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Advancing the Interoperability of Geospatial Intelligence Tradecraft with 3D Modeling, Simulation and Game Engines

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**Title:** USGIF Modeling, Simulation & Gaming (MS&G) Working Group Position Paper: Advancing the Interoperability of Geospatial Intelligence Tradecraft with 3D Modeling, Simulation and Game Engines

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1.0 Introduction

The emergence of the geospatially enabled enterprise has opened up new opportunities in the applications of 3D/4D analytics, AI/ML decision-support systems and game-engine applications for mission rehearsal and virtual training. Digital twin environments, such as the Nanjing Jiangbei New Area[[1]](#footnote-1), are pushing forward the transformation of the 3D/4D modeling community at a staggering scale and pace that requires a constant stream of new technology applications for urban planners, disaster response officials, environmental monitoring agencies, intelligent transportation system designers and hundreds of other organizations. The volume, variety and veracity of geospatial data is providing both opportunities and challenges for analysts looking to leverage 3D/4D location-intelligence for enhanced benefits over traditional 2D mapping approaches including:

* Higher spatial resolution and location accuracy with 3D data than 2D data;
* Conveyance of both aesthetic and spatial relationships with 3D data that cannot be understood in 2D space;
* Enablement of unique types of geospatial analysis with 3D data that cannot be done in 2D mapping environments; and
* 3D environments are easier to visualize and understand by ‘cadets and commanders’.

The challenges in data management, processing and exploitation of massive 3D datasets collected in real-time are enormous. Artificial intelligence and machine learning (AI/ML) approaches for data processing and cloud-infrastructure for data storage are fully capable of scaling to meet the challenges of the “data tsunami”; however, the tradecraft connecting communities of practice in geospatial intelligence and 3D modeling, simulation and gaming remains stove-piped. One of the principal objectives of this Position Paper is to identify tradecraft gaps that can be filled to bridge the divide through the promotion of community education, evolution of open-standards and increased interoperability between GEOINT and M&S approaches.

## Organization and Role of the USGIF MS&G Working Group

The USGIF Modeling, Simulation & Gaming Working Group (MSAG) educates and informs the global Geospatial-Intelligence (GEOINT) community on how 3D modeling, simulation and gaming technology can be made more interoperable with GEOINT tradecraft. We seek to collaborate with Industry, Academia, and Government to highlight advanced research concepts and commercial technology developments supporting geospatial modeling, simulation and gaming systems that are capable of delivering authoritative and relevant GEOINT at the point of need. A core tenant of our collaboration strategy is to maintain close working relationships with both the Open Geospatial Consortium (OGC) Interoperability, Simulation and Gaming (IS&G) Working Group and the Simulation Interoperability Standards Organization (SISO). Accordingly, the objective of the MS&G is to build a community of interest by focusing on the following technical topics and issues:

* **Interoperability** of software, workflows and data across the GEOINT and M&S communities to improve mission responsiveness by leveraging a growing diversity of geospatial information and just in time fusion of information from drones, body cameras, phones and other IoT sensors.
* **3D Reality Modeling and Analytics** of 3D geo-specific and geo-typical environments including terrain, buildings, roads, hydrology, vegetation and other features used to generate GEOINT analytical products and databases.
* **Simulation** **Technologies** supporting 3D geo-synthetic environments scenario testing and analysis in real world context.
* Virtual Reality (VR), Mixed Reality (MR) and Augmented Reality (AR) capabilities user experiences for immersive training, immediate context and information awareness in the field, remote mission monitoring.
* **Gaming Technology** supporting the visualization, content generation and hybrid-streaming of 3D geospatial data such as refer to combining optimized performant content with dynamic geospatial events and condition.
* **Geo-synthetic Environments** supporting machine learning and artificial intelligence (ML/AI) approaches for generating labeled training data through sensor fusion and 3D modeling.

## Objectives of Position Paper

The objectives of this MS&G Position Paper are:

1. Identify high-priority areas of basic and applied research that will address real-world needs and opportunities such as the availability of high-resolution digital elevation models (DEMs) as a foundational 3D data model for terrain analysis.
2. Promote applications of 3D/4D analytics that enhance situational awareness of first-responders and the warfighter.
3. Encourage research in AI/ML approaches supporting next-generation reality modeling and 3D database production to increase operational effectiveness.
4. Support technology advances in game engine platforms to support multi-sensory attributes (visual, audio, sensory touch) with geospatially accurate terrain, feature data and entities.
5. Tradecraft Gaps Between GEOINT and M&S Communities of Practice

## 2.1 Geospatial Analytics and 3D/4D Data Services for Mission Support

The goal of this section is to identify emerging trends and tradecraft gaps in geospatial analytical methods that are aligned with 3D/4D modeling and simulation applications for enhanced decision support, mission rehearsal, and situational understanding. Over the past 10 years, technology advances in the miniaturization of Lidar sensors, drone-based collection capabilities and improvements in global high-resolution digital elevation models indicate the time for “true 3D” analytics is now at hand. In addition, the “connectedness” of sensors, cloud-based geo-processing services and powerful mobile devices, supported by efficient 3D data streaming formats such as i3S and 3D Tiles, have reached the point where delivering 4D geospatial analytics at the point of need is an achievable goal. Accordingly, within this framework of technology innovation we discuss Change Analysis, Mobility Analysis and Contextual Analysis. Our principal objective being to spark a conversation regarding new methods for 3D/4D analytics that advance the tradecraft of both the M&S and GEOINT communities.

Our approach is to call-out potential areas of research that will improve decision-support, mission planning and situational awareness across multiple commercial, industry and government domains. In doing so, we leverage previous work by the OGC Innovation Program with emphasis on 3D/4D analytical support for the warfighter and first-responder community. Specifically, the 2019 OGC Concept Development Study (CDS) titled Mixed Reality at the Edge[[2]](#footnote-2) which provides an excellent overview of the key stakeholder issues in the convergence of geospatial 3D modelling, simulation, and gaming integrated with machine learning (ML) for automated 3D workflows. Mixed reality is both an intriguing as well as a highly-relevant methodology when considering the expanding role of game engine visualization, physics-based modeling approaches and AI capabilities using real geospatial data. For example, the use of geo-specific 3D terrain models with synthetic 3D models to generate labeled training examples for ML algorithms.

##  3D/4D Change Analysis

Traditional geospatial change analysis analytics, using satellite or aerial imagery, are typically 2D in nature. Pixel-based methods require accurate geo-registration of imagery collected at different times, such as two different Landsat scenes, and analysis must account for artifacts such as clouds, shadows, seasonal differences and other attributes to derive an accurate estimate of land-based changes in the scenes such as the amount of land inundated by a flood. Feature and thematic based change analysis methods, using imagery or raster map products, also require accurate co-registration; however, these approaches can provide object-specific metrics, such as “changes in the number of cars in a Walmart parking lot on Saturdays,” and have become increasingly automated due to advances in machine learning-based feature extraction. These types of 2D analytics are becoming increasingly valuable in the detection of patterns of life (POL) which support evolving geospatial intelligence and business analytic models. Contributing to the temporal component of these approaches are new commercial small satellite constellations, operating in lower Earth orbit in non sun-synchronous modes, which can provide intra-day revisit over geographic sites for POL analytics.

The availability of high spatial resolution DEM datasets, such as the Vricon 3D Surface Model, now provides the foundation for a wide-range of 3D analytics that can be paired with temporal change analysis of feature datasets. For example, monitoring changes in water storage reservoirs for large hydro-electric dams from a volumetric basis versus a surface area basis or assessing flood-plain risk for real estate with 3D data versus 2D imagery. Other areas of public safety that would benefit from 3D/4D change analysis would be improvements in geologic hazard risk analysis, such as hillside slumping or mud flows, wild-land fire modeling, tornados, earthquakes and heavy-rain events. Imagine the benefits of integrating soil maps, dynamic land-cover change analysis and real-time weather data with high-resolution 3D DEMs to forecast risks of earth movement or wild-land fire events to local communities and first-responders. In summary the availability of high resolution DEMs opens up multiple new opportunities for research in 3D/4D analytics including:

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| **Research Ideas Callout for Analytics: 3D/4D Change Analysis** |
| 1. New approaches and methods for integrating 3D analytics with mission planning and mission rehearsal synthetic training environments such as the inclusion of ground-clutter in urban environments.
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| * New ideas and methods for the integration of environmental models with 3D terrain and land-cover information such as prediction of flood water inundation when accompanied with storm surge or flood impacts from heavy-rain events in urban environments with extensive impermeable surface areas.
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##  3D/4D Mobility Analysis with Geospatial Data

In addition to new remote sensing paradigms for temporal revisit by small-satellite constellations, such as Planet and BlackSky, investments in the autonomous vehicle market over the past 10-plus years have accelerated the growth of street-level 3D mapping and derived analytics for navigation. Companies such as Uber, HERE Technologies and Google use mobile Lidar sensors, full motion video cameras and stereo-based photogrammetry to collect 3D data for urban environments and transportation networks. The connected nature of intelligent transportation networks – cars, sensors, cloud-based map services, etc. – are opening the aperture for innovative 3D/4D change analysis analytics. Contributing to this flood of 3D street-level data collection are drone-based collection of Lidar data for civil engineering and Public Works projects. A widely available, up to date DEM with history and provenance provides an intelligent substrate that can be combined with dynamic sensor data and locally high resolution (HD-maps) data to provide a system for monitoring, analyzing, and predicting change. In summary this wealth of 3D data collected from street-level and building-level views opens up multiple new opportunities for research in 3D/4D analytics. The data management challenges, however, are enormous as the sheer size of 3D data point clouds requires massive computing resources.

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| **Research Ideas Callout for Analytics: 3D/4D Mobility Analysis** |
| * New methods for the incorporation of pattern of life (POL) change analytics into 3D synthetic environments such as automated alerts triggered by simulation. For example, dynamic visualization of traffic accident/congestion patterns during a transportation routing simulation for a planned public event.
 |
| * Incorporation of street-level Lidar data into 3D/4D urban mission planning simulations that show changes over time such as street congestion, construction activities, line-of-sight (LOS) views and other analytics.
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## Contextual Geospatial Analysis

The adoption of 3D geospatial mapping, modeling and visualization approaches heightens the need for advancements in contextual analysis which opens up the need for volumetric data approaches for soils, lithography, water and atmospherics. For example, anyone who has ever walked down a crowded street in New York City or hiked through a rain forest is experiencing a multi-dimensional and multi-sensory environment which can be measured in 3D/4D. Voxel data from IoT sensors monitoring air quality, noise, etc. can be visualized and measured spatially using street-level and low-altitude drone based Lidar collection 3D surface models. Public health concerns related to congested environments, poor air circulation and the spread of COVID-19 can be potentially modeled using voxel-based analytics. The inclusion of sensory information in 3D volumetric data approaches is particularly well-suited for VR/AR/MR applications to enhance training for first-responders. In summary the integration of high resolution 3D data insets with DEMs opens up multiple new opportunities for research in 3D/4Dcontextual analysis which are summarized in the table below.

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| **Research Ideas Callout for Analytics: Contextual Analysis** |
| * New methods and approaches for geo-registration of 3D point cloud features into 3D scenes to enhance situational understanding.
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| * AI/ML approaches for contextual-based tipping and cueing of threats by leveraging multi-dimensional 3D information and time-series attributes of entities.
 |
| * Decision-support tools and services designed to operate in 3D/4D environments that fully leverage the contextual information of richly-attributed scene layers.
 |

# Next Gen Reality Modeling and Database Production

 Regardless of the fidelity, if a 3D Dataset exists solely as geometry, textures and imagery then a large amount of human effort becomes a necessity for any level of analysis and use. Accordingly, without additional attribution and annotation, machines don’t have much use for the raw polygonal data. However, the more realistic and feature rich a geospatial dataset, the more effective it will be for an expanded number of use-cases involving machines, which is specifically helpful for use in simulation and analysis. As the semantic fidelity of the geo-specific dataset increases, taking into account rich feature attribution, classification and segmentation, terrain realism, as well as data conflation from a variety of sources, the ability for rapid analysis, Machine Learning processing, and Artificial Intelligence based planning and decision-making become more and more accurate when measured against the virtual geospatial data’s real-world analogue.

## Current State of the Art in Automated Extraction of Terrain Features

A large number of efforts in automated classification and extraction exist today, especially for 2D Imagery, however in the 3D space there are far fewer solutions as the field is less mature. There are a number of approaches for this type of feature extraction, utilizing Machine Learning (ML), Mesh Data segmentation and analysis, and Point Cloud analysis. Particularly a majority of 3D-oriented efforts are focused on LiDAR segmentation with very little research into photogrammetric reconstructed data. Most recently researchers at USC ICT have focused on this particular use case – to enable rapid generation of terrain via inexpensive UAS and capture sensors, with a direct path to photogrammetric feature extraction. Some very promising efforts involve a 2D-3D hybrid approach on both sides of the feature extraction pipeline, both in the training data for the Machine Learning models as well as in the extraction pipeline. Machine Learning data models have incredible appetites for data in order to train them properly. Labeling and annotating a 3D Dataset is a very time-consuming process that also requires a high level of training in the process and software used. However, labeling and annotating 2D datasets is much more straightforward, and can be easily crowdsourced using methods like Mechanical Turk. The 2D-3D Hybrid annotation process enables quickly annotating 2D source imagery, for which camera poses can be estimated, and the classification labels can be projected back into the 3D space. For the extraction pipeline, 2D imagery provides a method to quickly identify small features as well as complex ground and building materials in ways that the 3D data doesn’t support. Again, by estimating camera poses from the 2D Imagery metadata, this classification information can be projected into the 3D data space for both qualifying and creating extraction and segmentation information. Esri, and others, have been working on direct feature extraction from mesh after production of imagery through SFM and other workflows. ML analysis benefits from data reduction that is inherent in the mesh generation.[[3]](#footnote-3)

##  Conflation of New or Existing GEOINT Sources to Support Terrain Database Production and Updates

Various levels of semantic classification and feature attribution may have already been evaluated and produced for datasets through various efforts, commercial, public, and government. This sometimes occurs through automated pipelines, though generally in the past has been painstakingly created by hand or through crowd-sourced initiatives. A great example of this would be Open Street Maps (OSM), as a large and detailed database of terrain features. The crowd-sourced nature of the data means that it’s inherently incomplete, and not always authoritative or true to the ground-truth. On the inverse of the latter you have NGA’s NOME program which is a more GEOINT friendly version of OSM, where the crowd-sourced data becomes verified and authoritative. Then for a similar, although much more richly featured dataset you have the Army’s SECORE program data, which is fully authoritative and feature-rich though requires a large amount of resources to create hand-tuned simulation ready databases. Disregarding any of this data leaves a trove of value untapped. Current research on feature extraction relies on sourcing information from various private, public, and government sources that can be conflated to verify results (compare automated road extraction vs OSM Road data), identify specific features that inherently require external data (bathymetry, no fly zones), as well as provide automated ground truth annotation for ML Model training datasets.

##  Tracking Feature-level Pedigree and Authoritative Data Sources

Of critical importance, especially within a GEOINT workflow and application for use, is the importance of understanding where usable data has originated from and understanding its provenance and chain of custody. This can be a complex process even when looking at a single unattributed 2-Dimensional image. Understanding its inherent information holistically - such as how an image may have been changed from the raw source, where it may have been transmitted or converted, what sensor captured it and when. This becomes even more complex when this image has user-added metadata, or has gone through automated image classification processes to enrich the data with relevant and pertinent information. That complexity increases a number of magnitudes when you begin looking at 3D data, whether derived from 2D photogrammetrically, or via 3D native data sensors. Adding in the additional level of conflated information from multiple sources, 2D, 3D and otherwise, you now begin looking at an incredibly feature-rich dataset with a multitude of chains of information that have led to its creation. Begin able to track, verify, and understand how this data has been combined and implemented is a crucial gap in the GEOINT realm, especially when a lot of this information is sourced and applied fully autonomously, either through basic computer applications such as info scraping, or through opaque but powerful processes such as deep learning. There are a number of technology initiatives available today, such as block-chain, that can help track and ensure the data pedigree, but a number of challenges exist along the way, and the higher the fidelity of the data the more difficult the understanding of pedigree, provenance, and custody.

## Round-tripping Geospatial data from Source to 3D Database to Simulation to 3D Database (Modified Data)

This is one of the more complex issues surrounding maintaining authoritative data while also allowing for versioning and derivative information. A number of issues revolving around guaranteeing custody and modification of the derivatives apply to this topic that include challenges previously discussed in ensuring data pedigree, but as this data can be modified via human or machine interaction, there must be a number of solutions in place to understand how to best control the versioned information and when it may be necessary to re-apply information to the original authoritative source. With this issue in particular there are a number of communication, networking, and transmission issues that must also be ensured, validating the data as it is pulled from a 3D database, determining the security and processing of the data while in-use, then ensuring the data and its subsequent derivative modifications are recorded, verified, and secured back through transmission, then fully authenticated and processed at the source point, completing the round trip.

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| **Research Ideas Callout for Reality Modeling: Modified Data** |
| * Machine-based methods for validating the version history of data and tracing modified to authoritative sources.
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# Game Engines and GEOINT: Redefining Multi-Dimensional Analysis.

## 4.1 Multi-Sensory Simulation Contextualization

When it comes to predicting the future of simulations there’s no hidden secret or all-knowing crystal ball. The simple truth is that the immersive training and simulation standards of tomorrow are rooted deeply in the innovations of today. We know that the simulation community has been an early adopter of XR (VR, AR, and MR), and we also know that we were among the first to experience their limitations. Thankfully, innovations in XR—such as the Open XR initiative—will allow for flexible deployment to all methods of XR, allowing simulation creators to focus on the curriculum at hand, and not on the display of a pixel on one HMD or unique display. Choosing your method of XR will soon be as trivial as mono vs stereo vs 5.1 sound, and this will unlock all kinds of new opportunities in the next ten years. If we take one more step in this direction it is ultimately a larger set of senses which will be stimulated in the simulation domain. Audio and Visual may be the first ones to be accessible but moving forward the push from the new use cases is bringing more importance to the kinesthetic cues to augment training transfer. Motion cueing systems have been used for ages now in the field but micro haptic devices producing heat variation, impact impressions as well as pressure or electrostimulation of our muscles are augmented signals which we are adapting to. In closing simulation and XR are not absolutely dependent, and many types of simulation can be used for analysis and prediction that doesn’t require a human experience.

## 4.2 Metaverse and the Digitalization Evolution

Advancements in GPU capabilities are ushering in a new era of display techniques (ray tracing, PBR, photogrammetry, virtual humans), ensuring that simulations not only behave realistically but also with a high level of authenticity and believability. The next generation of trainees demands a more immersive training experience, and real-time is the solution. The transition between virtual and live is still very noticeable because of the complexity of the devices we are using and their formats. Now imagine the next stage when HMD systems are not needed anymore and you don’t need them to be Head Mounted to be in your face all the time.

##  Education and Training Programs for the MSG Discipline

Education programs at colleges/universities and online/residential training programs can support these developments by using collaborative learning experiences. A number of disciplines contribute to the collective knowledge base necessary to be effective in this growing field. These include but are not limited to: Computer Science, Software/App Design, Modeling/Simulation Studies, Electrical Engineering, Spatial Science, Data Science, Psychology/Sensory Neuroscience, Animation Design, and the Visual Arts. Although there are not specific programs today that are tailored specifically to this field, there are increasing opportunities within education and training to build custom studies (via curriculum management) that support the knowledge needs and outcomes for the NextGen MSG specialist/developer.

##  Enter the Game Engines

While new simulation trends, including multi-sensory stimulation of trainees, very large open worlds, and visual realism become more and more of a challenge for legacy simulation systems, commercial solutions seem to be a way to alleviate these challenges. Only ten years ago, Modeling and Simulation techniques for defense and aerospace applications were ahead of the technology curve. Independent of the commercial computer graphics industry, this simulation sector continued to develop applications to solve its own challenges. The evolutions of the operation doctrines and tactics have been the drivers of CGFs, SAFs, and GEOINT software innovation, and still continue to drive more innovation to this day. Paradoxically, traditional simulation training and analysis software, while focusing on application layers, has incurred a technology debt at its core level over the last 10 years. In comparison with what is called traditional training solutions, the next era of digitization will be less hardware-intensive and more software-intensive, which will cause it to incur even more technology debt if the issue of software is not resolved. In order to reconnect the opportunities presented by high-performance hardware and the inherent limitations of older modeling and simulation software, game engines have emerged as an important element of the solution.

Experienced modeling and simulation creators and specialists have identified phases in the evolution of virtual training, going from monolithic prime-delivered solutions to defense-industry-grown COTS solutions. Because of the large technology and content-creation effort assumed by actors of the simulation niche, the industry never had a chance to change its mindset and its business model. The authors believe that we are now at the beginning of a new phase (not only because the technology is ready, but also because new actors are entering the Modeling and Simulation ecosystem). Some game engine creators are taking an open source route and teaming with the GEOINT community to support content creation and content pipelines already existing and standardized to ensure to prevent adding a “new standard” burden and avoiding the return to a walled garden ecosystem. This is leading to a strong change both in the technology but also in the business model. In this new phase of training, simulation companies and organizations are starting to augment their expertise in game engines to draw a bridge between these two worlds and generate training experiences that mix a high level of trainee involvement with the accuracy of a well-defined curriculum.

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| **Research Ideas Callout for: Game Engines and GEOINT** |
| * New concepts for multi-sensory applications and training solutions that fully leverage material properties of terrain and cultural features as well as the contextual settings of geospatial environments.
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| * New concepts in Geomatics in Game Engines: At present Game Engines are optimized for high-fidelity representation of objects in a local (game extent) environment. New methods and approaches are being introduced to transform or interpret GEOINT source data from a complex Earth-centric Coordinate Reference System to game performance extents.
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#  Conclusions

The goal of the USGIF MS&G Working Group is to educate and inform the geospatial community on how 3D modeling, simulation and gaming technology can be made more interoperable with GEOINT tradecraft. In this Position Paper we have identified multiple new areas of research for community members within academia, industry and the US government including:

* Applications that incorporate high-resolution DEMs for reality modeling and 3D database production to increase the operational effectiveness of warfighters, first-responders and others that depend on terrain-based analytics for mission planning.
* 3D/4D analytics for change analysis, mobility analysis and contextual analysis in support or urban planning, AEC applications, national security, disaster response and other time-sensitive applications.
* Reality modeling and 3D database production using AI/ML methods which fully leverage overhead and ground-based imagery and other ISR sensors to model indoor, outdoor and subsurface environments.
* Next-generation High Definition (HD) 3D maps produced from low-cost Lidar sensors and cameras supporting the autonomous vehicle market.
* Multi-sensory and geospatially accurate synthetic environments that leverage Game Engine platforms to support training, simulation and enhanced decision-support applications.
* Temporally-aware coordinate systems capable of supporting complex earth models and continuous data collection at ever higher spatial resolution.

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