Digital Twins of the Battlespace – Data and Formats for Enhanced Modeling and Simulation

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Presentation Outline

- Paper Purpose
- STE and OWT Background
  - OWT System Capability and Data Content
  - OWT Server and Data Architecture
- OWT Implementation Challenges
  - Full automation does not provide the required quality
  - No single format supports the rich data and metadata required for training and operations
  - Obtaining correlated authoritative geospatial data for operations and synthetically enhanced/refined data for training from a common process
- Conclusions
  - Battlespace Digital Twin, One Process, One Format, for Operations and Training

Paper Purpose

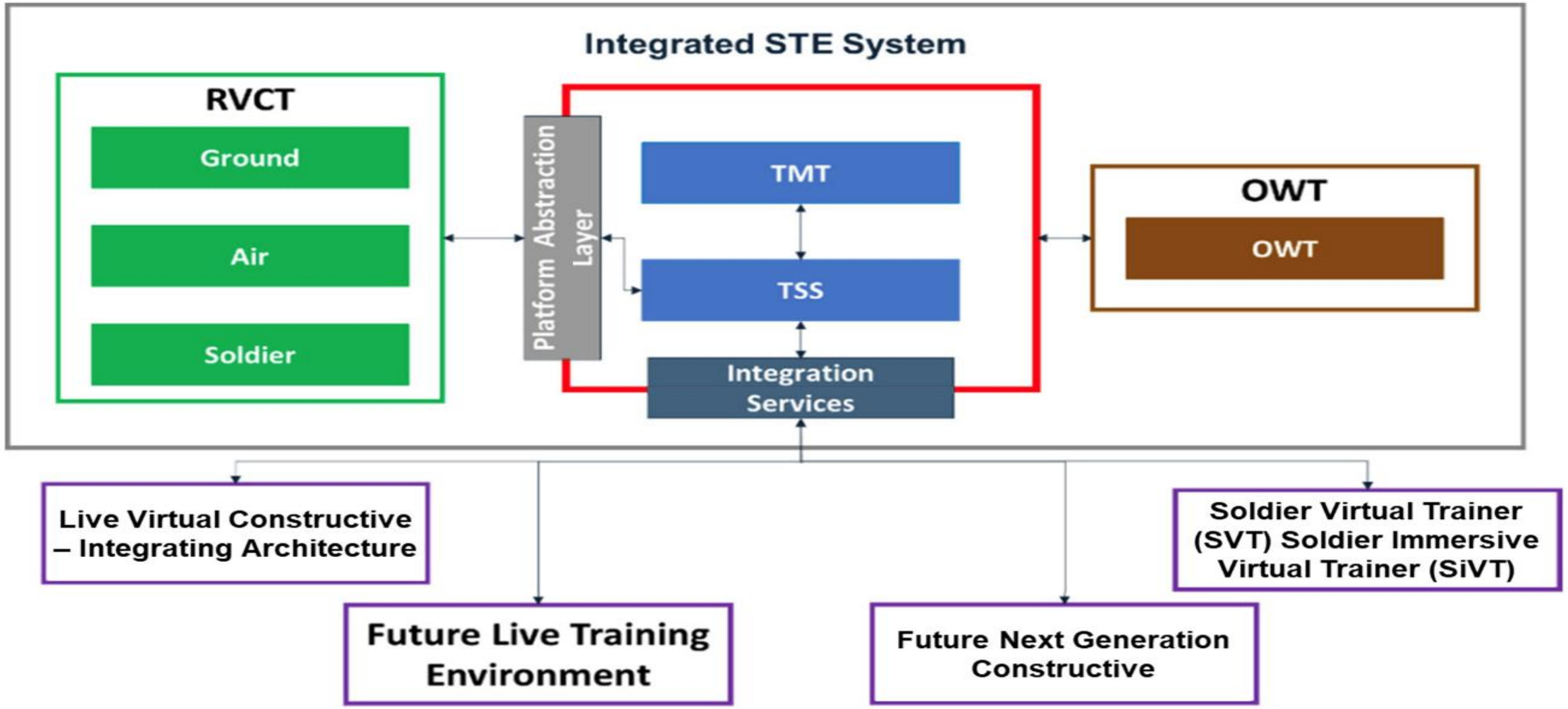
- Topic: Discuss the challenges in implementing the vision of the US Army's One World Terrain (OWT) program

OWT Vision:

Provide a single geospatial dataset (digital twin) for US Army training and operations from best available data using a fully automated process

STE and OWT Background

U.S. Army's STE goal: **Provide a comprehensive system to train US Army units and leaders in live, virtual, and constructive training domains**



OWT provides worldwide 3D terrain in a single, standard, well-formed format

One World Terrain Requirements

The key OWT Architecture and Implementation requirements:

OWT System Capability

- Reduce production time with full automation
- Support live, virtual, and constructive training
- Support training and operations
- Provide no less than current training capability
- Leverage continuous technology improvements
- Store all data in a single well-formed format

Requirements from PEO-STRI, STE-CFT, and TPO-STE

OWT Data Content

US Army **Training** data content requirements:

- Training locations
- Complete and consistent content
- Multi-resolution insets
- Rich metadata and complete material attribution
- Optimization for reasoning and rendering

US Army **Operations** data content requirements:

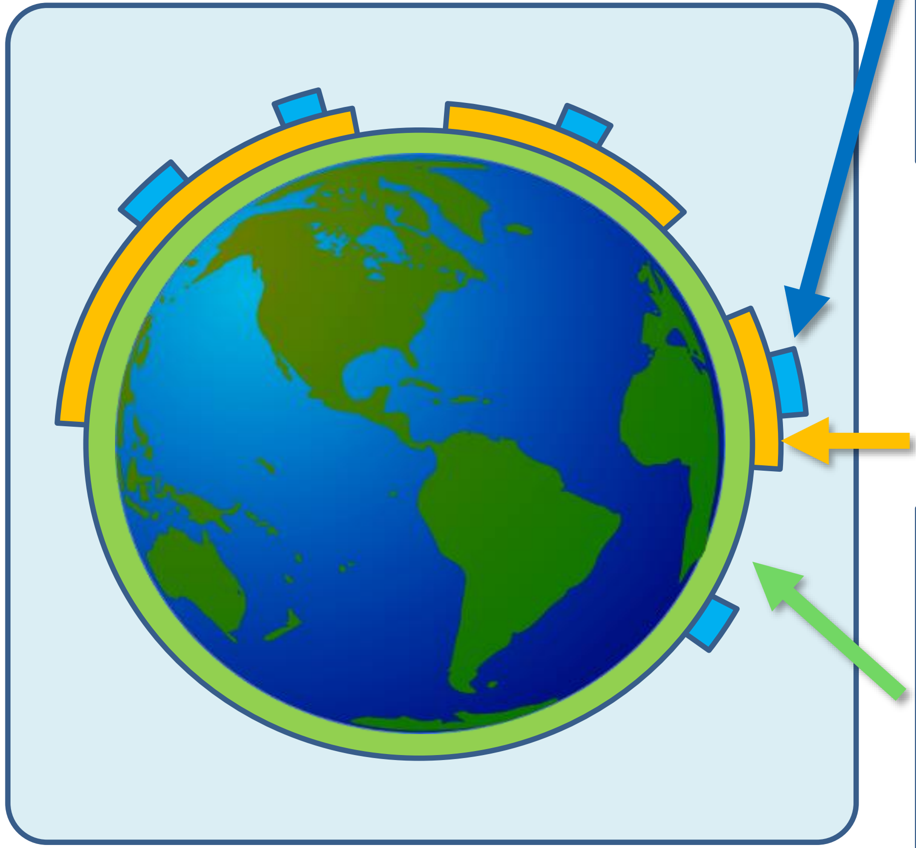
- Global coverage
- Accurate terrain surface representation
- High resolution imagery
- Efficient data storage
- Optimized for high-performance viewing

OWT System Architecture

- A Geospatial Terrain Server with:
  - high-performance compute clusters
  - high-speed compute storage and
  - very large data storage
  - connected with high-speed network
- Interfaced with:
  - Web-based Management Client
    - Data Ingress and egress
    - Composition definition
    - Processing control
  - Web-based Export Client
    - Data Egress
  - System-to-System REST API
    - Data Egress
- Populated with:
  - data sources
  - stored as independent assets
  - identified with data provenance
- Capability to:
  - provide upon request
  - with no human intervention
  - process the sources into the single runtime ready format
  - delivers the runtime ready data to the requesting systems

OWT Data Architecture

All source data is stored as independent assets within the OWT data Stratums, each asset with data provenance and metadata



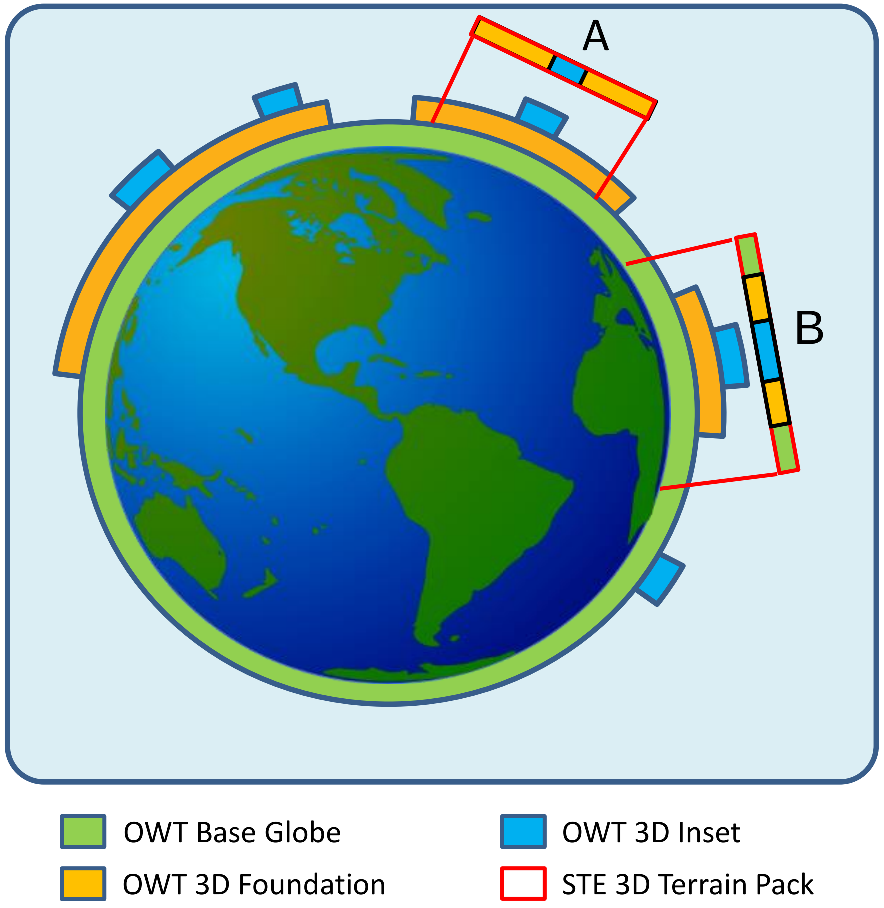
OWT 3D Insets – Local/Site Coverage
- Higher Resolution Data
- Drone-imagery-derived 3D Surface Model
- 3D Modeled
    - Buildings with Interiors models
    - Landmarks models
    - Vertical Obstruction models

OWT 3D Foundation – Regional Coverage
- High Resolution Data
- Satellite-imagery-derived 3D Surface Model
- Positional accurate data (3-meter LE/CE90)
- Reference for Geo-register of 3D Insets

OWT Base Globe – Global Coverage
- Low Resolution Data
- Open Source-derived 3D Terrain Model
- Open Source-derived Land Cover Classification
- Conflated Vector data
- Global context for selection of area of interest

3D Terrain Pack

3D Terrain Pack is the best available terrain data in the selected area, integrated into a single unambiguous dataset, tailored to the desired runtime system and content format



Use Case A

3D Foundation with OWT 3D Inset

- Covered by OWT 3D Foundation
- Includes OWT 3D Inset in 3D Foundation
- 3D Inset geo-registered and stitched in 3D Foundation
- 3D Foundation and 3D Inset areas at 3-meter CE/LE90 positional accuracy

Use Case B

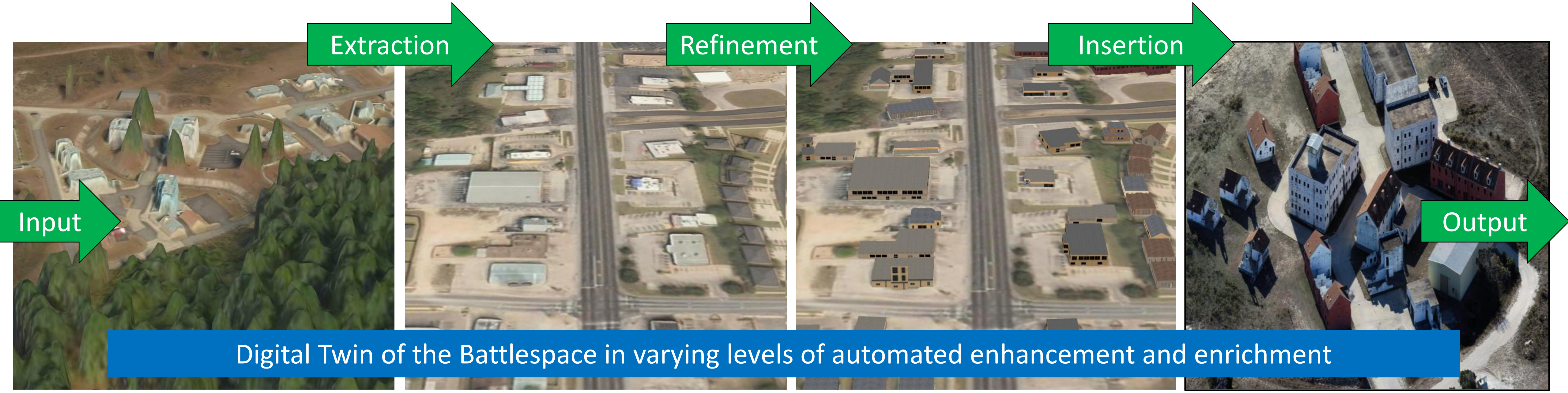
Base Globe, 3D Foundation with 3D Inset

- Cover by OWT Base Globe data
- Includes OWT 3D Foundation in OWT Base Globe
- Includes OWT 3D Inset in OWT 3D Foundation
- 3D Inset geo-registered and stitched in 3D Foundation
- 3D Foundation and 3D Inset areas at 3-meter CE/LE90 positional accuracy

STE system requests Geospatial data from OWT server

OWT Process Full Automation

OWT server creates runtime ready data from stratum assets



3D Foundation Stratum
3D Surface Model

3D Foundation Stratum
As Extracted Models, Land Cover Classification, on 3D Terrain Model

3D Foundation Stratum
w/Refined Models

3D Inset Stratum
Geo-aligned to 3D Foundation Stratum

OWT Implementation Challenges

- Challenge 1: Full Automation
  - Full automation does not provide the require quality
- Challenge 2: Rich Representation
  - No single formats supports the rich data and metadata required for training and operational
- Challenge 3: Multiple Usages/Multiple Exports
  - Obtain correlated authoritative geospatial data for operations and synthetically enhanced/refined data for training from a common process

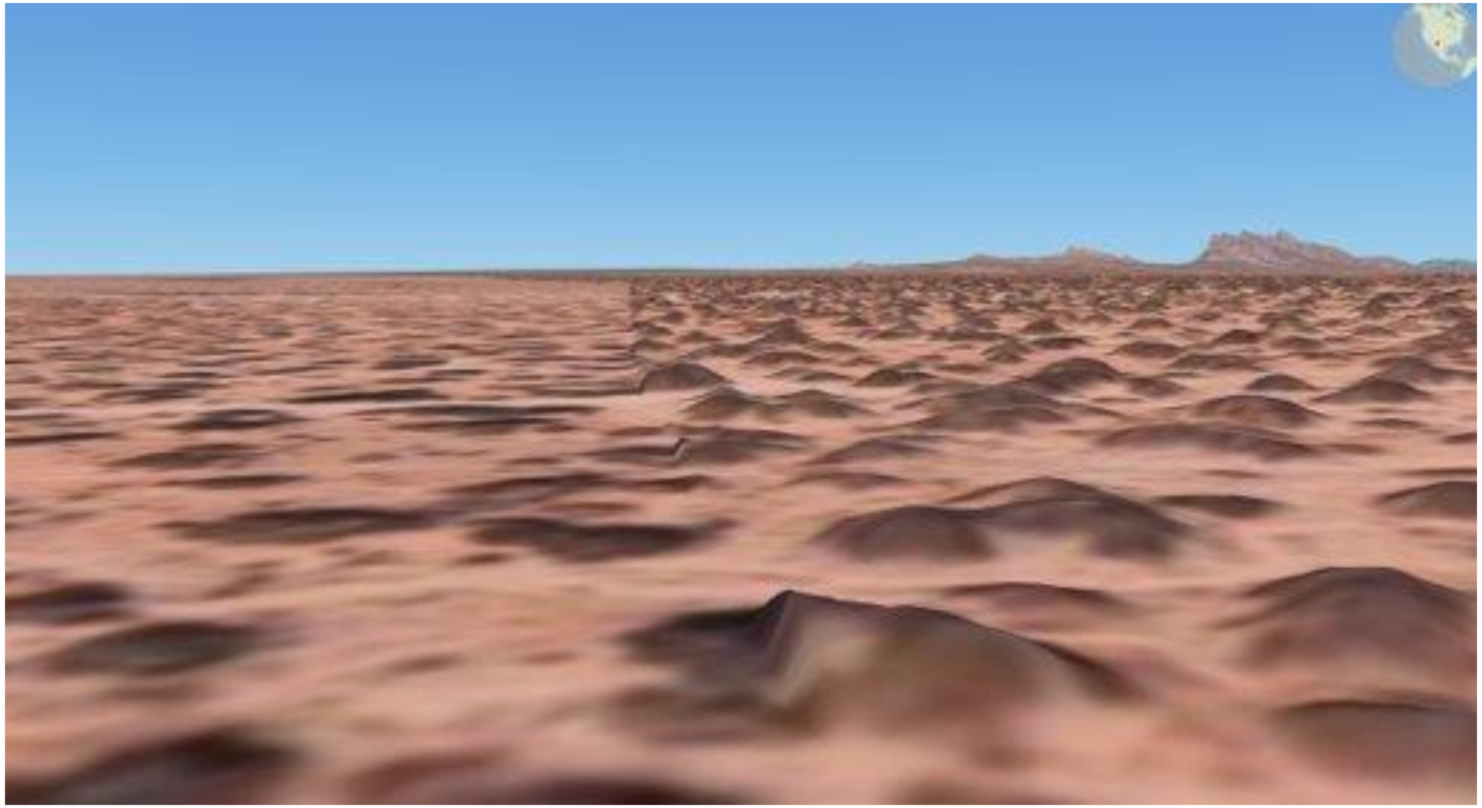
Challenge 1: Full Automation

Full automation does not provide the require quality

- What if the best available source data and fully automated processing results in geospatial terrain data with less than the required quality?
  - With a fully automated processing architecture there is no place in the processing pipeline for human intervention
- To solve this limitation, OWT has introduced processes and tools to:
  - Improve the source data
    - Introduced processes to apply touch labor to the “best available source data” to bring it up to a OWT minimum standard
  - Control processing
    - Introduced control vector features to guide the automated processing in a specific geographic area or location
  - Override outputs
    - Introduced override of vector features to replace the output of the automated process
- This allows the OWT team to cost effectively adjust the quality of critical areas within the fully automated OWT production pipeline

Challenge 1: Full Automation Restoration of Dunes

Left side of image shows the 3D Terrain Model (bare earth) from standard terrain model processing



Right side of image shows the 3D Terrain Model (bare earth) from control vector guided terrain model processing

Challenge 2: Rich Representation
Current formats don't support the rich metadata

- No single format supports the rich data and metadata required for training and operations
  - The STE-CFT selected 3DTiles as the format for the OWT solutions
- To address the challenge, OWT worked with OGC and geospatial industry partners to:
  - Updated the geometry representation of 3DTiles
    - Leveraging glTF and glTF extension
  - Added extensive support for metadata at all levels within the 3DTiles data hierarchy
    - OGC approval of the OGC 3DTIles version 1.1
  - Added tools and processes to automatically populate the metadata
    - Expanded attribute extraction from the 3D Surface Model AI/ML process
    - Added imposed values to ensure common "defaults" across all consumers
- This allows the OWT team to cost effectively populate and store the required metadata to support training and operations

OWT Well-Formed Format (WFF)

Based on Open Standards: 3DTiles glTF

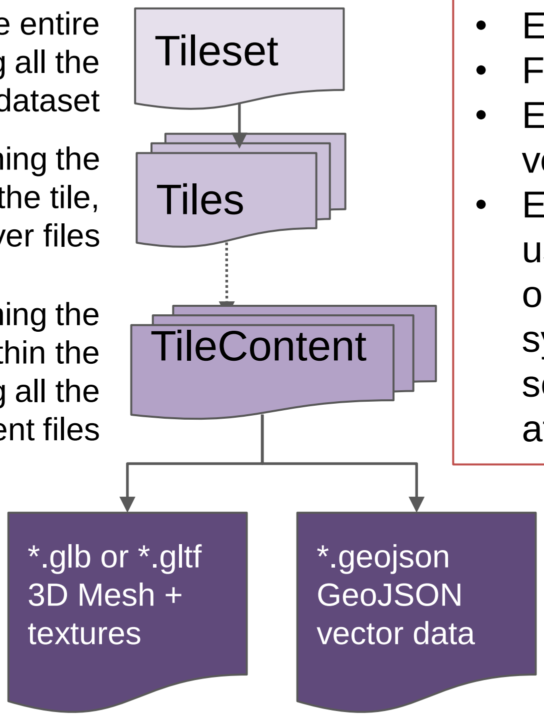
Well defined tile hierarchy:

JSON file defining the entire dataset, referencing all the tiles making up the dataset

JSON files defining the layers within the tile, referencing all layer files

JSON files defining the content files within the layer, referencing all the content files

glTF files store the geometries and textures of the terrain polygon mesh and 3D models

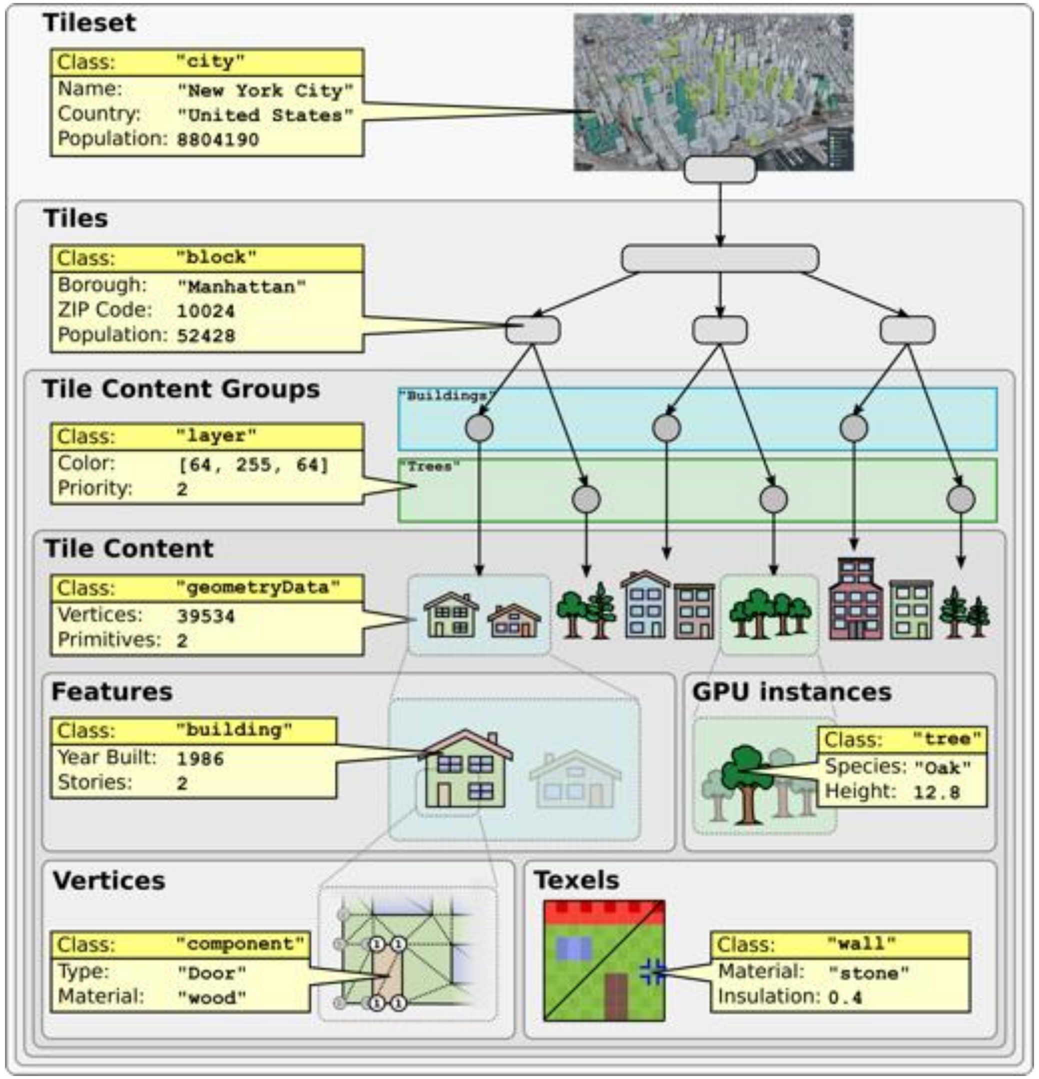


GeoJSON file storing the vector data for "GIS" features

WFF value:

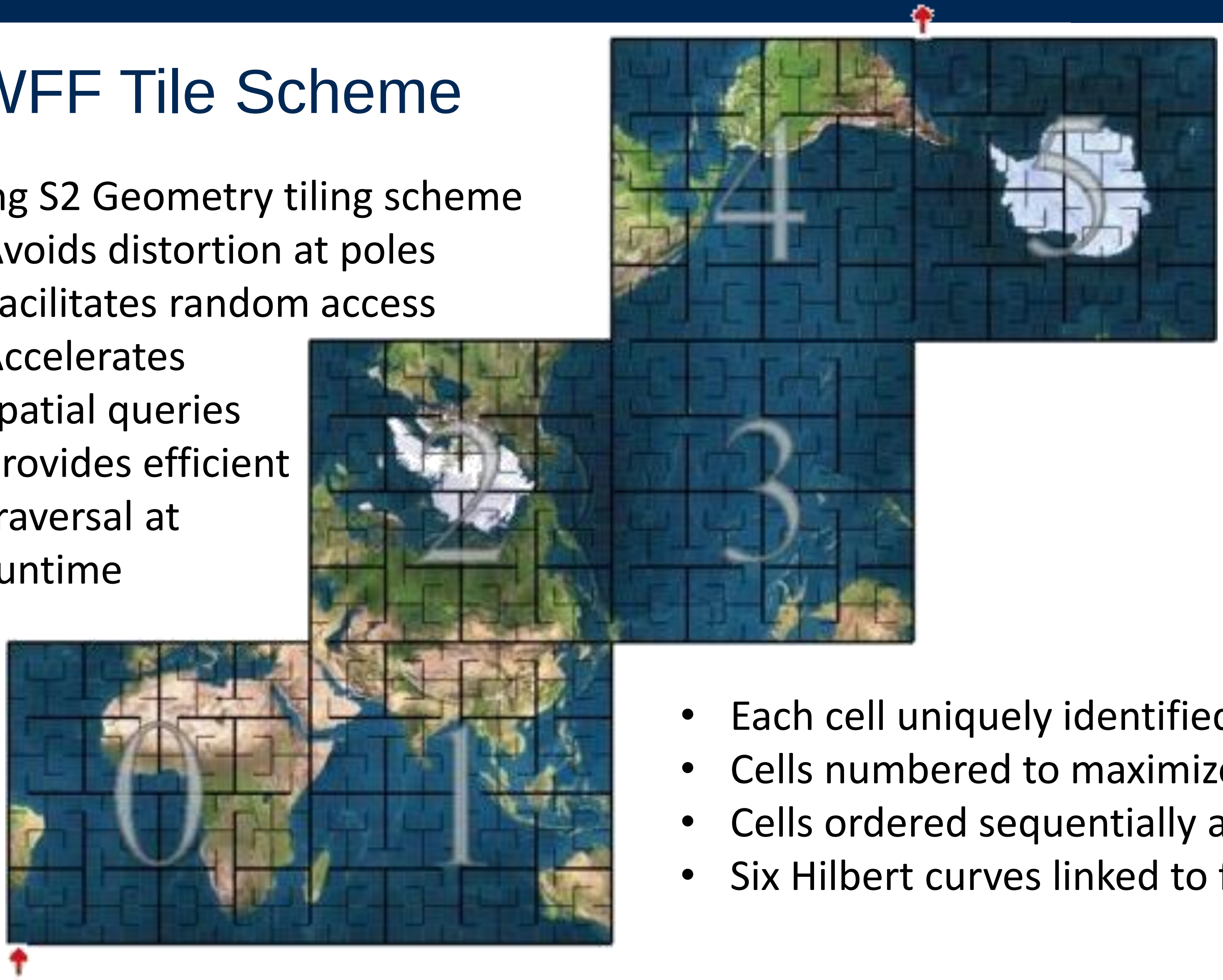
- Efficient streamable format
- Flexible spatial data structure
- Embedded metadata for vertex/polygon level attribution
- Explicitly expressed (well-formed) usage with defined levels of detail organization, coordinate systems, specific tiling scheme, layers, features, and attribution

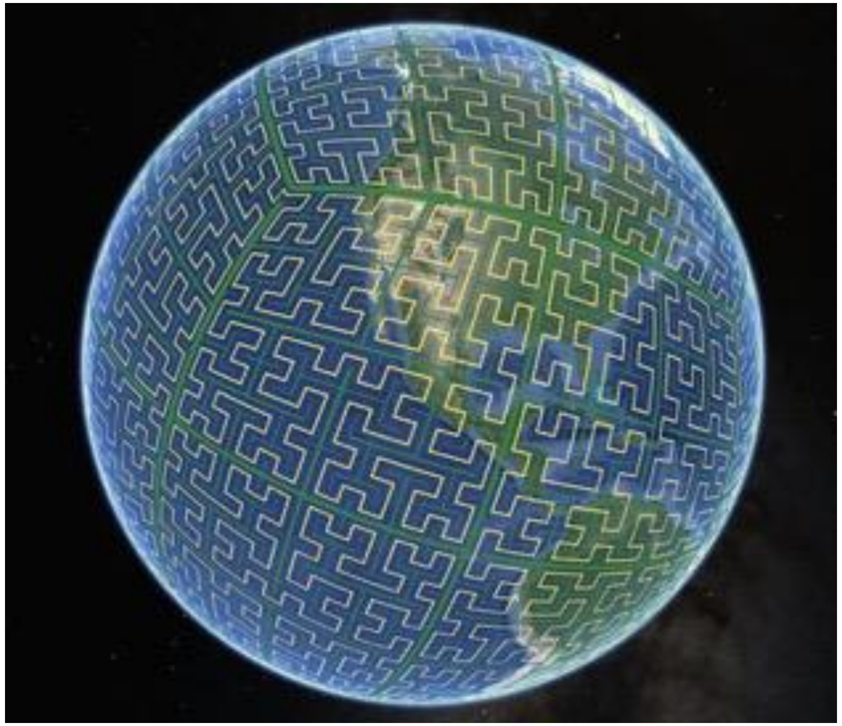
Rich metadata throughout the tile hierarchy -



WFF Tile Scheme

Using S2 Geometry tiling scheme
- Avoids distortion at poles
- Facilitates random access
- Accelerates spatial queries
- Provides efficient traversal at runtime





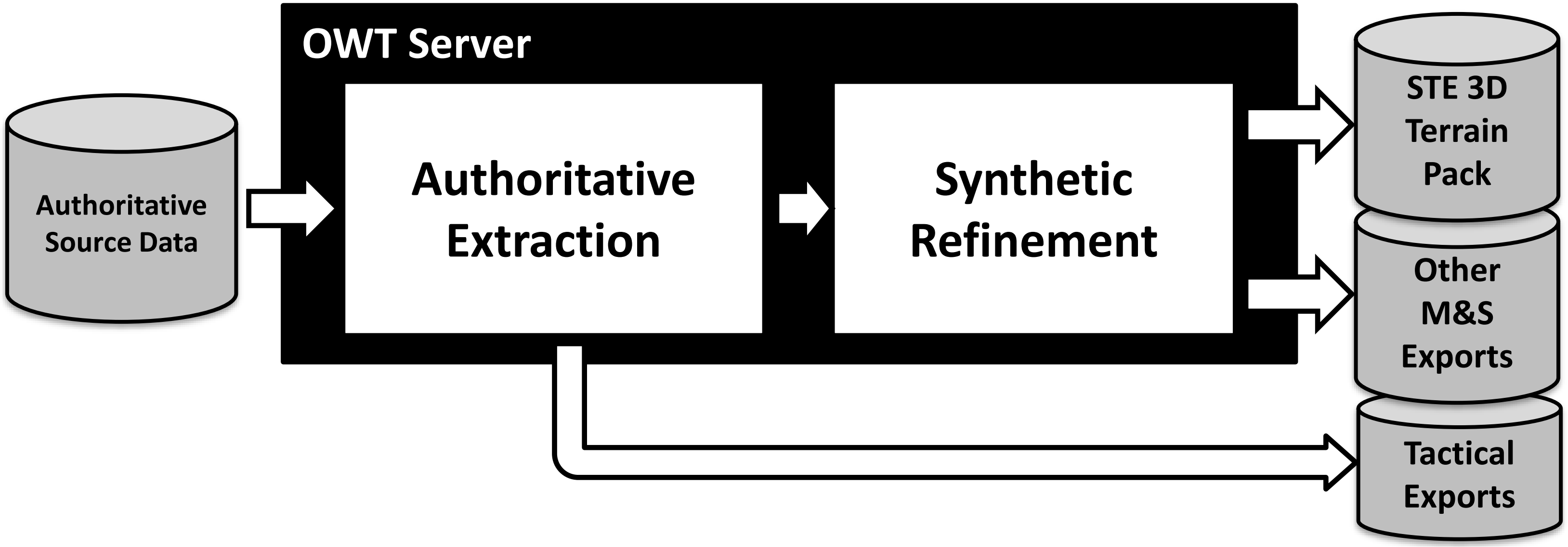
- Each cell uniquely identified by 64-bit S2CellId
- Cells numbered to maximize spatial indexing
- Cells ordered sequentially along a space-filling curve
- Six Hilbert curves linked to form single continuous loop

Challenge 3: Multiple Usages/Multiple Exports Correlated authoritative and synthetic data

- How to obtain correlated authoritative geospatial data for operations and synthetically enhanced/refined data for training from a common process?
  - Operations does not want synthetic data
  - Training needs synthetic data to ensure useability
- To resolve the conflict, OWT has introduced a two-stage processing architecture:
  - Authoritative Extraction uses machine learning and image science techniques to process the source 3D Surface Model into terrain data useful for operations
  - Synthetic Refinement allows the modifications necessary to support training, including thinning tree points, re-coding Land Cover, enhancing buildings, synthesizing bridges, painting imagery under-bridge, leveling of terrain beneath buildings, sculpting terrain around ramps, etc.
- This allows the OWT team to cost effectively deliver authoritative data for operations and refined data for training

OWT Processing Steps

Separated the processing pipeline into two distinct processing steps - the first step provides authoritative extraction, and the second step provides procedural/Synthetic refinement



Examples of Refinement Functions

Bridges Procedurally Created

Imagery Under Bridge Procedurally Painted Out

Predicted Accuracy in Operations Export

Export variations and derivatives of the authoritative extraction data in industry standard formats

Including predicted accuracy in NGA gpm format

Conclusions

Battlespace Digital Twin, One Process, One Format, for Operations and Training

- Separation of authoritative extraction and synthetic refinement enables OWT to support the exports required for live, virtual, and constructive modeling, simulation, and training applications and real-world data for operations
- Authoritative extraction capability supports a broad range of digital twin applications
  - Using a mesh-based representation, ensures an unambiguous definition of the terrain model
  - Using 3DTiles, with extensions, enables rich non-visual infrastructure data and metadata, all integrated and correlated, in a storage optimized and streaming efficient format
- Automated production process proves the maturity to automate the creation of usable geospatial data from a photogrammetry derived 3D Surface Model
- The highly automated process to create a fully correlated, high-resolution, global geospatial dataset, and richly attributed enables Maxar the ability to apply this capability to other opportunities

Questions