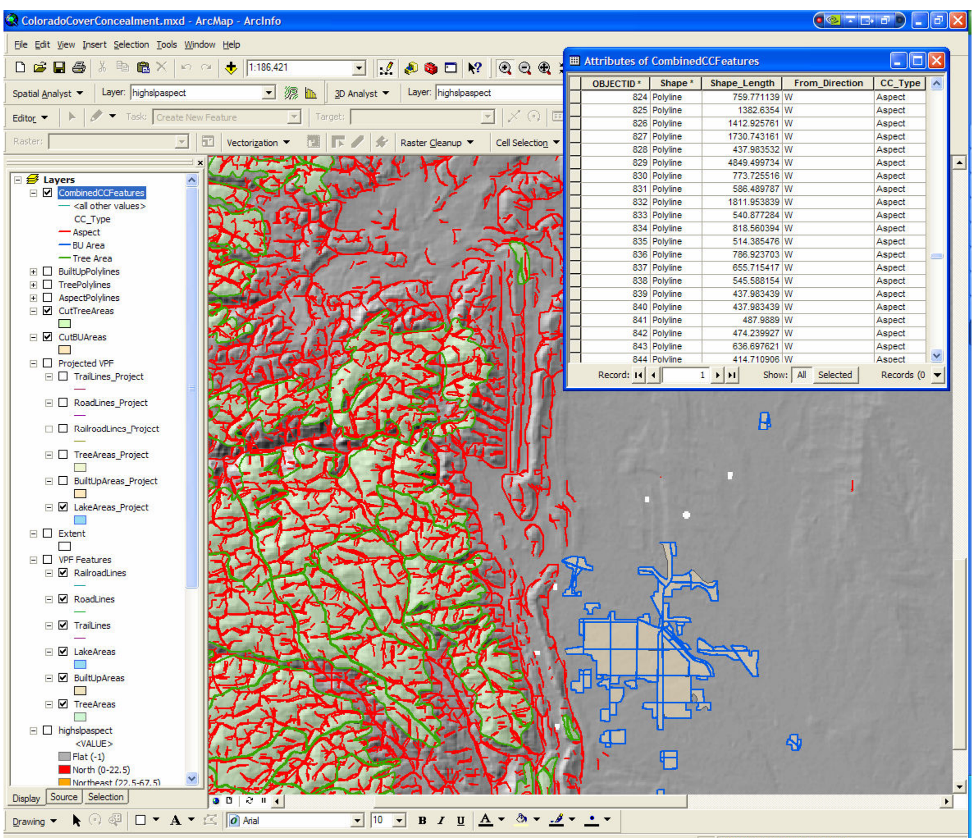

Figure 14: Combined Cover and Concealment Features

In combat models, these linear features can be used to generate routes that are concealed from potential enemy locations. Since these locations are not known until the simulation is run, we have provided the directionality attribute that can be used to select those linear features that are appropriate based on the direction of the unit to the suspected or known enemy locations. They can also be used for cover from fire from a particular direction.

8. Building Interiors

The IWARS simulation uses semantic information to navigate within building interiors. Combat models within IWARS have sophisticated algorithms, such as room clearing, where detailed information of the building interiors are necessary for navigation and reasoning.

The semantic information needed for IWARS consists of convex enclosures, apertures, and climbing devices, along with the topology of these semantic features. We are currently developing scripts in Autodesk 3ds Max that extend the user interface to perform automated steps to generate this semantic information from existing 3D OpenFlight models. These scripts find each floor and ceiling, along with stairs that connect them. For each floor, scripts locate walls, doors, and windows, and then break up the rooms into enclosures and apertures. There are scripts that connect apertures to enclosures, and data is written out in the comment fields of the OpenFlight model. The semantic data is also written out to a data file.

There are two general processes used to create the semantic information for building interiors. The first process is to generate the semantic geometry information, and the second process is to link the geometries into a topology. To find the semantic geometry information, the 3D model is first imported into 3ds Max. The Slice script is then run, which brings up the Convert Buildings tools menu. The user selects the model for the slice script to run on, which then creates the floor and ceiling schematic shapes for each level (Figures 15 and 16). The tool than works in the horizontal plane to find the window schematic shapes (Figure 17). Polygon objects are then created for each room, door and window and stored as enclosures and apertures.

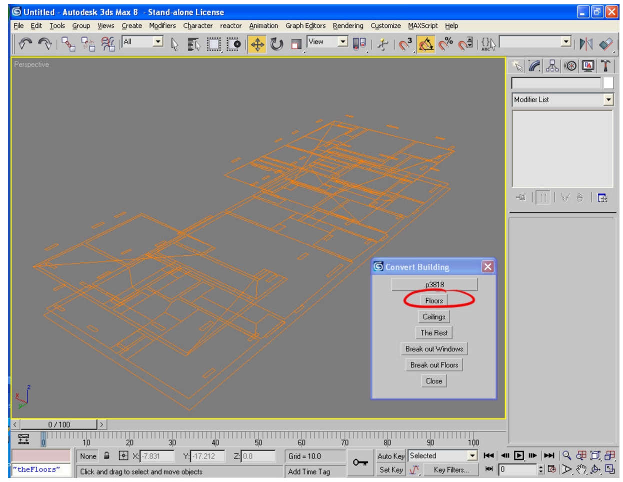

Figure 15: Create Floor Schematic Shape

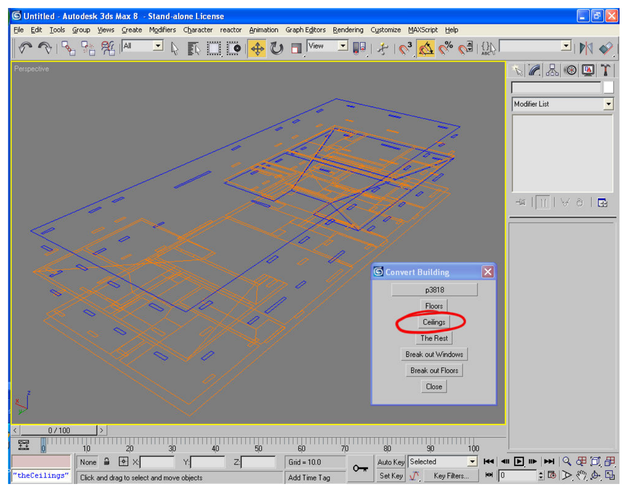

Figure 16: Create Ceiling Schematic Shape

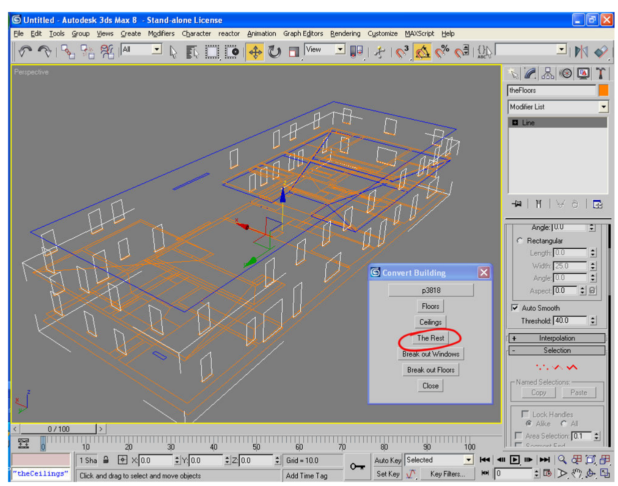

Figure 17: Create Window Schematic Shape

The Semantic Connection script is then run to generate the topology between the created geometric features (Figure 18). This script assists the user in making the connections between enclosures and apertures, and displays the results as they are generated. Figure 19 shows the connections (red arrows) between the enclosures (blue polygons) and door apertures (black polygons), and Figure 20 shows the completed topology. This semi-automated process with visual feedback to the user allows the creation of building interior information with much less error and in less time than generating this information by hand.

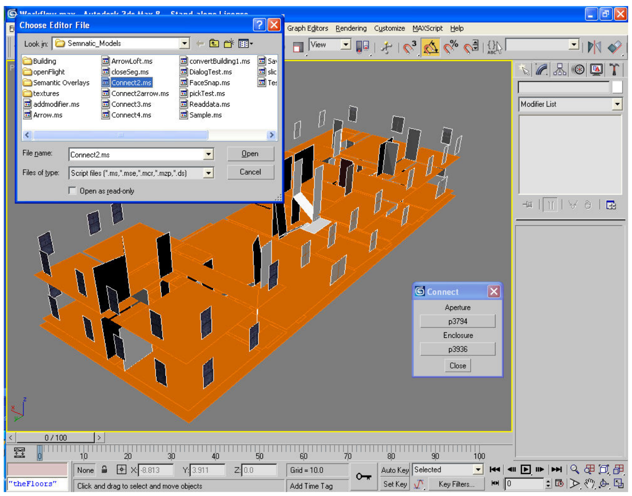

Figure 18: The Semantic Connection Script

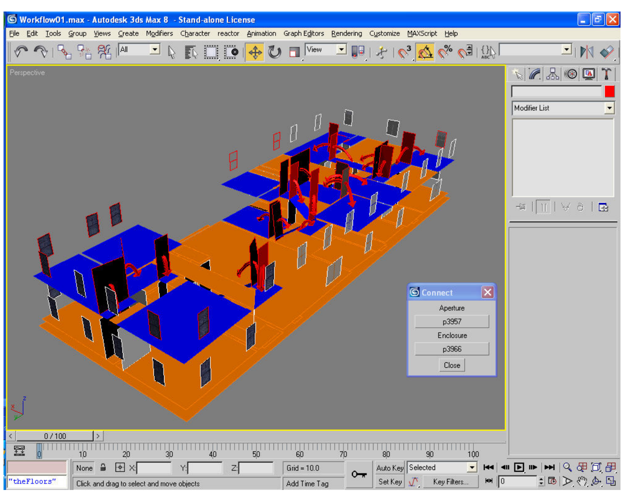

Figure 19: Connections between Doors and Enclosures

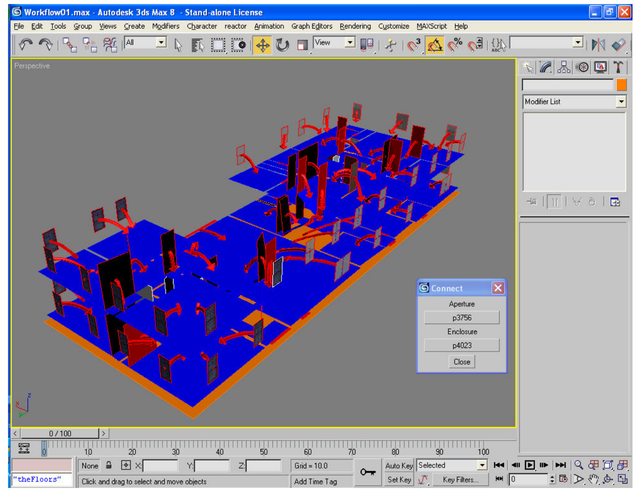

Figure 20: Complete Topology

9. Geography Markup Language (GML)

In order to use the results of these tools in simulations other than IWARS and VR-Forces, we are providing the semantic information in a number of different forms. For some simulations, like VR-Forces, we are providing the output in Shapefiles, that VR-Forces can read directly at runtime. For IWARS, we are providing the output in the Geography Markup Language (GML) [4]. GML is the XML grammar defined by the Open Geospatial Consortium (OGC) to express geographical features. ArcGIS provides a Data Interoperability extension that allows GIS data to be output as GML. Two files are output, a .gml file that contains the data, and an .xsd file that contains the schema. We are currently working to output the semantic information from 3ds Max as GML also.

10. Conclusions

Commercial GIS products, like those from ESRI in C/JMTK, provide a powerful set of features for generating semantic information for modeling and simulation. Similarly, commercial 3D modeling tools like Autodesk's 3ds Max, with its powerful scripting language, allows the creation of automated and semi-automated tools for the generation of geographic semantic information. We have successfully developed new feature types based on GIS information that are enabling higher level behavior models to be developed in CGF applications. In the future, we envision a tighter coupling of GIS and M&S systems, providing reductions in time and cost for geospatial data generation for M&S, increased currency of geospatial data for time critical applications, and improved interoperability and data correlation between military applications.

11. Acknowledgement

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[4] Geography Markup Language (GML) 2.0, OpenGIS Implementation Specification, OGC Document Number: 01-029, 20 February 2001.

Author Biographies

THOMAS STANZIONE is the Simulation Technology Manager at MÄK. Mr. Stanzione has over twenty years of experience in modeling and simulation, particularly distributed simulations and computer generated force (CGF) applications, simulation software development, and system integration. At MÄK, Mr. Stanzione is currently the principal investigator on the Smart Terrain Phase II SBIR project for the US Army Natick Soldier Systems Center, as well as the GIS-Enabled Modeling and Simulation project for US Army TEC. Mr. Stanzione holds a Bachelor of Science and Master of Science in Photographic Science from the Rochester Institute of Technology.

KEVIN JOHNSON holds a Master of Science degree in Computer Engineering from Rochester Institute of Technology and a Bachelor of Science degree in Electrical Engineering from Ohio University. Mr. Johnson joined MÄK Technologies in July 1999 and was a principal engineer responsible for improving efficiency on MÄK’s SIMinterNET and DARWARS tactical trainer projects. Before his tactical trainer work, Mr. Johnson developed an HLA Runtime Analysis and Monitoring Tools. Specifically he built on HLA to create a distributed data logger that minimized logger generated data traffic on wide area networks. Mr. Johnson is now the lead engineer on the US Army TEC GIS-Enabled Modeling and Simulation project, and was the lead developer on the building interior semantic information portion of the Smart Terrain contract.