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SIMSIA: Study of the contribution of simulation for intelligent autonomous systems

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MSG-197 20/21 October 2022

www.thalesgroup.com

The SIMSIA Project

Objective:

- Determine the contribution of simulation for intelligent autonomous systems, (operational systems using Artificial Intelligence (AI) mechanisms) and, in particular, define or identify the simulation methods and techniques adapted to the requirements of the development of such systems.
- SIMSIA was contracted by the French MoD to Thales (Sept. 19 → Jan. 22)

Some examples:

- Generation of the massive amount of data needed by machine learning algorithms.
- Simulation of collaborative combat scenarios with new categories of vehicles and doctrines.
- Validation in simulation of AI mechanisms before they are embedded in real systems.

3 phases:

- Characterize the requirements by identifying and analysing the most likely utilization of simulation.
- Analyse the solution alternatives and produce technical recommendations for each solution.
- Detail two solutions and build a roadmap proposing the evolution of the corresponding simulations.

Phase 1: Characterization of the AI needs for simulation

Objective:

- Analyze and identify the most likely utilization of simulation to develop AI tools.

Methodology:

- Constitution of a panel of 149 use-cases (UC):
  - Coming from another French MoD study "AI & Big Data" (114 UC)
  - And from the French Naval “Artificial Intelligence” Task Force (35 additional UC)
- Analysis of the panel of use-cases studied:
  - Identification of the AI algorithms used in each use case
  - Identification of the intelligent functions performed by the combination of the AI techniques in each use case (e.g. Anomaly detection, Recognition & identification, etc.)
  - Identification of simulation capabilities that are used, or might be used, to assist in the development of these AI techniques during the development cycle of the use-cases.

Phase 1: Characterization of the AI needs for simulation

Definition of two typologies (AI & Simulation)

AI category	AI techniques	Nb. UC
Formal Techniques	Decision trees, Behaviour trees, Markov processes, Bayesian networks, Transferable belief models, Fuzzy logic, Expert systems, Logic programming, Ontologies, Game theory, Multi-agent systems, Graph theory, State machines, Petri nets, etc.	82
Data-centric Learning	Multilayer perceptron, convolutional networks, recurrent networks, etc. Auto-encoders, Auto-adaptive maps (Kohonen). Boltzman machines, Regression methods, Random forests. Generative Adversarial Networks (GAN)	91
Environment-centric Learning	Reinforcement Learning (RL) and Deep RL. Genetic Programming. Classifier systems.	18
Operational Research	Formal Optimization: Linear & Nonlinear Optimization. Meta-heuristics: Simulated annealing, Genetic algorithms, CMAES. Tree search: A*, Branch & Bound technique, Constraint programming. Multi-criteria decision support: Over-ranking or utility-based methods.	32
Statistical Data Analysis	Dimension reduction analysis: principal components, correspondence factorial, multiple factorial, etc. Classification analysis: automatic, flat or hierarchical, K-Means. Regression Methods	56
Motion Planning	Formal Techniques: Utility Function Methods, Multi-Agent Systems. Operational Research: Meta-heuristics, Tree search. Environment-centric learning : Reinforcement Learning	3
Human-centric Techniques	Monitoring the physical and mental state of a human being. Adaptation of the provision of information. Adaptation of the proposed commands	6

Family of simulations	Simulations or Methods	Technical components
Operational simulation	- Instrumented simulation - Virtual simulation - Constructive simulation	- Image generator - 2D/3D Data Base - Computer Generated Forces (CGF) - Serious video games - Technical data generation
Technical simulation	- Numerical simulation - SIL simulation ("software-in-the-loop") - HIL simulation ("hardware-in-the-loop") - MIL simulation ("man-in-the-loop")	

AI mechanisms Development Cycle	
Upstream Phases	**Downstream Phases**
Design, preliminary testing & AI “education”	AI verification, validation & qualification

Phase 1: Characterization of the AI needs for simulation

Identification of the solution alternatives:

{AI; Simulation} Pairs Design, preliminary testing and "AI education" phases	Virtual simulation	Instrumented simulation	Constructive simulation	Numerical simulation	SIL simulation ("software-in-the-loop")	HIL simulation ("hardware-in-the-loop")	MIL simulation ("man-in-the-loop")
Formal Techniques	8	0	24	6	14	0	0
Data centric Learning	21	0	11	7	12	0	1
Environment centric Learning	0	0	8	0	5	0	0
Operational Research	1	0	15	4	8	0	1
Statistical Data Analysis	4	0	9	5	12	0	0
Motion Planning	0	0	3	0	0	0	0
Human centric Techniques	0	0	1	0	3	0	1

{AI; Simulation} Pairs Verification, validation and qualification phases	Virtual simulation	Instrumented simulation	Constructive simulation	Numerical simulation	SIL simulation ("software-in-the-loop")	HIL simulation ("hardware-in-the-loop")	MIL simulation ("man-in-the-loop")
Formal Techniques	1	2	24	4	8	5	1
Data centric Learning	1	1	12	4	11	4	2
Environment centric Learning	0	1	9	0	2	1	1
Operational Research	0	1	17	4	2	3	1
Statistical Data Analysis	1	0	10	3	10	3	0
Motion Planning	0	0	2	0	0	0	0
Human centric Techniques	0	0	3	0	1	0	1

The intersection of the two typologies allowed the identification of 27 solution alternatives represented by 27 {AI; Simulation} pairs:

- 16 pairs for the upstream phases (on the left)
- 11 pairs for the downstream phases (on the right)

Phase 2: Comparison of the solution alternatives

Objective:

- Comparison and analysis of the solution alternatives and construction of concrete technical recommendations for each family of solutions.

Methodology:

- Identification of the impacts on the simulation of its utilization for AI development.
- Analysis of the 27 solution alternatives on the basis of this impacts.
- Selection of 12 characteristic use-cases from the panel associated with one or more {AI; Simulation} pairs in order to ensure the concreteness of the recommendations.
- Construction of 25 technical recommendations sheets associated with the 25 solution alternatives finally selected.

  Note: Two solution alternatives were eliminated because of the lack of sufficient data.

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Phase 2: Comparison of the solution alternatives

Impacts on simulation of its utilization for the development of AI algorithms:

Simulation Interfaces	**Open interfaces:** to allow easier connection with the use-case and provide a very easily modifiable API
	Standardized interfaces (e.g. HLA) to formalize interconnections and easy replacement of simulation
Acceleration capabilities of the simulation	**Moderate acceleration :** (e.g. 10 times faster than the real time) to allow the testing, for instance, of a large number of scenarios very quickly
	Higher acceleration: (e.g. 1000 times faster than the real time) to allow the use of simulation by machine learning algorithms
Simulation models	**Models LoD:** Settings of the Level of Details of the models to adapt the simulation to the AI algorithms needs (e.g. to speed-up data generation, to increase the realism of the data generated, etc.)
	Validation of the models: validation of simulation models (used for instance for data generation) or learned models (build by machine learning thanks to simulation means)
Simulation Architecture (SW & HW)	**Parallel computation:** Needs of infrastructures to parallelize the calculations and thus, accelerate the simulation without having to reduce the quality of its models
	Time & models coherence: Needs to ensure the coherence of time and models within the simulation, or during the interaction with the use-case, to avoid temporal inconsistencies or biased data exchanges
Operational representativeness	**Representativeness of data:** generated by simulation or AI means compared to real operational data
	Representativeness of situations: generated during the execution of simulated scenarios

Phase 2: Comparison of the solution alternatives

Technical recommendations sheets for 25 solution alternatives (example):

SIMSIA | **Formal Techniques** | **Virtual Simulation** | **Upstream Phases** | **1**

Characteristic Use Case

IA BD 103 : Automatic Geo-referencing

Intelligent Function(s)	Navigation assistance (geo-location)
AI Technique	Registration algorithms (SIFT or SURF)
Technical Component	Image Generator
Phase	Design et preliminary tests

Expected Improvements:

- The use of an easy to use "design & test" environment with the ability to evaluate and visualize the results of the registration calculations.

Schema:

Other use cases of the panel associated with the pair

Use Case	Subject
IA BD 2	Detection of abnormal activity in the context of satellite site monitoring
IA BD 20	3D navigation in unknown environment
IA BD 23	Cognitive radar
IA BD 59	ATR SAR - Synthetic image generation by learning
IA BD 70	NAVALIA - Operation of autonomous sensors (buoys)
IA BD 91	Collaborative SLAM at soldier level
IA BD 95	3D terrain model construction

Hard Spots to deal with :

- None.
- The only issue is the ease with which the user can visualize the results of calculations made by AI algorithms.

Phase 2: Comparison of the solution alternatives

Technical recommendations sheets for 25 solution alternatives (example):

SIMSIA | Formal Techniques | Virtual Simulation | Upstream Phases | 1

Impacts	General Recommendations	Characteristic Use Case	Other cases
Interfaces	Use open interfaces in the virtual simulation to accommodate various types of data.	-	e.g. : IA BD 23 et 70
	Use a virtual simulation with a native standardized interface corresponding to the type of data to be displayed.	Possible use of geographic data standards for transferring between the use case and the virtual simulation (e.g. SHP, GML, etc.).	
Acceleration	No general recommendations.	-	-
Models	Enable a display in the virtual simulation with a multiple levels of detail.	Possibility to zoom in on the areas to be displayed to check that the results of the recalculations by characteristic points have been carried out.	
Architecture	Ensure the temporal consistency between the calculations performed and the display in the virtual simulation	-	Not in the panel
Representativeness	Use visualization to check the representativeness of the manipulated data in the upstream phase.	Visualize the manipulated images and the geolocation data to be adjusted.	

Phase 3 – Propositions for the evolution of simulation

Objective:

- Detail the two most representative solutions identified in phase 2 et propose a roadmap for the selected solutions in order to acquire new simulation means that will help to develop AI technologies.

Methodology:

- Analysis of the hard spots associated with each solution alternative and definition of a scoring system based on the criticality of these hard spots.
- Evaluation of each solution alternatives according to this scoring system and selection of the two solutions to be explored.
- Detailed analysis of the selected solutions and establishment of a roadmap for the corresponding simulations based on this analysis.

Phase 3 – Propositions for the evolution of simulation

Analysis of the criticality of the hard spots of each solution alternative:

- **Main hard spots:**
  - The speed of the simulation
  - The fineness of the models
- **Secondary hard spots:**
  - The operational realism
  - The complexity of the interfaces
- **Other hard spots identified:**
  - The integration in the simulation of specific codes or models
  - The use of operational component from the target system
  - The system consistency
  - The coverage of the tests

Phases	{AI; Simulation} Pairs	Simulation Speed	Models Fineness	Operational Realism	Interfaces Complexity	Integration of specific codes & models	Use of operational system's component	System Consistency	Tests Coverage	Score	Criticality
Upstream	{Formal Techniques, Virtual Simulation}	-	Medium	Medium	-	X				4	Low
	{Formal Techniques, Constructive Simulation}	Low	Medium	Medium	Medium	X				7,5	Low
	{Formal Techniques, Numerical Simulation}	-	Medium	High	Medium	X				8,5	Low
	{Formal Techniques, SIL Simulation}	-	High	Medium	High	X	X	X		12,5	Medium
	{Data Centric Learning, Virtual Simulation}	Medium	High	High	-					13	High
	{Data Centric Learning, Constructive Simulation}	High	Medium	High	High					16	High
	{Data Centric Learning, Numerical Simulation}	Medium	Medium	High	Medium					12	Medium
	{Data Centric Learning, SIL Simulation}	Medium	High	High	Medium	X				15,5	High
	{Environment Centric Learning, Constructive Simulation}	High	Medium	High	Medium					14	High
	{Environment Centric Learning, SIL Simulation}	Medium	High	Medium	High	X	X			16	High
	{Operational Research, Constructive Simulation}	Medium	Medium	High	Medium					10	Low
	{Operational Research, SIL Simulation}	-	High	Medium	High	X	X	X		12,5	Medium
	{Statistical Data Analysis, Constructive Simulation}	Medium	Medium	High	High					12	Medium
	{Statistical Data Analysis, SIL Simulation}	Medium	High	High	Medium	X				15,5	High
	{Motion Planning, Constructive Simulation}	High	High	Medium	Medium					16	High
Downstream	{Formal Techniques, Constructive Simulation}	Medium	Medium	High	Medium				X	10,5	Low
	{Formal Techniques, SIL Simulation}	-	High	High	-	x	x			8	Low
	{Data Centric Learning, Constructive Simulation}	Medium	Medium	High	High					12	Medium
	{Data Centric Learning, SIL Simulation}	-	High	High	-	x	x			10	Low
	{Environment Centric Learning, Constructive Simulation}	Medium	Medium	High	Medium				X	10,5	Low
	{Operational Research, Constructive Simulation}	Medium	Medium	High	Medium				X	10,5	Low
	{Operational Research, Numerical Simulation}	Medium	Medium	Medium	Medium	X				10,5	Low
	{Statistical Data Analysis, Constructive Simulation}	Medium	Medium	High	High					12	Medium
	{Statistical Data Analysis, SIL Simulation}	-	High	High	-	x	x			8	Low
	{Motion Planning, Constructive Simulation}	Medium	High	Medium	Medium					12	Medium

Phase 3 – Propositions for the evolution of simulation

Selection of the solution alternatives to be explored according to the criticality of the hard spots and the number of use-cases represented:

1. Improvement of the **Virtual Simulation** for the benefit of **Data-centric Learning** with the rapid generation of representative data from fine models.
2. Improvement of the **Constructive Simulation** for the benefit of **Environment-centric Learning** with the quick execution of high realism scenarios in CGF simulation.
3. Improvement of the **SIL Simulation (Software In the Loop)** for the benefit of **Statistical Data Analysis** with the rapid generation of data from hyper-realistic models.

Note: *This last solution was not retained because of its lack of maturity and of the apparent specificity of the systems modeled.*

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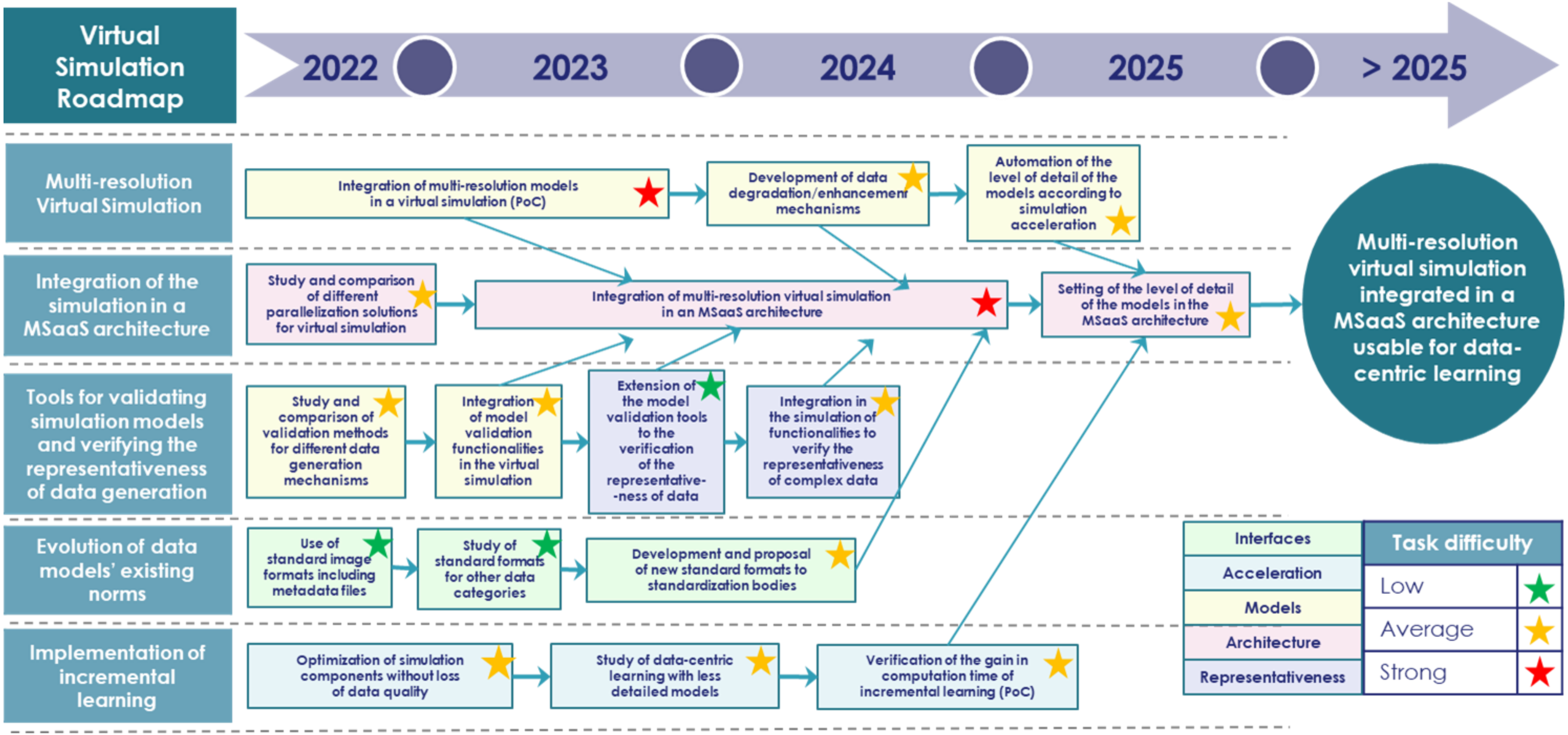
Phase 3 – Propositions for the evolution of simulation

Evolution of the Virtual Simulation:

1. Study and development of a **multi-resolution virtual simulation** that is, a virtual simulation containing models of different levels of detail, tools to build these models and interfaces to select them.
2. **Integration of this simulation in an MSaaS architecture** where the components and models are virtualized and may be activated as services when needed.
3. Development in the MSaaS architecture of specific **services to validate the simulation models and to verify the representativeness of the data generated.**
4. Study of existing standards for all categories of data that can be generated by the simulation and **proposition of the evolution of data model standards**.
5. This new virtual simulation will allow the **implementation of incremental learning**, that is an Data-centric Learning using a very quick generation of low resolution data in its first stages before using high resolution data in its final stages.

Phase 3 – Propositions for the evolution of simulation

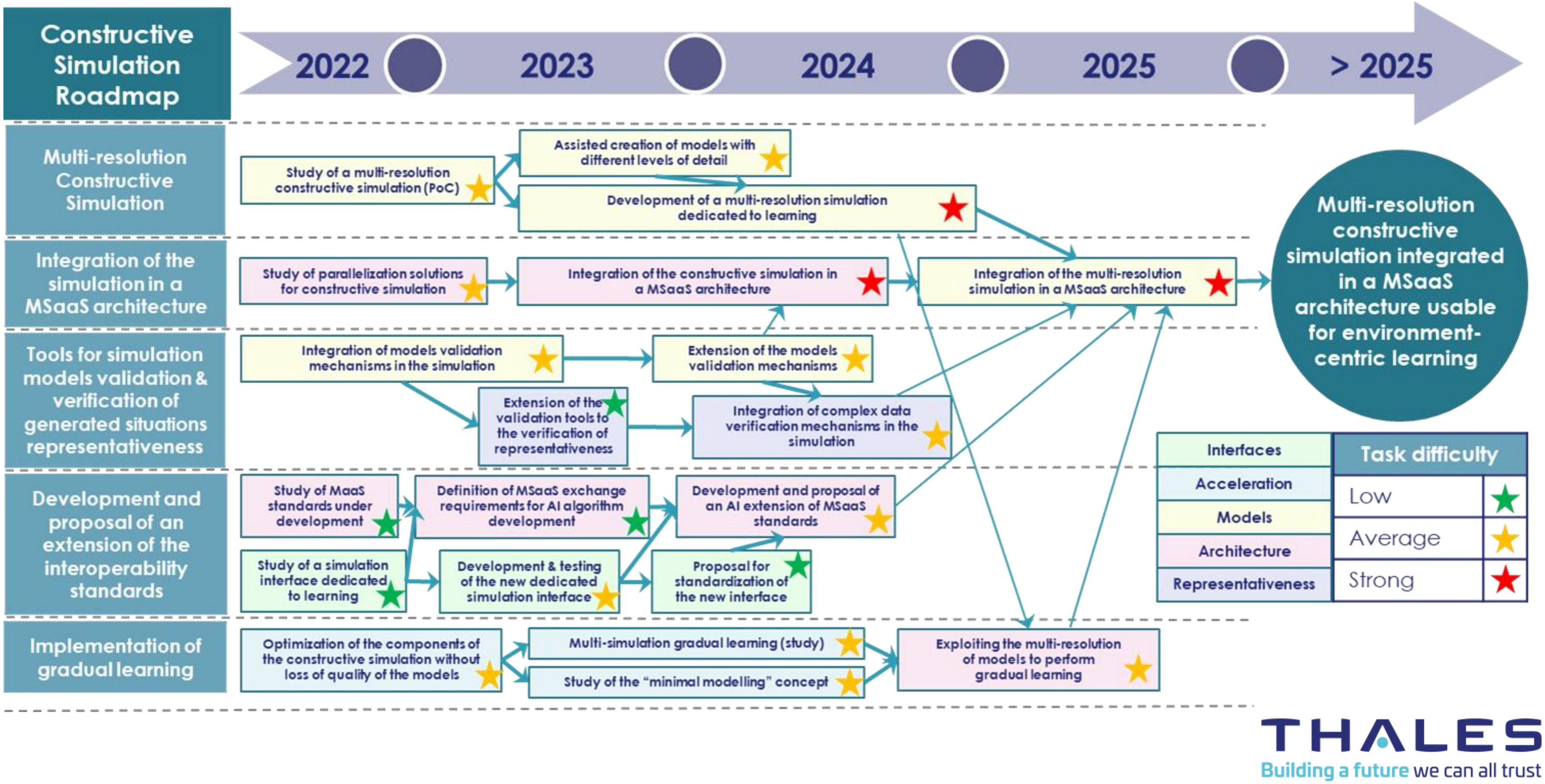


Phase 3 – Propositions for the evolution of simulation

Evolution of the Constructive Simulation:

1. Study and development of a **multi-resolution constructive simulation** that is, a constructive simulation containing models of different levels of detail, tools to build these models and interfaces to select them.
2. **Integration of this simulation in an MSaaS architecture** where all the components are massively parallelized in order to speed-up the execution of each scenario.
3. Development in the MSaaS architecture of specific **services to validate the simulation models and to verify the representativeness of the situations generated**.
4. Study of existing standards and, **development and proposition of an extension of the existing interoperability standards** adapted to the MSaaS implementation.
5. This new constructive simulation will allow **the implementation of gradual learning** that is, an Environment-centric Learning running very quickly simpler scenarios in its first stages before running much more realistic scenarios in its final stages.

Phase 3 – Propositions for the evolution of simulation



Conclusion & Perspectives

Main results of the SIMSIA study :

- Phase 1: Characterization of the operational systems based on Artificial Intelligence mechanisms that uses in particular : a typology of simulation techniques and a typology of AI techniques specially built for the study.

- Phase 2: Identification of the solution alternatives by the combination of the AI and Simulation typologies, and delivery of 25 technical recommendations sheets describing the impacts on the corresponding simulation of its utilization in the development of the corresponding AI techniques.

- Phase 3: Detailed study of the most two representative solutions and proposition to the French MoD of a roadmap describing the evolution of the corresponding simulations : The virtual and the constructive simulations to help, respectively, the development of Data-centric Learning and Environment-centric Learning.

Conclusion & Perspectives

Perspectives of SIMSIA:

- Triggering the studies, the tests, the proves of concept and the developments corresponding to each task of the roadmap and leading to the construction of the next generation simulations that were proposed.

- Extension of the roadmap for the other categories of simulation in order to help the development of other categories of AI techniques (for instance, evolution of "SIL" Simulations toward "Digital Twins").

- Development in the future of a general MSaaS platform where it will be possible to construct specific simulation for each use-case application with building blocks coming from different categories of simulation.