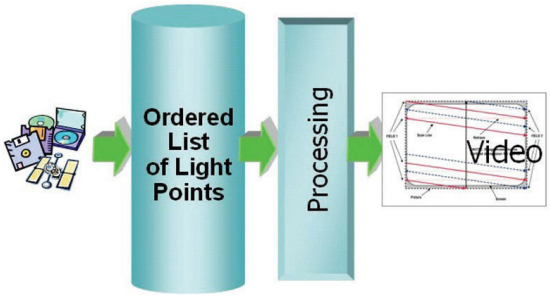
Converging towards synthetic environment interoperability

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ABSTRACT

The evolution of simulators from proprietary hardware platforms to affordable commercial-off-the-shelf (COTS) platforms has gone on for the past 15 years and is now nearly complete. Nevertheless, past efforts to standardise simulator synthetic environments (SE) have only been partially successful and have engendered considerable aggravation for users in need of creating content that can be deployed to distributed full-mission simulators. This paper provides a detailed description of the SE generation pipeline and the reasoning that has modeled its evolution over the past few decades. The arrival of digital multi-spectral high-resolution satellite imagery and highly capable visual systems now requires orders of magnitude more storage and processing than equivalent databases just a few years ago. These factors are threatening the equilibrium of the SE pipeline and are becoming important elements affecting SE interoperability, portability and re-usability. Past design trade-offs and compromises, appropriate at the time, must now be re-examined along with all SE-related processes, starting from ingestion of raw source data right through to the processing by the simulator devices. Clearly, greater standardisation is needed within the simulation community and a comprehensive, open SE representation would palliate to the many challenges we now face. To this end, this paper provides a checklist of the characteristics for a future 'ideal' SE representation and evaluates four emerging synthetic environment initiatives against this extensive checklist.



Data flow in early day visual systems.

1.0 INTRODUCTION – EVOLUTION OF SE GENERATION PIPELINE

The emergence of SEs coincides with the development of digital image generators which started in the early 1970s. The very first generation of visual systems made simplistic demands on their SE representation. Since first-generation visual systems (Fig. 1) rendered only light points, a very modest of amount of data pre-processing was required.

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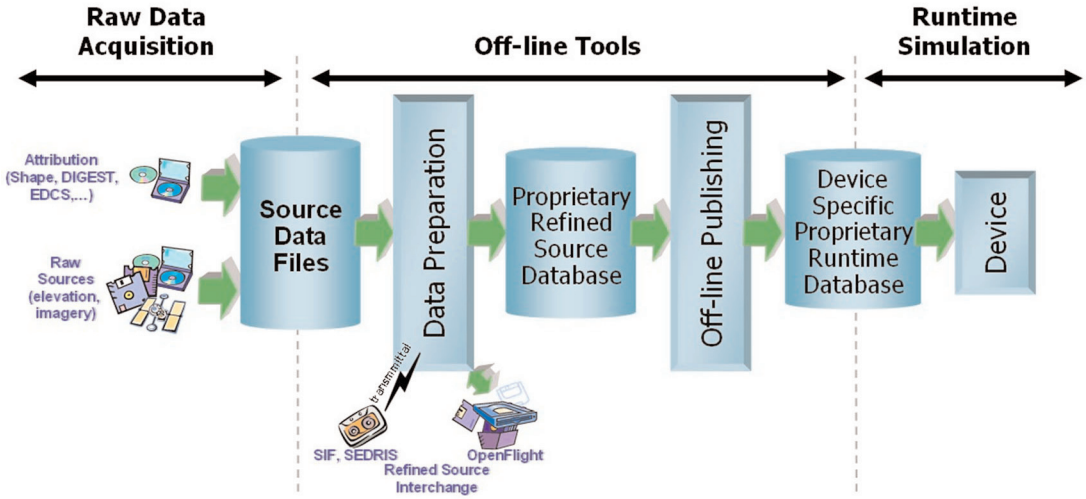


Figure 2. SE workflow for modern day simulators.

With the introduction of digital integrated electronics in the seventies, simulator systems, particularly visuals, computer generated forces, radars and other sensor systems grew rapidly in complexity and were implemented using massive amounts of custom hardware. Vendor product differentiation pivoted around proprietary hardware design approaches. Standardisation of runtime databases was impossible due to strong interdependence of runtime formats on custom hardware architectures. Hardware designers had little incentive in burdening their designs with the rather 'esoteric' SE considerations of correlation, interoperability, portability, standardisation and reuse, especially since none of these were perceived as prominent industry issues. The impact of the shortcomings was largely concealed because the training environments were quite simplistic and of limited geographic extents. At that time, the adoption of a runtime database standard by all members of the industry would have entailed huge development costs and would have imperiled product viability and affordability.

1.1 Off-line publishing

As systems grew in complexity and capability, simulator design engineers realised they could reduce hardware demands by having the SE heavily preprocessed, off-line, into a form closely aligned to the capabilities and constraints of their respective hardware & software designs. In order to palliate to these needs, each vendor created a software publishing utility whose function was to transform upstream SE data into a runtime database specifically tailored to the simulation device (Fig. 2).

The modeler's job now consisted of two distinct phases; first a data preparation phase followed by one or more device-specific data publishing steps. Virtually all SE generations tools in use today still follow this paradigm. The off-line publishing utility transforms the upstream SE representation into a runtime database that is formatted, structured and organised to closely match the idiosyncrasies of the proprietary hardware so that it satisfies the …

- device's internal native formats,
- device's data structure and organisation,
- device's internal naming conventions,
- device's number precision and number representation,
- device's data fidelity requirements,
- device's performance and internal memory limitations,
- device's level of detail representation requirements,
- data representation corresponding to the device's internal algorithms

Virtually all simulation devices in use today use proprietary format runtime databases. As a result, the off-line publishing utility can only be provided by the simulation device vendor, since he only, has the intellectual property and the competency to develop the off-line publishing utility. An analogous situation exists in the computer industry whereby device vendors supply Windows, MacOS or Unix compliant device drivers for their devices.

Hardware capability has historically provided the single-most important means for vendors to differentiate themselves in the simulation industry; consequently, the internal details of the runtime databases have been closely guarded intellectual property. This has had profound implications in retarding the evolution of the SE generation pipeline.

In recent years, we have witnessed a rapid adoption of commercial-off-the-shelf hardware platforms by most simulation equipment vendors. As a result, virtually all product differentiation has been relegated to elements that can be implemented in software. While custom hardware platforms has in the past provided the means for lasting product differentiation, there is much less to be gained by industry participants in maintaining the status quo, i.e. in perpetuating proprietary runtime formats which no longer drive massive hardware design considerations. We are nonetheless at a point in the evolution of our industry where runtime database formats remain proprietary and as a result off-line publishing is still required (Fig. 2).

1.2 Data preparation and modeling

Given the severe hardware and software constraints of early systems, databases were largely handcrafted and most of the content came from the modeler's own imagination. However, as the restrictions vanished, modelers could incorporate more and more real-world content into their SEs. Increasingly, the modeller's job was being re-fashioned from tasks relating to content creation into tasks involving the management, preparation and harmonisation of content obtained from external sources (Fig. 3).

In particular, the confluence of digital multi-spectral high-resolution satellite imagery and highly capable visual systems accel-

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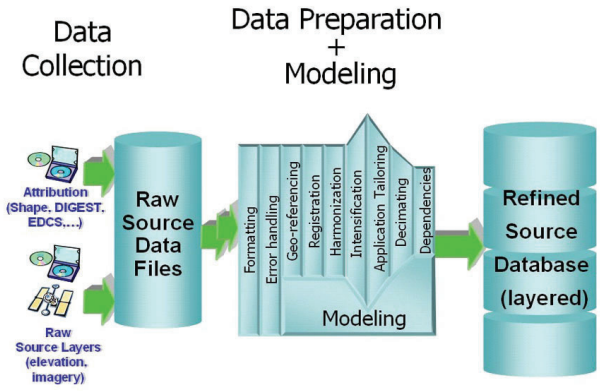


Figure 3. Dataset preparation.

erated this trend enormously. In effect, this aspect of the modeller's responsibilities was being gradually transformed into that of a geographic information system (GIS) specialist. This is of course lead vendors to gradually integrate more and more best-of-breed commercial-off-the-shelf (COTS) GIS tools into their respective tool suites.

In most modern SE tool suites in-use today, the data preparation step of Fig. 2 consists of many substeps (shown in Fig. 3) usually applied in sequence to each of the data-sets (aka layers) of the SE. The steps include:

- **Format conversion**: raw source data is provided to modelers in literally hundreds of formats. Early on in the SE generation process, modelers typically settle on a single format per SE layer (e.g. terrain altimetry, imagery, attribution)
- **Error handling**: raw source often contains errors or anomalies that, if left undetected, corrupt and propagate through the entire SE generation pipeline. As a minimum, these errors must be detected early on in the process. More advanced tools can correct many of these automatically, particularly if there is some redundancy across the layers of data.
- **Data geo-referencing**: this is the process of assigning a unique location (latitude, longitude and elevation) to each piece of raw data entering the SE pipeline.
- **Data registration**: each dataset is manipulated so that it coincides with information contained in the other datasets. These manipulations include projections, co-ordinate conversions, ortho-rectification, correction for lens distortions, etc. For images, this process is also known as rectification.
- **Data harmonisation**: the raw data of a dataset varies over a geographic extent if it was obtained under different conditions, such as from two or more sensors with differing spectral sensitivity characteristics, resolution, in different seasons, under different conditions of weather, illumination, vegetation and human activity. The modeler must factor for these variations when selecting and assembling the datasets into a coherent SE.
- **Application tailoring**: in many systems, the intended simulation application plays an important role in defining the SE data. Since the altitude gamut of simulated craft plays a dominating role, industry has organised (for the time being) applications along the lines of tactical fighter, civil and air transport, rotary wing, and ground/urban warfare. If a SE is intended for a single application, a modeler may elect to tailor some of the datasets in order to achieve a more equitable balance between training requirements and the capabilities of the targeted simulation equipment. Application tailoring can require either data intensification or data decimation.
- **Data intensification**: this is the process of augmenting or deriving added detail from the information found in the raw data. For instance, intensification can be used to augment flattened terrain imagery with 3D cultural detail relief. A typical example of this consisting in populating forested areas found in the terrain imagery with individual three-dimensional trees.
- **Data decimation**: this is the process of removing or simplifying the informational content found in the raw data. For instance, decimation can be used to transform individually modeled buildings into simplified city blocks or to reduce the resolution of terrain imagery. Data decimation is usually undertaken to ensure that the SE falls within the capabilities of the targeted simulator system.
- **Data inter-dependencies**: modelers typically deal with independent datasets for most of the SE process. This step is used to reconcile situations where one or more datasets are in potential conflict with other datasets. Vector elevation data often con-flict with terrain elevation data (e.g. floating building) due to different means of collecting this information. This step is similar to harmonisation yet differs in that it straddles datasets.

1.3 Refined source database

Modelers realised early on that much of the preparation and modeling step is independent of the targeted simulation devices and the targeted applications. Consequently, the results of the data preparation step could be stored into a refined source database (RSDB) and then re-targeted at modest cost to one or more simulation devices.

The next obvious step in the evolution of the SE pipeline was to standardise the RSDB. Standardisation of the RSDB could greatly enhance the portability and re-usability of developed SEs. However, the ultimate goals of portability and re-use could only be achieved if the RSDB was truly independent of the:

Application – a single SE representation that can simultaneously accommodate tactical fighters, civil and air transport, rotary wing, ground/urban warfare applications
Device type – a single SE representation that can simultaneously drive simulation devices such as visual systems, sensors, radar, computer generated forces, sonar, steal-view displays, map displays, etc.
Confederacy – a single SE representation that can be used for an entire confederacy of simulators.
Vendor – a SE representation that can be written and read by any or all SE tool suppliers and simulation equipment vendors because it is based on an open standard.
Platform type – a SE representation that is independent of the hardware and its operating system.

Unfortunately, standardisation has not been the focus of most SE tool developers nor of simulation equipment vendors. The challenge stems in achieving high portability, interoperability and reuse; this goal can be realised only if the SE is truly independent from the application, device, confederacy, vendor and platform.

The underlying difficulty in achieving this goal largely stems in the manner SE data is organised. The challenge is especially great if one strives for a SE representation suitable for both the database authoring tools and the simulator. Excellent structure is needed because the simulator effects the decimation of the SE in real-time. Without sufficient structure, the computational work-load to decimate the SE increases exponentially with content density, particularly if SE content exceeds the capabilities of the targeted device by an order of magnitude or more. While many devices can accommodate relatively modest variations in content density, most are easily overwhelmed as density grows significantly beyond prescribed limits.

Simulation equipment vendors also have had little incentive to fix this problem since most SEs were developed using the vendor's

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custom SE generation tools. However, in recent years, more and more modeling now falls outside of their jurisdiction. Increasingly, independent modelers are requested to develop SEs, but face the very difficult challenge of iteratively converging SE content so that it falls within the constraints of the targeted simulation device. Unlike the equipment vendors, they have relatively little insight in the performance characteristics of the device; consequently, the decimation step described earlier is largely a half-hazard process. The challenge is all the more impressive when the SE must be developed for an entire confederacy. In such a case, the modeler must iteratively remove SE content until the published run-time databases of all devices in all of the simulators of the confederacy is within the prescribed constraints of all devices, ie. the lowest common denominator. Consequently, portability and re-use is largely diminished.

2.0 CURRENT CONTEXT

Not so long ago, most simulation projects had to rely almost exclusively upon printed or 'paper' form GIS data. The ever increasing pace of the transformation from paper to digital sources has had many repercussions. When GIS first began to appear, the formats were often specific to the needs of particular projects and were not intended, initially, to meet the needs of a broader range of users. Recognising the limitations of being confined to these proprietary formats, GIS vendors began to develop in the 1980s far more effective and versatile file translation and conversion software. The development of standards and the proliferation of conversion and translation software had a galvanising effect on the GIS world and resulted in a tremendous expansion in the range and coverage of spatial datasets. In the past 12 years, we have seen the size of simulation SEs grow by approximately one millionfold! Satellite imagery accounts for much of the growth of simulation SE data. Remote sensing satellites are being launched every year. With each new generation, the resolution and the number of spectral bands increase, yielding a commensurate growth in raw data.

The capability of the simulation devices themselves has grown exponentially in the past five years. This is due in large part to a migration of the simulation industry to PC-based hardware platforms which have traditionally followed Moore's law. Moore's Law is the empirical observation made in 1965 that the number of transistors on an integrated circuit for minimum component cost doubles every 24 months. Certainly over the foreseeable future, this rate can be expected to continue, if not to increase.

The real-world crafts and vehicles that we simulate are also benefiting from the rapid advancement and proliferation of sensors and GIS-related technologies. While these devices sense the real-world environment, our simulators must also mimic this capability using the rich synthetic world supplied to them.

The industry has traditionally focused on the fidelity of the crafts and vehicles it simulated. The simulation market is demanding greater training value from these devices; additional training could be gleaned from a more realistic simulation of the real-world.

Transformation within national forces and those of NATO partners combined with new concepts and doctrine has greatly increased force interoperability. Increasingly, services are required to work collaboratively and tie together various network-centric architectures together. However, integration begins at the architectural level with the standards and framework that govern how systems work together and exchange information. And of course, in the simulation world, all of the systems must be provided a common view of the synthetic world.

The dynamic and evolving hyper-operations tempo battlespace of the future requires a rapid adjustment of the location and timing of intelligence and surveillance collection assets. This effort results in a mission rehearsal and analysis capability to 'fly-out' intelligence, surveillance and reconnaissance (ISR) collection plans. This allows ISR planners to adjust their plans to meet the dynamic nature of the battlefield. In order to reproduce this capability in simulation, SE generation process must be highly streamlined.

3.0 THE COMING THREAT

In the current context, synthetic environmental generation costs are swelling rapidly due to the larger SE geographic coverage, increased detail and fidelity and the requirements to drive a broad range of sensors devices.

While the industry is barely coping with the growing complexity of SEs, the industry is realising that the current SEs have low portability, interoperability and reuse across simulators, simulator confederacies and simulation programmes. If left unchecked, these factors could significantly moderate the proliferation of simulators in the future and threaten industry growth.

Currently, the amount of content, resolution and density of SE databases must be fairly well matched to the capabilities and performance of the targeted device(s). As a result, the SE becomes outdated and must be completely rebuilt to take advantage of evolving simulator capabilities which now track Moore's law. To overcome this shortcoming, the SE must be highly structured so that the simulation devices can efficiently find and access the data they need. More importantly, proper structure of the SE allows the devices to effortlessly skip over data that fall beyond their respective functional or performance capabilities. When combined with optimal device-resident filtering algorithms, it is possible to build a synthetic environment with content that far surpasses any simulation device's intrinsic capabilities. The matching of an optimal SE structure with appropriate device filtering algorithms makes the SE content relatively insensitive to the capabilities of the simulator devices and thereby significantly prolongs SE longevity. As device capabilities evolve, more and more of the original SE content (for instance, greater terrain imagery resolution, additional attribution, etc.) can be used by the simulation device.

These coming threats will not only affect industry profitability and growth but also affect the quality of the products it delivers. Correlation stands to be one of the major challenges in the years to come. Currently, each of the simulated on-board sensor subsystems requires its own copy of the SE in a distinct (proprietary) format. Invariably, the publishing software that produces each run-time database decimates and modifies the SE data resulting in additional sources of correlation errors. Upstream in the SE pipeline, more correlation errors are introduced because the industry has not yet succeeded in devising refined source databases (RSDB) that are truly independent of the application, device, vendor and platform. As a result, modelers are required to create several variants of the RSDB in order to overcome this limitation. Each variant introduces its own set of correlation errors. Finally, the advent of richer SEs provides an exponentially greater number of opportunities to introduce uncorrelated content.

The simulation industry is just beginning to feel the impact of the 'current context'. Unfortunately, all signs are pointing to a further degradation of the situation unless industry takes immediate action to reverse the trend. Past trade-offs and compromises, largely motivated by hardware considerations are no longer appropriate. Clearly, a comprehensive, standardised, open SE representation, endorsed by both vendors and users, is urgently needed to palliate to the many challenges we now face. Ideally, this new standard should bear all of the characteristics that are listed in the next section. The checklist will also prove invaluable in comparing and evaluating four new SE initiatives that will be reviewed in this paper.

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4.0 CHARACTERISTICS OF AN 'IDEAL' SYNTHETIC ENVIRONMENT

4.1 Standardisation and openness

- Public, open, fully-document database schema, preferably supplemented with a developer's toolkit
- Low reliance, high independence from any specific tool suite

4.2 Portability

- Plug-and-play SE portability to the database generation toolsets
- Plug-and-play SE portability to simulators
- Zero-effort deployment SE to a simulator or a confederacy of simulators

4.3 Interoperability

- Across the database generation toolsets
- Across simulators
- Across simulator applications (tactical air, rotary, urban/ground, sea, command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR), etc …)
- Across simulation confederacies
- Across simulation programmes

4.4 Correlation

- Across all producers (typically DB generation facilities) and all consumers (typically simulators) of SE data
- Elimination of source correlation errors through normalisation of all data sets (a single representation for each dataset)
- Elimination of runtime correlation errors through a standardised approach to the decimation, intensification and defaulting of datasets across the entire SE pipeline

4.5 Synthetic environment reuse

- Full re-use of SEs by eliminating depend-encies that are specific to the simulation application, the equipment vendor, the database generation tool suite, the simulation programme, the technology

4.6 Synthetic environment scalability

- Near-infinite SE addressability, spatial resolution and content density in each of the SE datasets
- Low reliance on the capabilities of operating systems and file system
- Structuring of SE data into tiles, layers and levels-of-detail with file and memory footprints that are well within operating systems (OS) and file system limits

4.7 Reduced mission rehearsal timeline

- Elimination of SE generation steps that are currently needed because the SE content varies with the simulation application, the equipment vendor, the database generation tool suite, the simulation programme, and the targeted technology
- Elimination of the off-line publishing step
- Zero-time deployment of the SE to a simulator or a confederacy of simulators

4.8 Modeler considerations

- Straightforward navigation and direct access to all datasets
- Built-in provisions for the cataloging of models into a global library
- SE versioning mechanism, preferably allowing instant access to prior versions
- Tolerance to partially-populated SE (data-set defaulting)
- SE structure favoring co-operative (e.g. team) SE generation (tile and layer independence)

4.9 Database generation facility (DBGF) considerations

- Efficient, low-overhead access to structured data by all tools
- SE structure amenable to parallel processing (tile and layer independence)
- DBGF facility versioning mechanism, preferably allowing instant access to prior versions
- Compatibility with legacy SE generation tools and compute infrastructure
- Straightforward SE archival and recovery

4.10 Simulator considerations

- Zero-effort deployment SE to a simulator or a confederacy of simulators
- Centralised SE storage infrastructure and management
- Simulator facility versioning mechanism, preferably allowing instant access to prior versions
- Seamless integration with distributed computer simulation communication standards such as distributed interactive simulation/high-level architecture (DIS/HLA)
- Straightforward migration of simulator hardware and software
- Straightforward SE archival and recovery

4.11 Scope

- SE capable of representing whole-earth, with near-infinite resolution and content
- Comprehensive suite of datasets to drive a broad gamut of simulation device ranging from tactical fighters, civil and air transport rotary wing, ground/urban warfare and C4ISR
- Optimal handling of geo-typical and geo-specific SEs

5.0 INITIATIVES ON THE WAY

Four new initiatives are currently under way in the United States in the quest to improve SE portability and interoperability. The four initiatives studied in this paper are:

5.1 NPSI – United States Naval Aviation Simulation Master Plan Portable Source Initiative

NPSI provides a set of guidelines that govern the processes, procedures and formats by which geo-specific datasets are built for and delivered to the US Navy. NPSI defines a common means of exchange of refined terrain datasets which exist in the 'gray area' between raw source and runtime databases. NPSI is not a database specification, but rather a collection of datasets in prescribed formats supplemented with extensive markup language (XML) wrapper documentation.

5.2 CDS – United States Air Force Training Systems Program Group Common DataSet

While this programme is sponsored by the US Air Force, its technical approach is nearly identical to that of the NPSI initiative since it stipulates the same guidelines and formats for each of the datasets. The CDS concept of operations is predicated on the principle of voluntary collaboration amongst Air Force programmes. To this end, the Air Force intends to maintain a registry of metadata that describes the information that can be shared amongst producers and consumers of SE data.

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5.3 MDB – United States Synthetic Environment Core Database Virtual Development Environment Master DataBase

The MDB is a component of the database virtual development environment for the SECore programme. Like NPSI and CDS, the MDB defines a common means of exchanging refined datasets. However, instead of providing SEs as a collection of datasets with XML wrapper documentation, the MDB is implemented as a structured query language (SQL) database. The rest of the database virtual development environment is based on a terrain database generation toolset and on a runtime database generation toolset which access the MDB via an application programme interface (API) and a supervisor tool. Simulation vendors can create runtime databases by supplying an off-line publishing 'plug-in' which interfaces to the Terrex run-time database generation toolset (RDGT). Initial consumers include large legacy systems such as close combat tactical trainer (CCTT), aviation combined arms tactical trainer (AVCATT) & Stryker and future systems such as object one SAF (OOS) and AVCATT future combat systems (FCS). The programme is currently in early stage of development.

5.4 CDB – US SOCOM Common DataBase

The CDB is an open SE database specification that offers plug-and-play interoperability between simulators and database authoring workstations. The specification defines the data representation, organisation and storage structure of a worldwide synthetic representation of the earth as well as the conventions necessary to support all of the subsystems of full-mission simulators. The specification makes use of several commercial and simulation data formats endorsed by leaders of the database tools industry. Adherence to the CDB specification ensures portability, reusability and interoperability amongst all producers and consumers of SE data. The CDB will act as a single repository of databases for Joint rehearsals and training for the Army's 160th Special Operations Aviation Regiment, the elite regiment known as the 'Night Stalkers'. The ASTARS programme is near completion and has two high-end simulators in conformance to the specification. In addition to the ASTARS programme, the CDB has been adopted by the US SOCOM; several companies including Quantum3D, Flight Safety International, IAI/Tiltan, and Diamond Visionics have developed, or are in the process of developing, solutions based on the CDB.

6.0 ARE WE CONVERGING?

Each of the initiatives presented here is sponsored by distinct programmes whose funding, scope, mandate and schedule vary considerably. These programmes largely focus on solving the problems that have garnered the attention of selected government officials. However, since few people have a global understanding of the entire SE pipeline, there are considerable differences in the mandate assigned to each programme. With the exception of the CDB, the other three programmes do not address the portability, reusability and interoperability of runtime databases.

How do these four initiatives stack up against the characteristics of an 'ideal' representation for SEs?

The Navy NPSI and the Air Force CDS are reflective of the practices, procedures and formats that have been in use by industry over the past five years. Both NPSI and CDS define a collection of datasets suitable to the needs of simulation; however, since it is not a database, it lacks the structure and organisation amenable to rapid and efficient queries. The single-most important innovation is the XML wrapper documentation syntax. This mechanism provides a formal means of cataloging information regarding the SEs developed by various programmes. This capability will undoubtedly improve awareness amongst programmes and encourage exchange of SE data in NPSI-approved formats.

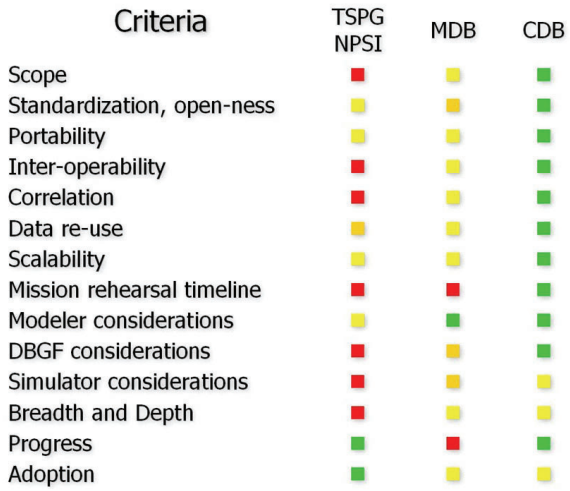


Figure 4. Comparison of SE initiatives.

The SECore MDB goes further in improving SE scalability and portability across different simulator applications. However, the scalability objective is only partially met due to shortcomings in the MDB's level-of-detail scheme. Similarly, portability is only partially improved due to the standard's permissiveness in allowing user-defined (ie. programme-specific) data layers. The most significant technical challenge of the DVED programme will undoubtedly be the software that will be required to provide a globally optimal, lowest-common denominator SE to all the vendor offline publisher plug-in software. Given the very real difficulty in characterising the ever-changing performance of complex simulation devices, a significant overshoot in this decimation function is anticipated, with a commensurate under-utilisation of simulation devices.

The SOCOM CDB is the most comprehensive of the four approaches presented here since it embodies most of the capabilities of the other three approaches. In addition, the CDB can be used as a refined source database and a global simulator runtime database. Furthermore, since the CDB internal formats match those selected by the NPSI and CDS initiatives, data can be exchanged with across these programmes. Both the CDB and the MDB can be used as a refined source database; in addition, the CDB's internal database schema is fully open and does not rely on GOTS tools. As a simulator runtime database, the CDB provides a single representation of the SE, one that is suited to realtime access by simulators. As a result, simulator deployability and interoperability is greatly enhanced and mission rehearsal pipeline is shortened significantly.

While each of these programmes are independently managed and funded, there have been some exchanges between the respective groups which in turn, have generated increased technical commonality. However, much greater benefit can be garnered if we can truly converge to a single solution whose characteristics closely match those of the 'ideal' SE. To achieve this goal, we will require a much greater level of governmental and industrial cooperation and ultimately, customer endorsement.

Figure 4 provides an evaluation of all four approaches based on the comprehensive list of criteria outlined in Section 4. A green rating signifies that the initiative rates the highest against prescribed criteria. Lesser compliance is denoted by yellow, followed by orange and the red.

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7.0 CONCLUSION

SE complexity is growing fast and shows no sign of abatement. Today's SE generation process is a significant bottleneck that hampers our efforts to fully leverage new simulator technologies that take advantage of fast-evolving commercial the shelf platforms. Current-generation SEs offer relatively low portability, low interoperability, low reusability and low scalability. The past couple of years have seen considerable increase of development activity in these areas and this is quite indicative of the acuteness of the problem. Given the explosive demands imparted to SEs, it is expected that the issues raised in this paper will deteriorate further unless industry takes mitigating steps to reverse this trend. An essential component of this strategy calls for the development of a comprehensive SE standard for the simulation industry. This paper provides an introduction to four such initiatives which are in various stages of definition and implementation.

These initiatives bring us closer to achieving all of the characteristics of the 'ideal' SE presented in this paper. However, there is considerable variation in the scope of each of these initiatives, thereby making comparisons and evaluations difficult.

The common database (CDB) sponsored by SOCOM is the most comprehensive and mature programme amongst the four studied here. Interestingly, NASMP portable source initiative and of TSPG common datasets share the same file formats as those called for by the CDB. Since the CDB is *de facto* format-compatible with NPSI and CDS, there is opportunity for further convergence between all of these programmes.

Without a concerted effort to rationalise on a global solution that addresses the needs of industry and of the marketplace, we face the threat of a further proliferation of standards. The past has shown us that proliferation of standards, particularly those that are either incomplete or overly complex, brings little or no benefit since they only exacerbate data duplication and move us away from our objective of SE portability and interoperability.

Furthermore, industry cannot afford to spread its effort over a broad range of standards, each entailing distinct development and governance.

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