Innovation and Rapid Evolutionary Design by Virtual Doing: Understanding Early Synthetic Prototyping (ESP)

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ABSTRACT: *The proliferation and maturation of tools supporting virtual environments combined with emerging immersive capabilities (e.g. Oculus Rift and other head mounted displays) point towards the ability to take nascent ideas and realize them in engaging ways through an Early Synthetic Prototyping (ESP) system. In effect, "bend electrons before bending metal," enabling Soldier (end-user) feedback early in the design process, while fostering an atmosphere of collaboration and innovation. Simulation has been used in a variety of ways for concept, design, and testing, but current methods do not put the user into the system in ways that provide deep feedback and enable a dialogue between Warfighter and Engineer (as well as other stakeholders) that can inform design. This paper will discuss how the process of ESP is teased out by using iterative rapid virtual prototyping based on an initial ESP schema, resulting in a rather organic design process - Innovation and Rapid Evolutionary Design by Virtual Doing. By employing canonical use cases, working through the draft schema allows the system to help design itself and inform the process evolution. This type of self-referential meta-design becomes increasingly powerful and relevant given the ability to rapidly create assets, capabilities and environments that immerse developers, stakeholders, and end users early and often in the process. Specific examples of using rapid virtual prototyping for teasing out the design and implications/applications of ESP will be presented, walking through the evolution of both schema and prototypes with specific use cases. In addition, this paper will cover more generalized concepts, approaches, analytics, and lessons-learned as well as implications for innovation throughout research, development, and industry.*

1. Introduction

While the United States Army is one of the best-equipped military forces in the world, designing, developing and fielding systems and platforms remains an expensive and time-consuming endeavor. And when systems and programs fail, the results are costly [1] [2] [3]. It may not come as a surprise that some of the top reasons cited for system failure include: inadequate design, unanticipated and improper use of equipment, as well as inadequate testing [4]. What may be surprising, however, is that beginning in the 1970s, the Department of Defense (DoD) had processes and personnel in place to provide development testing and best practices to evaluate the reliability, availability and maintainability (RAM) of systems during the design and development process. Unfortunately, these best practices were discontinued in the 1990s [5]. Per the Defense Science Board Report, testing after the fact will not fix RAM deficiencies during the design and development phases.

Testing also will not fix a lack of communication between Engineer and end user. One of the recommendations of the Defense Science Board Report was to align DoD terminology with systems engineering procedures in order to address the current disconnect between the military end user and the engineer tester. The military and engineering communities use different terminology to describe level of performance, conditions and how performance is to be measured [5]. A recent report from the National Research Council [6] also cited early testing in the design process as well as the need for early and clear communication regarding requirements. Promoting communication early on for all stakeholders would help clarify expectations during the design phase and help avoid costly mistakes during development and testing phases. Early Synthetic Prototyping (ESP) is a research project focused on providing tools to break down barriers in the system design and development process, nurture a community of collaboration between Engineer and Soldier, and place the power of real-time analytics and assessment in the hands of all stakeholders.

ESP is sponsored by the United States Army Capabilities Integration Center (ARCIC) and Office of the Assistant Secretary of the Army for Acquisition, Logistics and Technology (ASA(ALT)) that explores options to leverage emerging synthetic immersive environments to foster innovative design and testing. ESP seeks to bring the Soldier (i.e. the end user) into the design and testing process during initial planning stages, helping to connect those that design/build (engineers) and those that employ (Soldiers). ESP also is being designed to enable testing of nascent concepts and explore not only the art of the possible for today, but also the innovations of tomorrow.

ESP is different from existing game/simulation engines. Current synthetic environments track fairly traditional metrics giving data largely as scores with easily quantifiable outcomes. At the core of ESP is a new generation of metrics and analytics that focus on the wants and needs of the user, tracking not only their in-game performance – *what* they did – but also their inner motivations *how* and *why* they did things and how they *feel* at specific points in time during the interaction. In order to provide useful and untapped information back to a designer/engineer, ESP will need to assess a number of softer metrics such as user frustration. In addition, deeper granularity will be tracked as well – e.g. source of frustration (equipment design, team members, opponents, system performance, etc.).

ESP is currently in the early prototype stage, and in fact, the system is using the working ESP schema to facilitate understanding the requirements that enable creativity and innovation through ESP. These exploratory environments are multi-player and are exploring the design of next-generation vehicles as well as their use in a variety of contexts. Users can make modifications on-the-fly, and help find new ways to not only build but also employ the systems.

The current ESP effort is focused on four main areas of research:

- Idea ingest – how to bring an idea or concept into the ESP environment
- Emerging interfaces – wearable sensors, AR/VR/MR and how/why to use it effectively
- Analytics – next-generation soft-metrics that are user-focused
- Community – how to include a larger number of users to leverage a wide body of expertise

The broader ESP effort also includes research work at Naval Postgraduate School (NPS), U.S. Army Tank Automotive Research Development and Engineering Center (TARDEC), and other Army partners. The initial prototypes are undergoing testing and will inform the ESP design and requirements, with FY16 efforts focused on building a v1 system along with ongoing research into the four vectors listed.

The end goal of ESP is an integrated ecosystem where community stakeholders may propose, develop, test, discuss and refine concepts within a prototyping environment. To inform the design of such a system and develop requirements and specifications, and allow prototyping of some aspects of ESP before the entire ecosystem exists, ICT's development team is acting out some functions that will be handled within the prototyping environment itself, in the final system – "doing ESP on ESP."

Future goals for ESP analytics include filtering, displaying and analyzing aggregate data, across many runs of the same scenario to identify particularly effective or ineffective force compositions, TTPs, and so forth.

2. Main Research Vectors

In order to begin digging into the details of the scope and parameters necessary for Early Synthetic Prototyping, white board sessions both internal (ICT) and external (with SMEs and stakeholders) were held to create an initial schema (below).

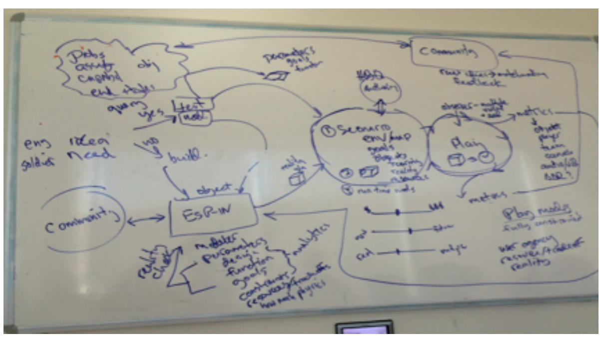

Figure 1. Iterative ESP schema diagram.

This process yielded a number of somewhat discrete steps necessary to take a nascent idea and instantiate it in a virtual environment that could provide meaningful data and feedback to various stakeholders. This is different from typical game development.

2.1 Ingest Nomenclature (ESP-IN)

Design ideas can come from a wide variety of sources and in a wide variety of formats. From the quintessential napkin sketch to a computer CAD model, the process for bringing an idea into synthetic exploration space can be wildly complex. This is further complicated by the realities of game engines and simulation in general. Typical in computer simulation the goal is to favor realism and increased granularity. This can quickly eat up computational resources and in the case of exploring nascent ideas, the details are either not known and need significant abstraction.

"Early Fidelity" is an outgrowth of teasing out the ESP-IN framework. The goal of determining Early Fidelity is not to ignore the laws of physics, but rather find a balance between rigor and flexibility that provides meaningful data. Finding the "minimum necessary" physics and parameters will be somewhat case-by-case with each idea brought into ESP, but there will be some generalizations that can be applied to facilitate ingest.

2.2 User-Centered Analytics and Metrics

Typically the "scores" in computer games are made up of a few different game events that are tracks and weighted, with the results being visualized and compared in different ways. These tend to focus on easily measured events like whether a shot hit the target, speed of a vehicle, etc. While this can be useful data, in order to better understand issues around design and implementation, one needs to not only understand what a user did, but how they accomplished it, and perhaps most importantly, why they acted in a particular manner and got a particular outcome.

The emerging area of user sensing provides opportunities to gather metrics far beyond traditional "game scores." A large part of the ESP current effort is looking at ways to gather and understand "soft metrics" and understand the underlying reasons for user performance.

2.3 Community and Crowd Sourcing

One early goal of ESP was to be able to put the software and capability into the hands of a large number of Soldiers and have them "play" on their free time. While the user population certainly has a high percentage of gamers, fielding a solution like ESP will encounter a number of challenges (OPSEC, Certificates of Networthiness, Information Assurance, etc). The current work cannot solve those problems, but there are ways to leverage game play in creative ways that don't burden networks, existing labs, or require users to have high-spec hardware.

While there may be ways in the future to deploy tens or hundreds of thousands of copies of a full-blown ESP application, current work is looking at smaller footprint ways to engage large numbers of users. Many commercial games have large audiences who follow along through Youtube or Twitch postings. We are looking at intermediate spaces with a playback application that would take user data from the full application and allow other users to replay, comment, and contribute. This can leverage the work far beyond initial deployment and does not burden existing infrastructure or protocols/doctrine.

2.4 Emerging Interfaces

For the past few decades, user interaction with a computer and/or game system has been through a game controller and/or keyboard and mouse. While technologies like the Wii pushed that forward, it is the emerging capabilities around headmount displays for virtual and augmented reality that will signal a sea change in how users engage with synthetic environments.

While these technologies are about to be commoditized, little is understood about how to develop for these new mixed realities, especially with regards to "serious games." There will be a temptation to reach for the new "shiny object" and use a head mounted display "because we can." Another main thrust of the ESP effort is to prototype these engagements so that we can use emerging technology not just because we can, but rather because we know where and why it is effective and important.

3. Experimental Design

ICT's ESP prototypes are developed in Unity 4.6 on Windows. While Unity may not be the platform for the final ESP system, Unity's tools facilitate rapid iteration and prototyping of novel interactions and systems in ways that are less afforded by more focused simulation tools.

To ingest a concept or capability ESP developers ingest requirements and goals, along with design information like sketches, artists' 3d models, CAD models, or technical specs. An art team prepares these assets for use in the sim environment by creating or refining/simplifying art assets for real-time rendering, and splitting systems into their articulated components for animation in the environment. The ICT art team works primarily in Maya and Photoshop, and exports FBX-format models for ingest into Unity. A set of common conventions (e.g.: wheels rotate clockwise around the X+ axis of the component) allow for clear communication between the art and dev teams, and re-use of common software components across similar systems.

In parallel, the requirements/goals are analyzed. Computational models are created using game engine physics, along with in-house code. A model of the configuration parameter space is constructed. For example, this parameter space for a ground vehicle platform includes different levels of force protection, the size and output of the power system, the type of drivetrain, and so forth. For a communications system like the Virtual Pointer, the parameter space includes the range and line-of-sight requirements of the radio system, accuracy of the rangefinder/IMU components, display system (mounted to a weapon optic; integrated into a rangefinder; integrated into an augmented reality helmet-mounted heads-up-display), and so forth. The ranges of these parameters may be selected to reflect various levels of optimism about future capabilities, and degrees of fidelity– it can be helpful to consider capabilities that may appear unobtainable in the short term, in the context of exploring emergent TTPs and shaping S&T research directions.

A model of the relationships between these parameters and other aspects of the system is also developed. Adding thicker armor plating, for instance, increases the vehicle's mass, which in turn impacts the center of mass of the vehicle, effective acceleration and top speed, endurance for a given fuel load, visibility, and cost per unit. The development team encodes these relationships into the software model. Cost/budget parameters are stored in an XML document that can easily be modified to evaluate different assumptions about future S&T realities.

Existing simulation and modeling capabilities are already capable of determining the mechanical and electrical performance characteristics of systems. ESP focuses instead on the human dimension – how Soldiers can leverage the capabilities provided by these systems to perform missions more effectively. For this reason, our ESP prototype's features focus primarily on the customization and post-review features, and assumes that data from these higher-fidelity, performance data from these existing offline simulations can be slotted into the capability/platform/system's model.

Relevant metrics are selected based on the requirements/goals. For instance, in the context of an IFV, survivability, crew situational awareness, stability, speed, and so forth may be measured. Components to capture these metrics are attached.

One or more scenarios is developed, based on the requirements/goals and desired metrics. The available systems and configuration options are selected.
During a multiplayer ESP session, the team leaders are given a goal. In our current prototype system, the scenario focuses on a two-vehicle team conducting an urban patrol, opposed by a small OPFOR insurgent team. The team leads first select force composition. BLUFOR's leader chooses between several vehicles, weapon systems, and sensor/comm

systems. Each system's parameters can be customized, as described above. All aspects of the force composition have attached costs, forcing the BLUFOR leader to make decisions about trade-offs. The total budget and relative costs may be adjusted on the server to explore different scenarios. The OPFOR team must select a location for an ambush and place obstacles (burned-out trucks, etc.) to channel BLUFOR into the ambush.

In the execution phase, all users control their characters and systems via a gamepad. The server logs and records the analytics described above, in addition to some common data such as position/orientation and look direction/field of view for each user. Each user may use an Android app on a tablet to provide feedback – users can flag one of several categories of positive or negative feedback, and provide a verbal report. These reports are time stamped and correlated with other analytics on the server. The system also employs the Intel Perceptual Computing SDK 2013 to capture sentiment analysis based on player facial expression, which is also logged as part of the analytics. The analytics are saved by the server as a JSON-formatted text file. Each event is time stamped, and locations are given in simulation-world coordinates (metric units, relative to the scenario world's origin). Numerical values are saved as fixed-point, both to optimize for file size and to reduce floating point rounding errors. Continuous values are saved per-delta – new values are written only when the current value exceeds a developer-defined difference from the last saved value; these values can be tuned to trade off between fidelity and storage for each type of value.

After OPFOR or REDFOR obtains their victory conditions, the scenario ends and all users are given a chance to participate in a Post Exercise Analysis (PEA). This phase presents each user with a 3d view of the scenario map. All units are represented on the map. The user can move through time, and jump to events (damage received; vehicle destroyed; unit killed; etc.). Users may track a specific entity in the world over time, or freely pan/rotate around the world. In addition to unit positions over time, weapon discharge/impact, and other parameters, the user can visualize the cone of vision for each unit.

The long-term goals for ESP include the design and implementation of a community portal through which stakeholders may review and comment on ESP analytics recordings, to identify exemplar tactics, force compositions, or other user decisions. Our current effort in support of this concept includes an application for Windows systems that can load and display analytics data for a single ESP session. ESP analytics data will be shared through a database-backed web system. While reviewing the recording, users may add additional time stamped feedback and annotations, which will be submitted back to the web community via HTTP and available for other viewers.

The ESP analytics format we have developed is not intimately tied to the ESP prototype simulation. JSON was selected to provide an open logging/analytics format – in theory any simulation system could log to this format, and read logs in this format, with the proper software infrastructure.

3.1 ESP Schema Elucidation and Expansion

Starting with the initial schema, canonical use cases identified by collaborators were applied to the process to begin to understand gaps and shape parameterization and scope. Each of the main areas (ESP-IN, scenario authoring/contextualization, game play, and community) were used to elaborate the use cases and explore more of the details of ESP. As details emerged, the schema was revised and use cases again applied against the process. This method of self-referential design proves to be particularly interesting when used with synthetic systems.

3.2 Initial Virtual Prototype

The first ESP prototype, codename “Creep”, was based on the concept of a virtual pointer (VP). In the field, a VP would allow individuals in different locations to identify targets and “show” the location without grid coordinates. While the technologies to execute this are not currently available, this is an example of a “far left of boom” use of ESP – to explore the art of the possible, identify emergent behaviors, and indicate possible research and development vectors.

The Creep prototype began with basic ESP-IN exploration. The capabilities were developed from previous written concept descriptions. Initial parameterization was around user modifiable inputs, display type (always visible head mounted AR-type display vs. rangefinder optic), and tracking capability (transmit points vs. transmit updated positions. The scenario/contextualization was for two BLUEFOR two-man teams with VP and call for fire vs. two OPFOR snipers in a geo-typical rural terrain.

3.3 Second Iterative Virtual Prototype

The second prototype, codename: Pretty, was designed to move to vehicle instantiation and provide an abstract environment to explore parameters and use cases that are relevant to vehicle employment.

The Spider Tank originated from an article borne out of research done by the Fellows of the Chief of Staff of the Army Strategic Studies Group. This article, "The Gotham Division and Staff Sergeant Parker: Imagining the Future of Urban Warfare" by Sergeant Major Richard Russo, was set in a fictitious location in 2029. This narrative along with the visualization provided an ideal canonical use case for ESP, as it looked at a future capability and involved systems that didn't exist outside of drawings.

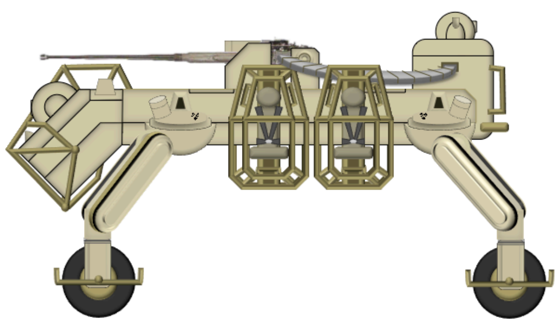

Figure 2. Spider Tank rendering

Spider Tank was modeled by students, and we obtained the rigid model (OBJ format) which was then split into 23 articulated components including the body, turret, weapon barrel, 4 legs, hip joint (splays out legs), leg (legs tile up/down), ankle joint (maintains consistent wheel orientation), wheel mount, and wheel.

Initial testing showed the most obvious shortcoming on the design – exposed passengers, so the model was revised to add option up-armor capabilities. This basic model included PhysX rigid bodies attached to each leg's articulate components to get physical "reality." Model leg suspension was a series of PhysX one-dimensional hinge joints with driven angle and springs. User modifiable parameters included for a subset of the components including armored hull, leg details (crouch, hip angle, steering angular velocity, enable disable auto-leveling, enable/disable learning into turn, leg length), drivetrain (fuel capacity, max engine torque, max braking torque, enable/disable infinite fuel).

In order to provide a reference, a more traditional Humvee vehicle was brought into the prototype. This was a model from a previous project (build as a Unity asset), and had simulation programming, a modeled drive-train (engine torque, gearbox, etc.), user modifiable parameters.

These vehicles were contextualized in three different ways. First was simply driving the vehicles through abstract terrain and urban cityscape. Second was a waypoint race, comparing completion times between Humvee and Spider Tank. Thirds was a Virtual Reality Spider Tank Driver Experience where a user would use an Oculus Rift DK2 and see what it was like to drive the spider tank with and without armor (i.e. a user-centric test of being inside the test system).

Figure 3. Abstract environment for head mount display examples.

This prototype also introduced analytics, with the system logging acceleration and forces experience by each rigid body element as well as acceleration and forced experience by proxies for each of the five mounted infantry on the Spider Tank (driver and four passengers). These were visualized though color-coded dots that were location accurate and size changed to reflect the scope of the force values.

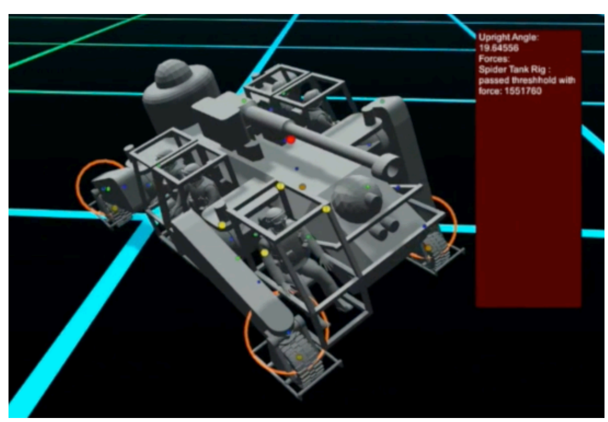

Figure 4. Spider Tank with forces analysis/display.

3.4 Third Iterative Virtual Prototype

This iteration, codename No Scrub, was designed to integrate previous capabilities and expand thinking around ESP-IN and especially analytics. The Virtual Pointer capabilities was brought in and integrated into GPS/Map capabilities in the environment. The Spider Tank gained a mounted weapon system operated by one passenger. Another vehicle was added, running through the ESP-IN process. In this case, a model of the Next Generation Close Combat Vehicle (NGCCV) was ingested. A rigid model was provided by TARDEC and split into 25 components including body and 4 legs (hip joint, leg tile, ankle joint, wheel mount, lower suspension, wheel). The simulation programming including driving dynamics as a single PhysX rigid body with leg suspension modeled outside of PhysX for increased vehicle stability and flexibility. PhysX wheel suspension model was used for vertical suspension travel. The weapons system was a remotely operated mount with interchangeable capabilities.

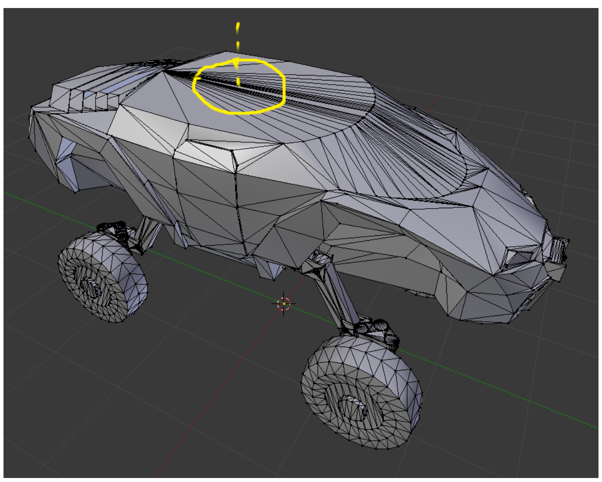

Figure 5. NGCCV model with initial articulation.

User modifiable parameters included the legs (crouch angular velocity, hip angle angular velocity, steering angular velocity, enable/disable auto-leveling, enable/disable learning into turns, leg length) and drivetrain (fuel capacity, max engine torque, max braking torque, enable/disable infinite fuel).

Figure 6. Vehicles choices for scenario.

Additional vehicles included an M1114 Humvee from previous work. This included simulation programming for weapons systems modeled on M2/Mk19 capabilities. In addition, an OPFOR technical truck was created with .50 cal mounted weapon.

The terrain was "urban mega city" geo-typical. Player tasks involved two BLUFOR vehicles (selected and customized by players) to conduct a mounted patrol One OPFOR technical truck and two dismounted insurgents attempt to ambush.

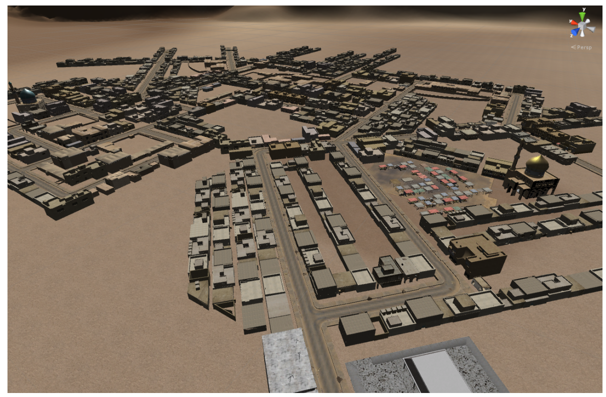

Figure 7. Geo-typical urban terrain.

Analytics include record and replay capabilities that track the following: per vehicle (position/orientation, damage received, components destroyed, mounted weapon discharged, mounted weapon reloaded, mounted weapon orientation), per character – mounted and dismounted (look direction, damage received, death, weapon discharge, weapon reload, use of weapon optic) and per player (biometric parameters from Intel Perceptual Computing SDK Emotion and ICT MultiSense).

4. Preliminary Observations/Results

Internal play testing was performed on all three prototypes. In addition, a dozen USMA cadets were involved in testing for the third No Scrub system. This work was focused on bug identification along with anecdotal player feedback. A larger scale test is scheduled for the NVGETS Conference in Detroit, MI in August 2015.

Cadet feedback was positive, with engagement in both the gameplay as well as the broader ESP concepts. In particular, one Cadet commented that he could forsee units using ESP to give feedback to designers/engineers, and also that this approach could result in significant cost savings.

4.1 Granular User Frustration Framework

Identifying the reason for user actions in a game/simulation is challenging. These initial prototypes explore the art of the possible with regard to user sensing with machine vision algorithms and trying to track user intent. The goal is to not only understand why a user did something in ESP, but break that down further into the elements of their actions. For instance, if a user fails at a certain task (e.g. misses shooting a target), the system should be tracking events and data that provide the granularity necessary to assess underlying causes. For instance, was the failure due to not understanding the weapon system, or a poor user interface (for the system or for the game), or mistakes made by a team member, or an especially skilled opponent? While a typical game/sim would report a missed shot, the goal for ESP is to be focused on the user rather than the system. Preliminary results show that inclusion of perceptual computing enables the beginning of deeper user analysis and tracking that to events in the ESP system. As these technologies become increasingly commoditized, they can be better implemented into ESP systems.

4.2 Post Exercise Analysis Sharing

After Action Reviews (AARs) are a common tool for training exercises, be they live, virtual, or constructive (or a combination). Since ESP is focused on gleaning information about design and employment, we created a Post Exercise Analysis (PEA) application that enables results to be shared more broadly. The PEA is a standalone PC application with low system requirements (less than the full ESP application). When players run an ESP experiment, the data can be sent to the cloud. Other users can download the game data and replay the session, with the ability to scrub through the timeline of events and see different view points including player positions, key events, and user-centric data such as sightlines and biometrics. They can then rate, score, and/or comment on the session, much as existing game communities do via Youtube, reddit, or other sites.

4.3 Early Fidelity and Minimum Necessary Physics

A typical vehicle has thousands of parts and hundreds of physical forces at work. Modeling this to the nth degree is computational expensive, both from physics and art perspectives. In these initial ESP systems the vehicles were obtained as solid objects. The process of articulating and applying appropriate physics was done manually, with an eye towards possible automated or semi-automated pipelines in the future. In addition one could imagine a process were a fully articulated model was ingested and is simplified/abstracted. For the initial Spider Tank build, a few dozen articulations and various physics models were implemented. After initial testing, these physics models were refined and in some cases simplified, as the increased "fidelity" wasn't necessary to obtain interesting results. The concept of minimum necessary parameters will be an ongoing are of inquiry with some generalizations being distilled after processing a number of use cases.

4.4 Enabling the Second Screen

Handheld devices are ubiquitous and provide an opportunity to expand the capability and reach of ESP. Initial experiments have focused on creating so-called "second screen" experiences, where a phone or tablet provides an alternative interface to collect more data. For instance an application that does voice recording and time stamping was devised to enable a user to verbally annotate their game play and automatically contextualize it to game events. The lab has also pioneered real-time display between PC and tablet with casual immersive viewer hardware. Finally, being able to run the Post Exercise Analysis app on a handheld device and enable remote commenting/collaboration provides a significant scaling opportunity for ESP given the market penetration of these devices.

5. Conclusions

During the last six months of research and development work, ESP has gone from a high-level concept to a more defined schema to three iterations of prototypes with canonical use cases. While still very much in the early stages, the current work hints at the promise that Early Synthetic Prototyping will bring to the design process. The ability to connect end users with designer and engineers in meaningful ways is an important goal to pursue in order to enable not only more efficient/effective procurement, but also to foster innovation and give a voice to the end user.

ESP can also be used to look at issues beyond just equipment design. Being able to immerse users in an environment and gather broad metrics can help inform doctrine, TTPs, and other aspects of the Doctrine, Organization, Training, Material, Leadership, Personnel, and Facilities spectrum. The emergence of new technical capabilities such as immersive displays, robust game environments, and affective computing/sensors has created the cusp of a "perfect storm" to take design, development, manufacturing, and deployment to the next level. ESP can play a part on this, and the ongoing research vectors will remain viable for years to come.

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