# STATE OF ART AND FUTURE TREND ON CGF

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## Introduction

With the events of today, military and civilian organizations are under great pressure to train their people for the ever-changing battlefield. Simulation has helped them solve this training problem with a reduction in cost and an increase in the possible scenarios that can be investigated. Computer Generated Forces are tools which aim at supporting this kind of simulation.

Computer Generated Forces (CGF) are automated or semi-automated entities (such as tanks, aircraft, infantry) in a battlefield simulation that are generated and controlled by a computer system, perhaps assisted by a human operator, rather than by human participants in a simulator.

Usually the applications of CGF systems in simulation are grouped into three classes: training, analysis, and experimentation [Petty 2001].

- *Training*. Training simulations, in general, are simulations intended to induce learning of some kind in the (human) participants. CGF systems are often used in training simulations to provide both opposing forces and supplemental friendly forces for human participants in a simulation.
- *Analysis*. CGF systems are also used to generate entities in battlefield simulations being used for non-training purposes, such as analysis and experimentation. Analysis is the use of simulation to answer questions about some aspect of the system or scenario being simulated (effectiveness of new weapons systems, force structures, or doctrine). In analysis applications simulation is used in a carefully controlled way with run-to-run initialization differences restricted to the factors under question (e.g., different weapons performance levels).
- *Experimentation*. The experimentation application is similar to analysis, in that the simulation and CGF system is being used to answer questions, but in experimentation the questions are more open-ended and exploratory. Strict control of run-to-run differences is less important in experimentation than exploring in simulation a space of possibilities (e.g., a set of different notional weapons systems).

After less than twenty years of growing, military simulation environments, CGF appear to be at a new stage in their evolutions, concerning both design and development trends. Domain experts speak about a "third revolution". After having acquired totally or partially the capability of modularity/composability ("second revolution") and providing significant enhancements on main models accuracy, some other aspects are to be tackled, among which:

- Full level interoperability and real time distributed simulation ;
- Defining moderator (fatigue, stress, …) for human behaviour models which usually represent perfect soldiers;
- Enhancement (and often providing) the representation of low intensity conflict, multi-sided, without clearly identified friends, enemies or neutrals, civilians, non governmental organisations, in urban environments, …;

The first point can be qualified as an old dream of every institutional client (and particularly US DOD administration), expecting systems to work together, exchanging data, making distributed computing, allowing some benchmarking, etc. Such a suitable situation can make it possible to rationalize efforts made until now, with regard to project costs or with regard to the high level of redundancy between tools. Redundancy concerns a general set of functionalities systematically offered and another bigger set of functionalities rarely provided since they are too much specific.
The posted strategy consists in design and development of a collection of specific tools for particular aspects, plugged into a central system providing the main functionalities. These tools have to be able to communicate using a standardised protocol and language. Specialisation of such approach of development enhances the chances of success as the quality and accuracy of results.
The other way to tackle the first issue, is to define and diffuse standard representations of some components of CGF, like for scenarios with MSDL (Military Scenario Definition Language, § IV)
For the two other points situation is more complicated. Accuracy and realism of modelled behaviours mainly depends on level of aggregation/de-aggregation accessible for a model. Thus, such a capacity relies on the cognitive models used to perform decision when human entities are handled and entirely simulated.

## Several problems of Computer Generated Forces (CGF) systems

Armies presently have and use multiple SAFs (Semi-automated forces) that originated to fulfil different requirements. However, each has evolved and developed capabilities which overlap. And in spite of these overlapping, there are types of operations which are not supported, there are problems with the usability of systems (too complexes because too riches) and with hard-coded entities behaviors.
For example the recent paper of [1] Archer et al 2002] that claim «*CGF entities don't always behave realistically (i.e., as if human soldiers were operating them) ..... The CGF soldiers don't show the effects of fatigue, their performance doesn't show the effects of extreme heat or cold and they don't show the effects of different amounts of training or soldier aptitude*."
An other important report [2] have sketch some weakness and great issues concerning CGF environment which are still to be tackled. From these different issues and our own analysis of CGF literature we can list several of points to deal with in order to improve current solutions.

- **Lack of dynamics for Weapon & Ammunitions Prioritization :** Presently CCTT SAF (Close Combat Tactical Trainer Semi-automated forces) uses a static weapon engagement table to decide which weapon a platform has to best engage a given target type. The logic used in weapon engagement needs to be modified to include ranges and general Mission, Enemy, Tactics, Terrain and Troops (METT-T) factors such as the units available ammunitions. According to authors, a similar issue exists with ammunition that "*also uses a static table for deciding which ammunition to load after deciding on the weapon system to use*". In general, one can conclude that ammunition logic needs to include range, target and METT-T factors
- **Rules for determining priority target and disengagement situation:** Current logic used by SAF systems for choosing which target to engage immediately, like the "closest target", and consequently which weapon to use, needs to be improve using a more detailed taken into account of METT-T factors. The current prioritization

methods frequently fall short and create situations such as a tank shooting at infantry that is nearby only to be killed by a tank from a distance. Furthermore in most cases decision of disengagement could be taken only after having inflicted at least Firepower/Mobility serious damage. Frequently it expends all its ammunition in vain trying to achieve this goal

- **User Control Interface (UCI)/Workstation Improvements:** despite real improvements (qualified as minor by authors[3]) important efforts have to be done in order to greatly increase the operator's productivity who still has to make many decisions in a very complex technical environment and situation. Low cost visual systems that could provide a 3D view to the operator are now becoming available. They have to be integrated in SAF systems [2]
- **Maneuver/Obstacle Avoidance/ Routing Improvement:** One of the most common complaints from SAF operators is the maneuver capability of the SAF entities. The operators complain about units not following paths, getting confused and spinning, and other abnormalities [4]. The addition of infantry and helicopters to current CGFs has shown that these types of units have unique maneuver requirements that need refinement
- **Suppressive Fire Effects: O**ne weakness in current virtual simulations and CGFs is a realistic simulation of suppressive fire effects. The designs of current CGFs were built around providing direct fire effects and the current suppressive fire designs are modifications of the direct fire design. Typically, in CCTT exercises the suppressive fire effects go mostly unnoticed by both the simulators and CGFs. Another weakness of current systems is the suppressive effect of artillery fire on a target. The effect in the manned simulators of enduring suppressive or artillery fire is nowhere near as shocking as real life. Furthermore, "soft effects" such as fatigue, confusion, due to conflicting, or excessive information, or stress are still weakly taken into account in CGF models of behavior and decisions processing.
- **Stability and Support Operations (SASO):** requirements for low intensity conflicts appear to increase during last years. CCTT and Onesaf have already started development in order to take into account such new needs. Nevertheless, as Marshall has noticed "… *one of the issues with SASO is the training requirements are not well defined*. *CCTT had an analysis of SASO done at Fort Knox and they determined a list of likely models to support this training*" [3]. To perform the analysis the researcher would have to understand the limitations of the Constructive or Virtual simulation. Similar processes could be used on NBC and amphibious operations. Needs also are growing concerning multisided scenarios where the behaviors, and particularly supportive or hostile actions, are based on the various allegiances and relationships between numerous factions (non stable).
- **Infantry Simulation:** Till now, most of the simulators and CGFs were based on supporting tank simulation. As the virtual and CGF technology progressed it became apparent that infantry had to be added to the simulation. The addition of infantry has proven to be difficult because of it unique behavior and maneuver characteristics. While the Close Combat Tactical Trainer (CCTT) has been fielded to provide training for Soldiers fighting from within vehicles, Soldiers who fight on the ground, such as Infantry and Special Operations Forces, do not have a comparable training capability. Thus while research conducted over the last decade has led to technical advances in Virtual Environments (VE) technology applicable to Soldier training [5], there has been little progress in actually making the technology available to the Soldiers who need it.

- **Military Operations in Urban Terrain (MOUT):** One of the current hot topics is the training of MOUT in a virtual or constructive environment. Most of current tools have a limited implementation of this capability. One of the difficult areas of this technology is the representation of urban structures and features as well as the maneuver aspects of the infantry entering them.
- **Digital Message Processing:** As the Army moves to digitize its communication systems, providing a CGF that can send and process these messages is a major challenge. In CCTT an operational concept of how the CGF entity would react if it received a message, which including operator tasks, and when it would send a message. Many of these messages have intent and free text messages that could make an interesting research topic.
- **Fair Fight with Manned Simulators:** During the development of CCTT a major concern was achieving fair fight between the manned simulators and the CGF. This is an interesting problem since the manned simulator is constrained by the visual system and the SAF is based on real world data from validated providers. In addition, fair fight issues can be behavioral as well as physical. An example is the DIMM in CCTT where the manned component of the module cannot typically react as fast as a corresponding OPFOR infantry unit [6].
- **Command From Simulator (CFS) Issues:** in this case objective should be to improve the maneuver and operator control of the CFS. A tied topic would be to control CFS units from voice recognition or gestures. Advantage should become very significant when larger exercises are attempted since the company commander or platoon leader could act as commander of their own vehicle, while having tethered SAF for their subordinate elements, which will "follow the leader" through appropriate battle drills and firing exercises. This can be qualified as modular approach of behavior permitting reusing standard well known exercises.
- **Aggregate-Disaggregate algorithms:** One of the major issues facing CGF systems is how they move entities between different domains such as a constructive simulation that may operate at the platoon company level and an entity based virtual simulation. Current solutions are still marginally effective. Current streams of research deal with : algorithms so that aggregate formation templates, determination of how many individual weapons systems within the templated formation have actual line of sight on individual entities within another, federated, simulation, and adjust the firing exchange rates within aggregate lookup tables (Lanchester/Bondar-Farrel) accordingly. A common approach to increasing system capacity is to use constructive, aggregate-level representations until some run-time interaction requires disaggregation to maintain training value. This de-aggregation often spreads and increases the system load and it is very difficult to re-aggregate in a manner that preserves a consistent simulation state. For example, the destruction of one tank in a platoon is not the same as minor damage to two of the tanks, but commonly used reaggregation techniques might map these back to the same constructive representation. Research in de-aggregation and re-aggregation techniques which preserve changes in relevant attributes of virtualized entities could vastly improve system performance and interoperability among live, virtual, and constructive systems [7].
- **Opposing Forces (OPFOR) Skill Levels/Variable skill leadership behaviors:** Current SAF systems have methods to create different skill levels that modify detection, engagement rates and delivery accuracy based on the competency level identified. This implementation(s) are mainly speculative and need an empirical analysis based on actual field data. Such modification of the outcomes of physically-based algorithms is a poor approach to simulating differences in skill-based behaviors since it precludes direct re-use of code for simulating these physical phenomena and

may adversely impact fair fight requirements. The researcher should develop a methodology and identify data for selection of variable level situational awareness, decision skill level, and speed of decision, within any given command behavior, based on the military grade and experience input with the command entity description. This methodology could investigate a monte-carlo selection of skill levels and errors, based on the input grade and skill, replacement of the initial grade and skill level by another person due to combat attrition, and ensure that changes in command entity during exercise runtime has a resulting degradation in situational awareness-based command decisions.

Other set of difficulties deals with the type of conflicts to be represented and simulated on environments. In 2001 some authors pointed out the changing nature of conflicts and the necessity to adapt CGF/SAF to such evolutions : "*What's needed from defense simulations today are models which can take into account the messy decision making processes of commanders and troops in the face of incomplete, conflicting, and sometimes wrong information in an atmosphere in which the rules and constraints upon which decisions are based are neither clear nor static*" [8] This condition alone wreaks havoc with the defense establishments' huge installed base of simulations based on deterministic rules for obtaining outcomes. The playing field today just does not support use of such models.
In terms of designing decision support aids, the challenges are multiple. Authors lists the following eight challenges to effective team decision making [8]:

- **The evolving nature of conflict.** Novel situations demand innovation, and analogical reasoning to transfer knowledge and experience from one situation to another.
- **Operational imperatives.** The emergence and adoption of knowledge dominance strategies for conflict resolution highlight the criticality of shared understanding amongst members of a command and control structure. Such understanding must include shared situational awareness, team awareness, command intent, and metacognitive aspects.
- **Asymmetric threats.** Such threats demand the maintenance of multiple perspectives amongst team members.
- **The discontinuous battlespace.** Highly fragmented nature of contemporary conflict (brought about in part by the collapse of the strategic-operational-tactical hierarchy) requires non-linearity and the capability for dynamic visualization as integral parts of the decision process.
- **More open doctrine.** Increased openness and delegation of responsibility leads to the requirement for both team adaptation, and for better preparations as a foundation to team decision making.
- **Distributed team formations.** For geographical distributed forces, maintaining Shared Situational Awareness can become problematic, and degrade critical teamwork behaviors, to the detriment of operational readiness.
- **Ad-hoc teamworking.** Teams operating in contemporary conflict settings often comprise composite forces, consisting of rapidly assembled and deployed personnel who may have had limited opportunity to train and work together previously.
- **Multi-national and coalition teams.** Many operational forces and teams are now composed of units from many different countries, each of whom may bring cultural and linguistic barriers to effective team communication and co-ordination.

Kallmeier was addressing problems in the "real" domain, but each item listed is just as applicable to the domain of models and simulations. The major thread running through all of these challenges is the same – how is an organization "organized" to optimize information density, distribution, and presentation to enable timely, effective, coordinated, and correct decisions among multiple C2 nodes connected across one or more networks.
"To be pro-active rather than reactive"; it could be another aspect to be improved in a global way of CGF system (joint or not) design and project pacification. A number of modeling and simulation tools have been developed and more are being developed for emergency response applications. The available simulation tools are meant mostly for standalone use. Addressing an emergency incident requires addressing multiple interdependent aspects of the situation. The simulation tools addressing different aspects of an emergency situation need to be integrated to provide the whole picture to planners, trainers, and responders. A framework is required to ensure that modeling and simulation tools can be systematically integrated together to address the overall response.
These tools indicates that a large number of efforts with highly qualified resources have been focused on this area [9]. Each of these tools has focused on a specific aspect of the selected problem, for example, the modeling of dispersion of an agent in the environment using plume simulation. The emergency response agencies have to use their planning skills to take the output of such tools and develop their action plans. The simulations are also used in training to describe the event and its short-term impact and prepare the trainees to develop. [9]

**Current Situation and Needs in CGF/SAF Development**

According to PIOVRA CGF State of Art and experience main current trends which could be highlighted are the followings:

- improvements of human behavior models at the scale of individual or little groups [10][11]
- interoperability and federation of M&S tools (despite HLA and others). The need for headquarters is not only a response to a specific warfighting threat against the force, but a solution to reduce duplication of M&S investments, foster interoperability and reuse across M&S domains, and meet M&S requirements of the future force [12][13][14]
- development of specialized tools and models for MOOTW (Military Operations Other Than War), for instance in urban environment,s which take into account a great variability of involved agents and goals.

Verification and validation of models and outcomes could also be in this list, but this is recurrent topics and needs not specific to current stage of evolution.
In order to illustrate the first point it is interesting to understand a real trend and a true impasse that designers are tempted to take, exploiting current accessibility of technology; this problem has clearly been detailed [11]. Human decision making depends largely on mental models of the situation within which the decision is to be made. These mental models usually take the form of enactive (mental) imagery. There is currently a largely implicit assumption that the best mental model in this context is an information-rich picture. This assumption leads to the provision of IT that focuses upon the delivery of increasing quantities of data. This can be observed in the continuing quest for greater bandwidth provision to Command Posts (CPs). However, this assumption does not appear to be valid. All models are simplifications, and simpler models often give greater insight than ‘richer pictures’–‘seeing the wood for the trees’. The question of what sort of mental model

best supports tactical decision making is highly significant and, critically, it is a human rather than a technical issue.
Another issue which come more and more important is those of embedded simulations tools, in the hearth of operations is related to the point raised by Surdu, Haines, and Pooch, whom plead for adding this kind of capacity to CGF system, have enumerated the desirable properties for an operationally-focused simulation for use during operations[15]:

- the simulation must be runable from a single workstation by a single user
- the simulation must be runable on low-cost, open systems, multi-platform environments
- the simulation must be capable of running in multiples of wall-clock time (i.e., real time and much faster than real time)
- the simulation must be able to receive and answer queries from external agents
- if needed, multiple simulations should be capable of operating together
- the simulation should be based on an aggregate-level model

Such systems (embedded training system), and maybe requirements listed above, are now an obvious objective of US Army included in the Future Combat System (FCS). Today, Army Research, (Development & Engineering Command -RDECOM) sponsored the development of a technology demonstration and experiment with an integrated architecture linking intelligent evaluation mechanisms with their Command and Control Vehicle (C2V) testbed [16].
An other important issue of CGF systems deals with the effectiveness of training when a team is to be trained. How measure and enhance the effectiveness of team training: the creation and employment of synthetic entities designed to improve team training. Among several existing problems one is the difficulty to train multiple individuals simultaneously in configurations considered as "teams":
(1) multiple individuals; (2) multiple information sources; (3) interdependence and coordination among team members; (4) defined roles and responsibilities for team members; and (5) common goals for the team ….
Such configuration requires, over and above the competences needed for the "taskwork", specific "teamwork skills" necessary to be able to hire benefit from the training. These skills can be defined and trained with a result of enhancement of performance. Current CGF as focused on "taskwork". Some research try now to face this problem of team training [17][18][19]. Solution proposed, as often in tutorial system is to add a specific tutor agent in the system which acts as an expert instructor, familiar both with instructional strategies and with a specific set of team skills [18].
A last other great issue and challenge of new system could be the training of headquarters in order to avoid conflicts. No needs of table of attrition, rule of engagement. Actually this issue doesn't mean it is necessary to forsake the CGF, but that an important effort must be put on conflict resolution with system able to take into account this kind of situation.
Are we witnessing a fundamentally new kind of conflict, to which previous ideas do not apply? If modern conflicts are becoming neo-medieval struggles between warlords, drug barons, mercenaries and militias who benefit from war and have found it their only means of making a living, what value will be efforts to resolve conflicts between them peacefully? Can conflict resolution apply in situations such as those that prevailed in Bosnia, where ethno-nationalist leaders whipped up ethnic hatred and courted war in order to serve their own political purposes?
Strengthening the capacity of conflict resolution within societies and political institutions, especially preventatively, is a vital part of the response to the phenomena of warlordism and ethno-nationalism. We argue that conflict resolution has a role to play, even in war zones, since building peace constituencies and understandings across divided

communities is very often an operation devoted to army (SASO, peace-making, peace-enforcement).
Conflict resolution is an integral part of work for development, social justice and social transformation, that aims to tackle the problems of which mercenaries and child soldiers are symptoms [20].

## Future Trend on CGF

The Army depends upon tough, realistic, battle-focused training to build winning teams. Computer and simulation technology will continue to revolutionize the way Armies plan and fight. After less than twenty years of growing, military simulation environments, CGF appear to be at a new stage in their evolutions, concerning both design and development trends. Domain experts speak about a "third revolution". After having acquired totally or partially the capability of modularity/composability ("second revolution") and providing significant enhancements on main models accuracy, some other aspects are to be tackled or privileged. Reasons of these evolutions have also to be found in progress in the Modelling and Simulation (M&S) field or research. Indeed, evolution of CGF or SAF environments is strongly related to the evolution of research in the field of M&S.
Coming from difficulties and lacks enumerated previously we would like to highlight some aspect of CGF industry and research currently investigated in order to provide during the next decade, some more useful and more reliant CGF.
The main factors we chose to detail are the following:

1. **Modelling aspects**: an issue which concerns models and results verification, VVA, HBR, scenarios and interoperability ;
2. **Type of supported conflicts:** addresses the capability to be ready to deal with new kind of threats.
3. **Using aspects:** addresses CHI (Computer Human Interface) enhancement, remote and distributed simulation, to follow and even anticipate changes in the forms and means of conflicts;
4. **Training aspects:** addresses new way of training in order to take into account collective aspect of training but also to dynamically acquire information from action performed by trainees...
5. **Technological aspects:** deals with taking advantage of new technologies, web and networks enhancements, always increasing capacity of PC, …

Many others come from our own experience and the current specific literature on this topic and particularly the SISO conferences (SISO, Euro SISO and BRIMS).

## Models Improvements

The last century, particularly the past 50 years, has seen enormous growth in the tools available to support modelling and simulation, as well as vast growth in our knowledge and understanding in many scientific fields. Military models and simulations have taken advantage of these developments in a variety of ways – from including more complex interactions to creating better displays and linking models and simulations to more powerful analytic engines.

New efforts are currently engaged concerning the models of entity and behaviour in CGF. Improving trends particularly address the following fields:

- **From SAF to FAF** (*F for fully*)

A continuous trend aims to give more autonomy to SAF by increasing capacities of Human Behaviour Representing (HBR) and the descriptions of handled situations and surrounding context. Explicit or implicit goal is to give more autonomy to the force and to the enemy in the computer system. A good example could be the representation of subordinate friendly units. In the case of a Division-level CAX, this would generally require the representation of units at battalion and below. HBR requirements for representing subordinate units would include the ability of such units to reason and take action with respect to their own tactical situation. Opposing Force (OPFOR), or “Red” response cells have slightly different requirements for HBR. In this case, the simulation must be able to represent the potential reasoning that a particular enemy might use in a conflict – a potentially much more complex M&S requirement than just representing reasoning of blue subordinate forces. Such a level of entities autonomy is a traditional cornerstone of CGF. In order to get real qualitative improvement some existing solutions and models - which can not be improved due to their level of complexity - have to be dropped. More modern, realist and efficient available solutions from HBR research should be taken into account and integrated in current tools. Indeed, Human behaviour, to the extent that it was included in such models, was expected to follow well-understood patterns derived from the doctrines, idealized work processes, and formal organizational arrangements of the forces being modelled [21]. Information flows and communications systems were treated as mechanical systems with known throughputs, error rates, and time delays. Decision making (friendly, adversary, and other) was based (and often are still being based on) on simple rules or programmed into tables based on doctrine. Major military models are measured in millions of lines of code. Person years of effort and months of calendar time were often required to initialize a new application. Moreover, many analyses involve multiple models, either run as a federation or as cross-checks on one another. Because of their size and complexity, these military models could not be directly or fully validated. Rather, individual elements within them (aircraft in flight, sortie rates, artillery fire, movement rates for different types of platforms across different terrain, and so forth) were validated and subject matter experts were used to establish the face validity of the larger elements. These validation approaches reflected the Industrial Age practice of decomposition and assumption of an underlying reality that could be understood and replicated.

Once again a better solution could be reached only by widening the expertise used for the development of the models. Modelling and simulation require effective interactions among three very different types of expertise:

- Domain Expertise;
- Applied Sciences and Engineering;
- Basic Sciences.

Military modelling has historically had all three of these, but as a subset of each. For example, military domain expertise for modelling and simulation has been dominated by technicians – communicators, logisticians, intelligence specialists, experts in the key platforms and weapons systems – because they had the relevant knowledge for the decomposed pieces. Military command, considered an art, not a science, was not modelled, but represented by doctrinal solutions. Today, however, commanders and decision makers from coalition partners, international organizations, and private voluntary organizations are available to the military modelling community, making much richer expertise available. Similarly, the engineers and applied scientists involved in military modelling became, during the 20th century, principally drawn from a relatively narrow spectrum of operations researchers, and engineers involved in military hardware and software, with a sprinkling of mathematicians and data modelers. The 21st century team has increasingly involved a broader range of technologists, algorithm developers, data miners, and information theory specialists. Finally, and perhaps most important, the scientific expertise on modeling and simulation teams was dominated by physical scientists and mathematicians. Today, however, these teams are becoming much broader. They increasingly include psychologists, sociologists, anthropologists, and political scientists. This enables models to be informed by social science as well as physical science. With the advent of complexity theory and other new ways to organize and analyze information, the relevance of biological science is also emerging. As in other fields of endeavor, the greatest progress can be expected at the intersections between the established disciplines. Getting more and different perspectives involved in the teams that build and apply models and simulations is a key step

- **Human Factors integration in "non-standard" situation**

It's a well known issue which can now be tackled due to current development of cognitive sciences. A great number of project deals with integration of moderators into human entities models. Indeed methodologies for representing ambiguity in the actions and responses of human and organizational entities in domains of interest are now available. As an example, group modeling of native population actions/reactions to conduct of security patrols by deployed peacekeeping forces. Results about new different techniques and processes for collection, analysis, and display of information can be used to contribute to situational awareness and understanding of options available to decision makers. One other current trend of research deals with the patterns and processes used by teams and individuals in their employment of digitized and automated information displays and decision support tools. By this is meant research into how human best relate to such displays and tools.
Such trends and efforts are based on a single fundamental assertion – that the next generations of models and simulations must recognize and take into account, as primary design criteria, the patterns of behaviour exhibited by human operators making decision in complex and ambiguous situations. The hoped for outcome is knowledge to allow design of models and simulations to better prepare forces to engage in non-combatant, stressful, and ambiguous environments [26].

- **Full level interoperability and real time distributed simulation**

A general goal is to continuously improve the interoperability and federation of M&S tools (despite HLA and others). The need for headquarters is not only a response to a specific warfighting threat against the force, but a solution to reduce duplication of M&S investments, increase the interoperability and reuse across M&S domains, and meet M&S requirements of the future force [27][28][29]. After years it appears to be as a real challenge of creating systems that can efficiently exchange data (where that makes sense), and to manage budgets to minimize duplicate efforts. In the past individual services and agencies allocated resources to create independent stand-alone simulations. Today's environment requires a much greater degree of coordination and commonality than ever before. This point can be qualified as an old dream of every institutional client (and particularly US DOD administration), expecting systems to work together, exchanging data, making distributed computing, allowing some benchmarking, etc. Such a suitable situation can make it possible to rationalize efforts made until now, with regard to project costs or with regard to the high level of redundancy between tools. Redundancy concerns a general set of functionalities systematically offered and another bigger set of functionalities rarely provided since they are too much specific.

The posted strategy consists in design and development of a collection of specific tools for particular aspects, plugged into a central system providing the main functionalities. These tools have to be able to communicate using a standardised protocol and language. Specialisation of such approach of development enhances the chances of success as the quality and accuracy of results.

The other way to tackle the first issue, is to define and diffuse standard representations of some components of CGF, like for scenarios with MSDL (Military Scenario Definition Language)

- **Aggregate and Disaggregate units**

One of the major issues facing CGF systems is how they move entities between different domains such as between company and platoon level. Current solutions are still marginally effective. Current streams of research deal with : algorithms so that aggregate formation templates, determination of how many individual weapons systems within the templated formation have actual line of sight on individual entities within another, federated, simulation, and adjust the firing exchange rates within aggregate lookup tables (Lanchester/Bondar-Farrel) accordingly. A common approach to increasing system capacity is to use constructive, aggregate-level representations until some run-time interaction requires desegregation to maintain training value. This de-aggregation often spreads and increases the system load and it is very difficult to re-aggregate in a manner that preserves a consistent simulation state. For example, the destruction of one tank in a platoon is not the same as minor damage to two of the tanks, but commonly used reaggregation techniques might map these back to the same constructive representation. Research in de-aggregation and re-aggregation techniques which preserve changes in relevant attributes of virtualized entities could vastly improve system performance and interoperability among live, virtual, and constructive systems [23].
The **scalability of behaviour models** also enters in this category of works to be able to provide gradual "scaling-up" of automation from lower echelons (individual or little groups [25][26], platoon and company) to higher ones (brigade and battalion)[21]. In this context an important trend is the ability to represent **human behaviour of commanders** (both friendly and enemy) as a specific behaviour different from soldiers but with special effect on them.

- **Integrate psychological warfare in models**

Such issue not only deals with the definition of rules, methods and principles about information broadcasting, wrong or true information, partially wrong, … but also imply the capability to evaluate the impact of such action on civil population or military personnel. Such models are still very simplistic and non operational.

- **Re-define the quality results and models assessment**

A good question to ask at this point might be "how good does the simulation have to be?" In this instance, fidelity and realism need only be good enough to "fool" the training audience into thinking that an actual manned response cell is in place. A potential test that could be employed might be to fully-automate portions of either an OPFOR or Blue response cell and try to see if the training audience can determine which is manned and which is automated. This might lead to a kind of military training Turing Test in which the underlying behavior of the computer simulation need only be representative of a human that is traditionally operating the simulation.

In order to illustrate the first point it is interesting to understand a real trend and a true impasse that designers are tempted to take, exploiting current accessibility of technology; this problem has clearly been detailed [26]. Human decision making depends largely on mental models of the situation within which the decision is to be made. These mental models usually take the form of enactive (mental) imagery. There is currently a largely implicit assumption that the best mental model in this context is an information-rich picture. This assumption leads to the provision of IT that focuses upon the delivery of increasing quantities of data. This can be observed in the continuing quest for greater bandwidth provision to Command Posts (CPs). However, this assumption does not appear to be valid. All models are simplifications, and simpler models often give greater insight than 'richer pictures'–'seeing the wood for the trees'. The question of what sort of mental model best supports tactical decision making is highly significant and, critically, it is a human rather than a technical issue.

**Type of conflict**

- **Changes in Threats**

  During the 20th century, military modeling and simulation were dominated by classic "force on force" engagements, battles, and campaigns. The dominant military experience came from World War II, the Korean Conflict, and Desert Storm. Moreover, the dominant threat was from massive Soviet forces in Europe. Other kinds of conflicts were seen as less important and less likely to threaten genuinely vital Western interests. Even the colonial wars and Vietnam were understood primarily as problems that could be managed if the guerrillas could be manipulated into fighting conventional battles where the superior firepower and maneuverability of professional forces could be brought to bear. Hence, while the contexts were different, the engagement-level models were seen as relevant. Most other aspects of conflict were treated primarily with less formal tools such as seminars, less formal war games, or abstract game theoretic structures. As we entered the 21st century, however, it became clear that threats to "the West" were taking new forms. Whether we look at peace operations, counter-terrorism, counter-narcotics, counter-proliferation, information warfare, or ensuring the rule of law and opportunities for fledgling democracies and free market economies, the military is being placed in roles where force-on-force models are either irrelevant or only capable of supporting part of the needed analyses. Moreover, capable military establishments are only one type of adversarial force. Paramilitary organizations, insurgencies, guerrilla forces, terrorists, drug cartels, hackers, media warriors, and ethnic or religious mobs are among the enemies we expect the military to deal with routinely. Military forces are also constrained in new ways – their actions need to be conditioned by religious, cultural, and humanitarian considerations that have not been part of traditional warfare. Coalition warfare has become commonplace, but often requires changes in the way military missions are conducted. However, the vast majority of existing models do not treat these phenomenon in any reasonable way. In 2001 some authors pointed out the changing nature of conflicts and the necessity to adapt CGF/SAF to such evolutions : "*What's needed from defense simulations today are models which can take into account the messy decision making processes of commanders and troops in the face of incomplete, conflicting, and sometimes wrong information in an atmosphere in which the rules and constraints upon which decisions are based are neither clear nor static*" [24] This condition alone wreaks havoc with the defense establishments' huge installed base of simulations based on deterministic rules for obtaining outcomes. The playing field today just does not support use of such models.

- **Supporting SASO (Stability and Support Operations)**

  Requirements for low intensity conflicts appear to increase during last years. CCTT and Onesaf have already started development in order to take into account such new needs. Nevertheless, as Marshall has noticed "… *one of the issues with SASO is the training requirements are not well defined. CCTT had an analysis of SASO done at Fort Knox and they determined a list of likely models to support this training*" [22]. To perform the analysis the researcher would have to understand the limitations of the Constructive simulation. Similar processes could be used on NBC and amphibious operations. Needs also are growing concerning multisided scenarios where the behaviors, and particularly supportive or hostile actions, are based on the various allegiances and relationships between numerous factions (non stable).

- **The discontinuous battlespace**

  Highly fragmented nature of contemporary conflict (brought about in part by the collapse of the strategic-operational-tactical hierarchy) requires non-linearity and the capability for dynamic visualization as integral parts of the decision process.

- **Military Operations in Urban Terrain (MOUT)**

  One of the current hot topics is the training of MOUT in a constructive environment. Most of current tools have a limited implementation of this capability. One of the difficult areas of this technology is the representation of urban structures and features as well as the maneuver aspects of the infantry entering them.

- **Needs for managing information's conflict and psychological war**

  The Information Age has brought profound changes to the way warfare is conducted. First, sensors have improved, both in terms of the range of phenomenon they cover and in terms of persistent coverage around the globe. Second, the networks available to move information has improved massively, so data and information can be processed, shared, and acted upon with speeds and in ways never before possible. Third, collaborative processes have been enabled that mean flatter organizations and increasingly integrated patterns of action are possible. Rather than organizing forces hierarchically and using large numbers of control measures to prevent fratricide, the Information Age force is free to combine its elements in novel ways to generate synergistic effects across the spectrum of political, military, economic, social, and informational arenas where 21st century wars are fought. Fourth, the performance parameters of platforms have changed in ways that make it very difficult for traditional models to reflect them correctly. For example, lighter, faster cheaper weapons mean that swarm tactics, not feasible in recent centuries, become preferred in some situations. Finally, greater precision in weapons means much greater lethality with a decreased likelihood of collateral damage. At the same time, these more powerful technologies are also associated with greater vulnerabilities. These take many forms. For example, a richly connected network is very vulnerable to penetration and to cyber attacks. Similarly, dependence on technologies means difficulty in functioning if they become degraded or fail. As events in Afghanistan and Kosovo have shown, these technologies also demand skill under pressure and can result in friendly or neutral casualties if misused. Moreover, adversaries often seek to employ countermeasures to avoid or spoof technical systems. However, except for some specialized models developed in the electronic and signals warfare areas (part of traditional combat), none of these new developments can be readily reflected in Industrial Age military models. In most cases, they are simply outside the essence of what has been modelled. In many cases, the "hard wired" assumptions, such as multi-layered hierarchical military organizations or the doctrinally correct responses to enemy actions are so fundamental to the models that it would be easier and faster to build new models than to reformulate the existing ones. Even the vulnerabilities are all but impossible to reflect in Industrial Age models without massive effort.

- **Conflict resolution, a new challenge**

  A last other great issue and challenge of new system could be the training of headquarters in order to avoid conflicts. No needs of table of attrition, rule of engagement. Actually this issue doesn't mean it is necessary to forsake the CGF, but that an important effort must be put on conflict resolution with system able to take into account this kind of situation.
  Are we witnessing a fundamentally new kind of conflict, to which previous ideas do not apply? If modern conflicts are becoming neo-medieval struggles between warlords, drug barons, mercenaries and militias who benefit from war and have found it their only means of making a living, what value will be efforts to resolve conflicts between them peacefully? Can conflict resolution apply in situations such as those that prevailed in Bosnia, where ethno-nationalist leaders whipped up ethnic hatred and courted war in order to serve their own political purposes?
  Strengthening the capacity of conflict resolution within societies and political institutions, especially preventatively, is a vital part of the response to the phenomena of warlordism and ethno-nationalism. We argue that conflict resolution has a role to play, even in war zones, since building peace constituencies and understandings across divided communities is very often an operation devoted to army (SASO, peace-making, peace-enforcement). As for conclusion one can claim that conflict resolution is an integral part of work for development, social justice and social transformation, that aims to tackle the problems of which mercenaries and child soldiers are symptoms [35].

### Using aspects

As a corollary of the trend concerning the models of CGF, improving, the usability and affordability of such systems –one of the main goals of the future M&S training – should be to reduce the footprint of manned response cells by creating fully automated simulation forces (FASF as we already explain before) that can replace many of the tasks currently done by human operators. However, the use of fully-automated simulations should not

come at the price of reduced capability. To state a new benchmark for synthetic forces: the training audience should not be able to distinguish between an OPFOR cell which is utilizing a FASF and one which utilizes a semi-automated force (SAF) or manned simulation. We submit that achieving this new benchmark should be one of the central Grand Challenges for future M&S.
Other issues in usability or uses of systems should be the following:

- **Towards embedded simulation system**

  Another issue which come more and more important is those of embedded simulations tools, in the hearth of operations is related to the point raised by Surdu, Haines, and Pooch, whom plead for adding this kind of capacity to CGF system, have enumerated the desirable properties for an operationally-focused simulation for use during operations[30]:
  - the simulation must be runable from a single workstation by a single user
  - the simulation must be runable on low-cost, open systems, multi-platform environments
  - the simulation must be capable of running in multiples of wall-clock time (i.e., real time and much faster than real time)
  - the simulation must be able to receive and answer queries from external agents
  - if needed, multiple simulations should be capable of operating together
  - the simulation should be based on an aggregate-level model

  Such systems (embedded training system), and maybe requirements listed above, are now an obvious objective of US Army included in the Future Combat System (FCS). Today, Army Research, (Development & Engineering Command -RDECOM) sponsored the development of a technology demonstration and experiment with an integrated architecture linking intelligent evaluation mechanisms with their Command and Control Vehicle (C2V) testbed [31].

- **Reducing distance between system and training audience**

  One of the biggest technical hurdles involved in automating response cells would be in developing the means for simulations to directly interpret command and control messages and orders generated by C4I systems. In current staff-level training exercises, one of the key roles of the response cell is to receive transmissions from the training audience (operations orders, Air Tasking Order, fragmentary order, etc.) and perform the manual interpretation of that C4I message for the simulation. The opposite is also true – simulations must be able to automatically generate a robust set of real C4I messages that appear to be "real" to the training audience (or at least appear to have been generated by a human simulation operator).

- **Instrumenting reality**

  An other new idea, capable of even more fundamental transformation of military modeling and simulation, has emerged more recently. This is the concept of "instrumenting reality." Military models suffer, as many types of models and simulations do, from serious validation problems. In many cases they are built on algorithms and patterns of interaction that are the "best guesses" or "hypotheses" of relevant subject matter experts. This same problem bedevilled modelers working on human behaviour for a very long time, including those in industry charged with marketing, advertising, and stocking the shelves. In an other context, industry has learned, particularly over the last two decades, how to use data mining to organize and analyze data it collected at points of sale, from client feedback, from returns, from suppliers, and other sources it had long ignored, to gain a richer and more valid understanding of its operating environment and its marketplace. Many companies have instrumented their work force in order to understand how they spend their time and to identify best practices.

More recently, commercial enterprises have learned to instrument the reality in which they live. This began with instrumenting the stores so that sales were known when they occurred. This permitted more efficient reordering, better production schedules, and improved logistics chains from suppliers to transportation networks. These systems were also linked to knowledge about the operating environment, which enabled them to make predictions about changes in demand based on everything from the time of year to the popularity of different sports. This richly instrumented reality allows companies to made predictive models that are linked from the consumer all the way back to suppliers.

Military modelling is just beginning to instrument its reality. We have ranges on which we can follow the movement of every vehicle and every soldier, including their physical actions and communications with one another. The information from these ranges should tell us more than we have ever known before about how individuals, groups, and units perform their jobs – not ideally as we have trained them, but in reality. This is also an increasingly trend for organizing and instrumenting military experiments, from small force-on-force engagements up to major efforts involving thousands of troops and dozens of command centres. The goal of these efforts is to give us valid data and information about the actual behaviour of commanders, staff officers, and organizations. There is also an interest to update or replace data on subjects we have dealt with in the past by assumption or by relying on subject matter experts who (a) were really good at their jobs rather than learning to do them and (b) gained their experience in earlier decades and with equipment we no longer use. Key issues include:

- Who talks to whom, when, for how long, and on what topics?
- Who is involved when important, rapid decisions are made?
- Who uses what information, when, and at what level of detail?
- What happens when systems break down?
- What happens when casualties occur?

These, and a host of other issues, can best be understood by instrumenting reality. As military systems move toward the Information Age concept of Network-Centric Warfare, we will increasingly be able to take data from real engagements and campaigns. Bringing together these two trends will fundamentally change military modelling and simulation. Modelling will be richer, involving both more realistic phenomenon and also more rapid running models that allow exploration of larger variable sets and larger sets of operating environment. Probabilistic outcome sets, alternative models and simulations used as stimuli for groups of experts with very different backgrounds, and rapid model prototyping designed to explore and experiment with national security issues will become very important decision support systems in arenas as diverse as force structure planning and integrated planning and operations.

**Training aspects**

An other important issue of CGF systems deals with the effectiveness of training when a team is to be trained. How measure and enhance the effectiveness of team training: the creation and employment of synthetic entities designed to improve team training. Among several existing problems one is the difficulty to train multiple individuals simultaneously in configurations considered as "teams": (1) multiple individuals; (2) multiple information sources; (3) interdependence and coordination among team members; (4) defined roles and responsibilities for team members; and (5) common goals for the team ….
Such configuration requires, over and above the competences needed for the "taskwork", specific "teamwork skills" necessary to be able to hire benefit from the training. These skills can be defined and trained with a result of enhancement of performance. Current CGF as focused on "taskwork". Some research try now to face this problem of team training [32][33][34]. Solution proposed, as often in tutorial system is to add a specific tutor agent in the system which acts as an expert instructor, familiar both with instructional strategies and with a specific set of team skills [33]. Other important issues to be tackled for team training problematic diversity are the following:

- **Distributed team formations**

  For geographical distributed forces, maintaining Shared Situational Awareness can become problematic, and degrade critical teamwork behaviors, to the detriment of operational readiness.

- **Ad-hoc teamworking**

  Teams operating in contemporary conflict settings often comprise composite forces, consisting of rapidly assembled and deployed personnel who may have had limited opportunity to train and work together previously.

- **Multi-national and coalition teams**

  Many operational forces and teams are now composed of units from many different countries, each of whom may bring cultural and linguistic barriers to effective team communication and co-ordination.

**Technological aspects**

Military modeling and simulation are no different than other areas of science and engineering. They are benefiting from the massive and ongoing increases in computational power and bandwidth inherent in the Information Age. Derivative benefits also exist in database structures and processes, analytic tools (inductive and deductive), as well as visualization tools and techniques. A variety of tools, from better data mining tools and search engines to more flexible types of analytic approaches (neural nets, agent based modeling, etc.) have also been developed to take advantage of the increasing power available. Some examples between others concern:

- A broader integration of virtual reality tools;
- The use of technologies around Internet (XML, AJAX, Web Services) in order to facilitate the communication between heterogenous application or software modules or workstation. This also should be use to integrate data from Geographical Information System;
- Developing web compliant Graphical User Interface.
- …

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