Quadridox QSim on the Rendered.ai Common Application Framework

Whitepaper, April 2021

1.0 Security Screening on the Common Application Framework

Whitepaper Executive Summary

Data is necessary for robust and quantitative development of X-ray system architectures and algorithms. Synthetic data generated by physics-based numerical simulation tools is an inexpensive, well-controlled and sometimes the only source of available data. This Whitepaper describes Quadridox's QSim synthetic X-ray data generation toolset and how that toolset is made more useful by having it hosted on Rendered.ai's Common Application Framework.

The QSim security screening solution enables system design, virtual testing and evaluation, evaluation of performance with dangerous or controlled substances, system of system analysis, certification readiness demonstration, detection, and false positive performance analysis against representative data, all enhanced by the generation of synthetic data that is sufficiently realistic for both humans and AI.

QSim and its capabilities are described in Section 2.0. The benefits of hosting this synthetic data X-ray generation tool on the Common Application Framework by Rendered.ai are discussed in Section 3.0. The Framework was designed from the ground up for faster and agile synthetic data generation, experimentation, collaboration, and integration with AI/ML systems with a focus on security applications.

2.0 The QSim Synthetic Generation Toolset

Synthetic data can augment or replace empirical data in a variety of applications, to enable better, cheaper, and more scalable AI/ML and human centric solutions. However, for synthetic data to be effective it must include:

- An excellent simulation of sensor phenomenology
- High-fidelity representations of interaction physics
- Flexible, realistic representations of target objects (bags, pallets, etc.)
- A robust, flexible method to engineer, generate, improve, analyze, store and re-use the synthetic data in an agile fashion.

Quadridox's QSim applications meet all of these requirements and more, to represent a complete solution for synthetic data generation.

Physics-based Synthetic Data

Physics-based synthetic generation, where the user has complete control of the X-ray system architecture and virtual objects under consideration, involves several steps (see Image 1 below):

1. Creating virtual objects (simulants, weapons, luggage, pallets, etc.)
2. Creating a virtual X-ray system (e.g. CT scanner)
3. Generating raw synthetic data
4. Processing and/or analyzing the synthetic data

In this paradigm, **Quadridox's QSim allows a user to quickly and accurately create the virtual objects and virtual X-ray scanners required to create synthetic data**.

The Rendered.ai common application platform helps make the data generation process simple, robust and high-volume while also providing a natural environment for performing data analytics.

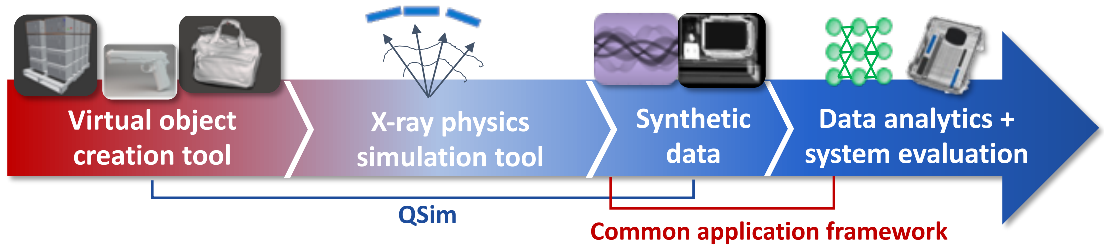

Image 1: QSim + Common Application Framework

QSim generates raw data that mirrors the output of real X-ray scanners, including existing and not-yet-built systems. To accomplish this, QSim natively includes:

- Flexible X-ray scanner architecture definitions, including the locations and motion of sources, detectors, samples within a system
- Energy-dependent X-ray-matter interaction physics, such as absorption (including loss due to photoelectric absorption and scatter), Compton scatter, and coherent scatter (or X-ray diffraction)
- Well-parameterized and/or user-definable descriptions of component performance, such as source spectrum or detector response

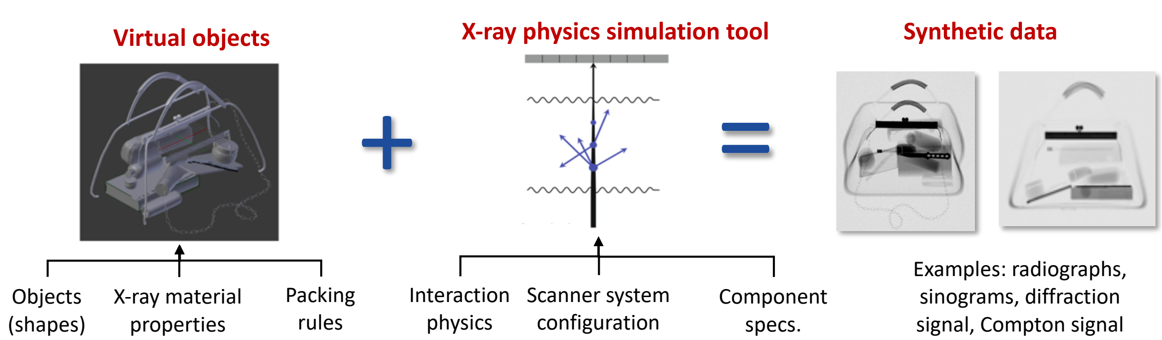

Image 2: QSim Synthetic Data Generation

As a result, QSim can represent arbitrary X-ray scanner configurations, including (but not limited to):

- Dual energy, multi-view radiography systems, such as the 2-view Rapiscan 620DV or 4-view Smiths aTiX AT2 scanners)
- Single and dual energy rotating gantry CT systems for carryon or checked baggage, such as the Smiths CTX series or the Leidos MV3D, eXaminer, and Reveal EDSs
- Multi-energy fixed gantry CT systems, such as the SureScan x1000, Scantech IBS SENTINEL, Rapiscan RTT series, or the Astrophysics Multi-view CT
- Compton scatter systems, such as the the Rapiscan Z-backscatter system
- X-ray diffraction tomography systems, such as the Smiths XDi, Halo HXT and Quadridox systems

In addition to these existing systems, QSim's flexible parameterization of system configuration allows for **quantitative analysis of optimizations for existing systems or the design of completely novel system architectures**. This capability is not possible with non-physics based synthetic data derived from experimental measurements, as no data exists for such a non-extant system.

QSim applications combine this powerful physics-based simulation capability with an extensive shape and material libraries for world building and virtual object creation. These – in tandem with the powerful simulator – support rapid experimentation with changes in the sensor tuning and synthetic data characteristics and how these changes effect human centric realism and AI/ML realism is important to understand. QSim component response, detectors, sources, and optics are designed for realism, are customizable, and thoroughly validated.

Validation: is the data 'good enough'?

Synthetic data and associated tools must be validated in order to be trusted. QSim has been thoroughly tested and validated against both laboratory-grade measurements by third-party University collaborators and against real, certified, deployed OEM equipment. Examples below include a multi-energy fixed gantry CT EDS systems, a 4-view, dual energy AT2 system, and a prototype X-ray diffraction system. Beyond simply appearing realistic or even matching quantitatively the raw empirical data, the real proof of QSim's value is evidenced by the fact that the **SureScan x1000 algorithms, developed entirely on experimental data, are able to perform CT reconstruction, segmentation, and feature selection on QSim synthetic data without any modifications to the algorithms.** This demonstrates the QSim's realism is sufficient for the purposes of algorithm development.

The Uses of QSim Synthetic Data

- **Supplemental Data** for rare events, edge cases or novel events
- **Cold Start problem** where sensors or entire system architectures or algorithms are new and have little or no field data
- **User defined threats** or anomalies of different sizes, shapes and compositions that are completely controlled
- **Agility and flexibility** to be adaptive and confident in response to new standards and emerging threats
- **Human training and testing** with realistic synthetic images (including physics-based, 3D threat image projection-like images)
- **Overcome restricted Data issues**, where security or confidentiality make data unavailable
- **Perfect data labeling** for testing and training of algorithms, which includes material composition, segmentation, item metadata
- **Fast and efficient algorithm comparison** against existing standards and
- Establish model and/or **fundamental performance limits** of a measurement architecture or algorithm
- **Evaluating real-world detection and false alarm rates** on a controllable ensemble for pre-certification testing and extrapolation of results on small datasets to performance in a specific, deployed operational environment
- **Quality assurance/quality control** studies for evaluating performance envelope of system lifetime and analyzing component selection or vendor changes
- **Open architecture compatibility** for future worldwide requirements and collaboration with third parties

Example 1: X-ray System Design and Analysis

The QSim toolset facilitates evolutionary and revolutionary new system design approaches. New products can be significantly better and reach the market faster boosted by ample data. Exploratory systems need data to target and test against as they need a benchmark of comparison with earlier or competitive architectures. Subsystems, component selection, quality control and price/performance analysis need data for comparisons. QSim enables safe and easy access to virtual threat objects or controlled substances, enabling one to evaluate both detection and false alarm rate in-house (without testing at a cleared third-party facility). The virtual threat objects become an easy to reuse and repurpose capability that enhance an enterprises' intellectual portfolio.

Go-to-Market: The proof-of-concept stage can be reached faster, with less expense and higher confidence. Comprehensive trade studies can explore arbitrary design choices quickly and quantitatively. With ample synthetic data, pre-certification testing can be more expansive and complete.

Example 2: Algorithm Development

The QSim toolset powers the development of better algorithms. Optimal algorithms must balance detection performance, generalizability and computational load. Developing new algorithms and evaluating different software implementations of the algorithms requires data that includes common and edge-case configurations, is fast and inexpensive to generate, is of sufficient fidelity, and automatically contains perfect labeling. QSim synthetic data meets all of these requirements and enables the development and testing of image reconstruction, segmentation, feature extraction, classification, and display/rendering algorithms.

Go-to-Market: The optimization of existing algorithms to a particular set of threats, ability to quickly train and test on new threats or objects of interest and perform meaningful Pd/PFA studies means accelerating algorithm development and ensuring optimal performance as specifications and the threat envelope varies. This helps guarantee certification testing and no ‘surprises’ in real-world deployment of systems. Automatic labeling means inexpensive and perfect ground truthing, which saves time, money, and human error. Finally, non-proprietary, non-sensitive data means that third parties (Universities, government labs, non-vendor companies) can potentially provide performance improvements and easily integrate a system into an open architecture paradigm.

Increasing the Velocity and Agility of Data Generation

QSim is the tool for modeling and understanding sensor phenomenology and generating synthetic data; the Common Application Framework is the part of the tool for increasing the velocity and agility of data generation, data experimentation, development collaboration, human recognition and AI understanding. Both elements, Framework and QSim, are equally important for good synthetic data generation outcomes.

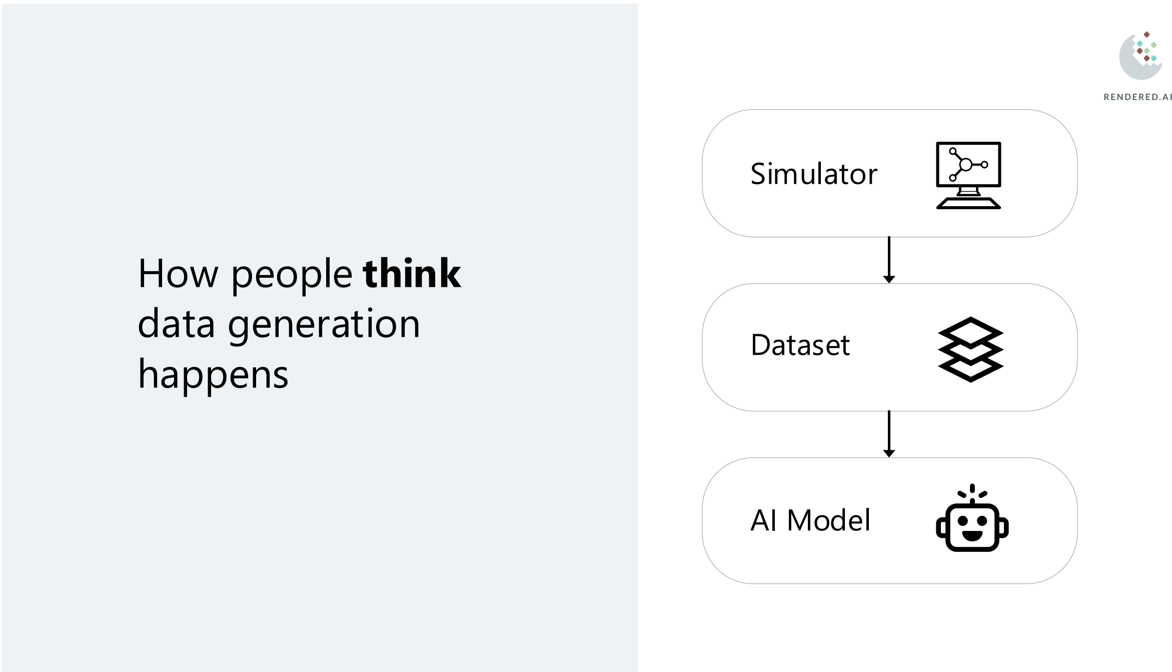

Image 4: How people think data generation happens

There is a popular notion that says: if one has a good enough synthetic data generator, if you can recreate ground truth synthetically so it is just 'so', that will yield a great dataset that can be incorporated into your AI model and your confidence scores will soar.

In this "throw it over the wall" approach, it is impossible to have rapid experimentation with changes in the sensor tuning, sensor placement and synthetic data characteristics. In this model the inertia of data creation is so high that testing different sub-systems against different objects of interest, and importantly, data artifacts is not practical. Understanding what the AI and human constituents are keying on, what it is recognizing, and why the algorithms are not generalizing underscores the importance of agile data generation to enable the collaboration between the next generation security screening systems developers and synthetic data.

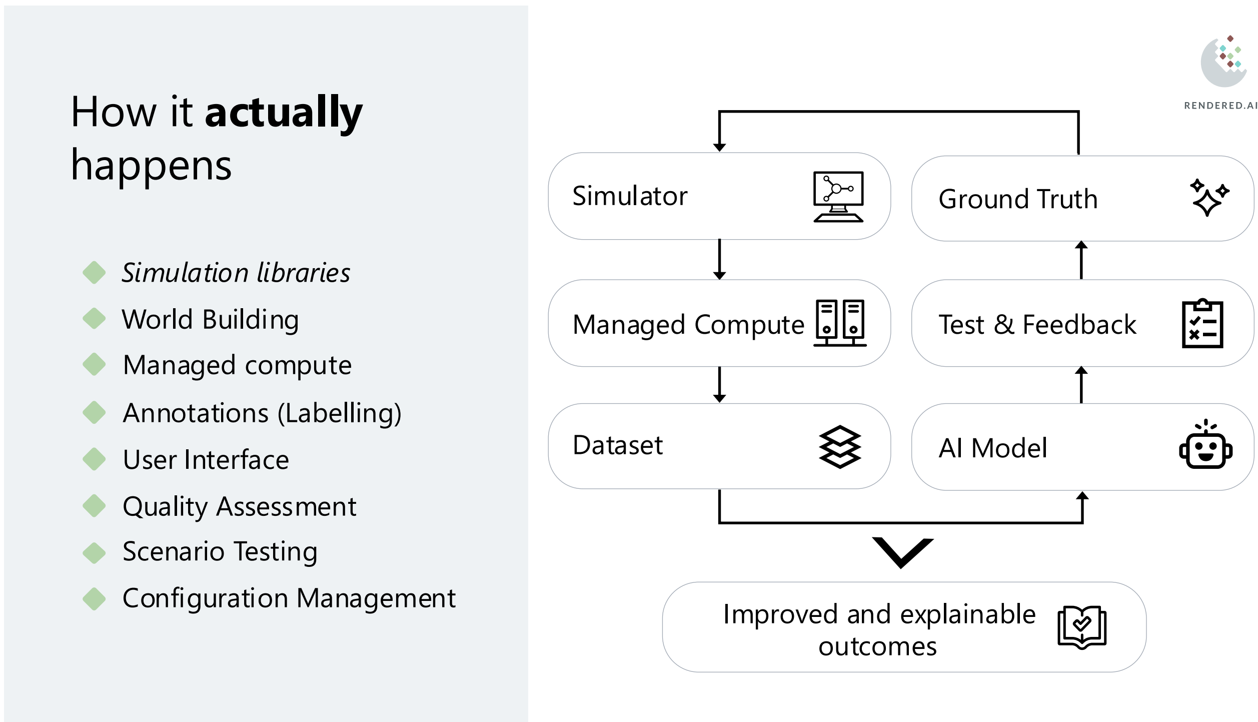

Image 5: How data generation actually happens

How the process actually happens is an iterative, engineering process like any other engineering process. What the Common Application Platform has done is recognize this engineering workflow and automate it. The Common Application Framework facilitates agile synthetic data production.

3.0 The QSim Application on the Rendered.ai Framework

Utility of the Framework

The QSim X-ray simulation and synthetic data generation toolset is fully integrated into the Rendered.ai Common Application Framework. The value of the Common Application Framework is in the management, creation, recreation, modification and analysis of synthetic data made by the QSim application. The Common Application Framework increases the velocity at which QSim synthetic data is generated and modified.

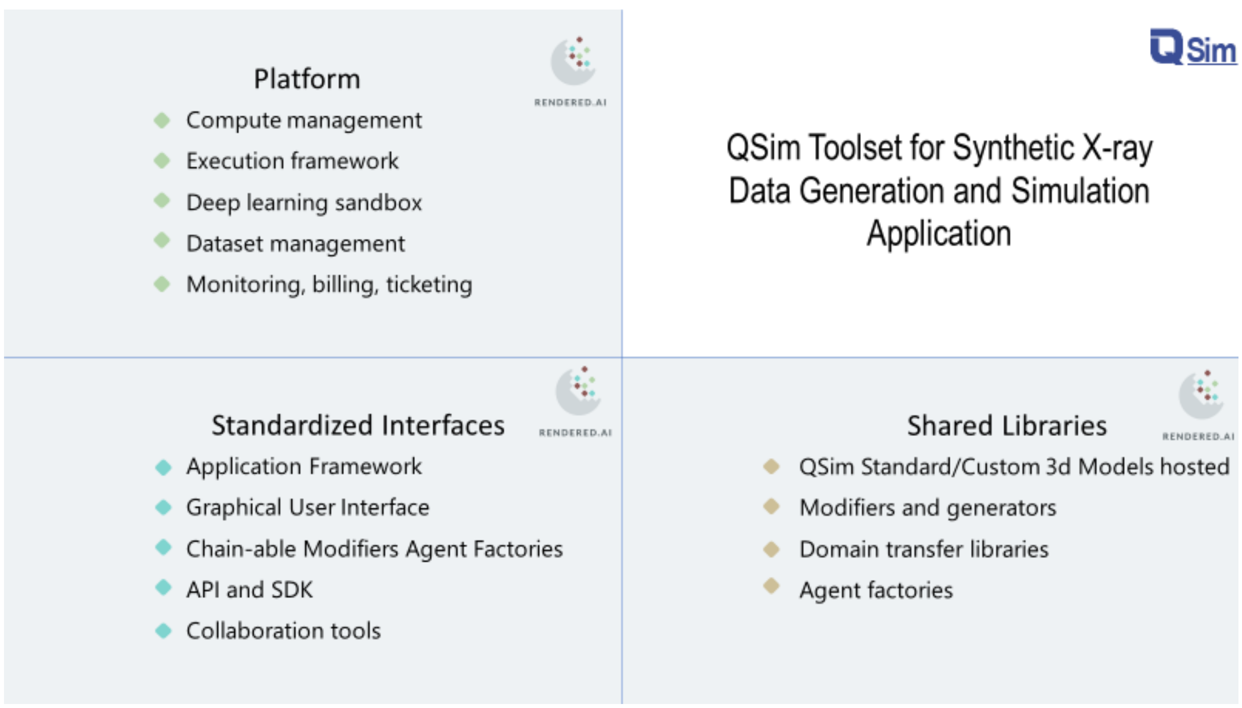

Image 6: The QSim application on the Rendered.ai framework

The Common Application Framework

Synthetic X-ray data generation and simulation is best thought of as an Application that rides on top of the Common Application Framework. The Common Application Framework leverages the extensive engagement experience of Rendered.ai in the synthetic data simulation environments beyond X-ray, specifically Satellite EO, SAR, RADAR, and MWIR. The Common Application Framework has produced over 10,000,000 images to date.

The Platform, Standard Interfaces, and Shared Libraries blocks in Image 6 are required in all engagements. The QSim offering includes this Framework, which has immediately usable building blocks that enables the creation, modification and workflow management of X-ray synthetic data.

Platform	**Compute management**. Parallelism, quantity of GPUs, instances and other computational issues are all abstracted away from the user. The Framework is cloud native. The QSim customer has the most powerful computing environment for simulations at their command without worry
	Execution framework. A scripting-free node-based collaboration-friendly data generation environment
	Deep learning sandbox. Analysis, visualization tools, comparison tools
	Dataset management. Pre-views, archive, librarianship and retrieval are in place. Simulation images, masks, annotations and metadata are handled together
	Monitoring, billing, ticketing. Alerts, costing and cost recovery tools are in place
Standardized Interfaces	**Application Hosting.** The QSim application has access to all the Framework's features
	Graphic User Interface. Node based interface with pull-down modifiers. Point and click connection
	Chain-able Modifier Agent Factories. Objects are created in a procedural fashion and can have cascading modifications
	API and SDK All Common Application Framework can be accessed by API and extended thru an SDK.
Shared Libraries	**QSim standard and custom 3D models.** QSim standard assets and models can be shared among users. Any custom 3D models introduced by the customer or made by request to QSim can also be shared through a set of pull-down menus among authorized users
	Modifiers and Generators Adding physics-based modification and generator nodes adds additional capabilities to library objects
	Agent Factories Procedurally generated, placed, rotated, and populated objects. Extensive shapes and materials can create objects

QSim as an Application

In Image 6 above, the upper right hand quadrant represents the specific application for QSim. The QSim application is visually represented in Image 7 below as a series of linked nodes. The term of art for this is “Graph”. This “no code” diversity generation interface of chain-able modifiers encourages domain experts in Security Screening and/or AI/ML, who may have few or no scripting skills, to create and modify images and videos with diverse 2D and 3D backgrounds, scenes, and containers. Once the base Graph is created, new objects are easy to integrate. This same functionality can be accessed through APIs. Physics based synthetic data objects leveraging ray tracing populate a scene or video through a user-friendly interface. Modifiers such as payloads, clothing, coloring, and reflectivity can be added to objects. Other surveillance conditions can be varied. The output can be images or videos of arbitrary quantity and length. For maximum flexibility during the project life cycle, the objects can be hand selected, their density and placement determined procedurally or left to algorithmic control in a user-friendly environment.

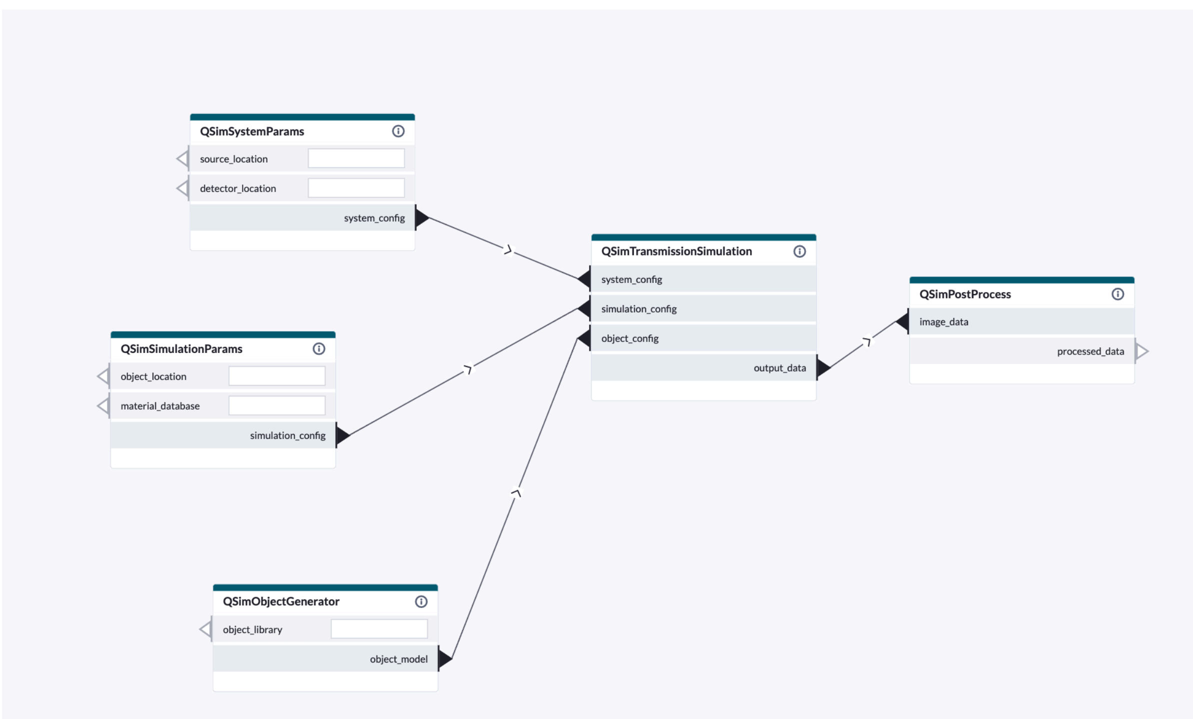

Image 7: A “graph” on the Rendered.ai framework

The Common Application Framework is a collaborative tool that can support multiple subject matter experts working together on a scene. The characteristics and placement of sensors can be modified, as can the zoom characteristics of the sensor. If sensors or models are upgraded or modified, synthetic data engineers have a tool for an instant A/B comparison of that change and its effect on human recognition and AI learning.

4.0 Conclusion

QSim and the Common Application Framework

The Common Application Framework has created over 10,000,000 images and related synthetic videos to date. The QSim Application on the Common Application Framework delivers a complete security screening solution that enables virtual testing and evaluation, evaluation of performance with dangerous or controlled substances, system of systems analysis, certification readiness demonstration, detection and false alarm performance analysis against representative data. Together the **QSim and Common Application Framework is an agile toolset for increasing the velocity of cutting-edge synthetic X-ray data generation and with it the better AI and human understanding**.