Enhanced Scenario Visualization for Simulation-Based Training

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This paper describes the development and initial experiences of an enhanced scenario visualization system recently introduced at the Swedish Air Force Combat Simulation Centre (FLSC). FLSC provides team training of fast-jet pilots, performs research on training effectiveness and human performance, and simulation-based development and acquisition. The system has been developed in-house, based on an extensive set of experiences and needs among various user groups, to support and enhance the effectiveness of simulator-based team training, as well as research and development programs. It provides enhanced presentations of scenarios, enabling pilots, instructors, training designers, researchers, and operational analysts to observe, reflect, and analyze sorties during and after execution. Initial experiences and reactions are promising, and the paper will address and relate those to other relevant efforts and elaborate on future interesting development paths.

The Swedish Air Force (SwAF) runs a program for simulator-based training, research, and development at the SwAF Combat Simulation Centre (FLSC). FLSC mainly conducts training of fast-jet pilots and the facility is designed to provide experiences that develop the trainees' knowledge and skills in decision making, planning, communication, tactical behavior, and situational awareness. The emphasis is on developing skills and knowledge on a team and inter-team level using eight fast-jet cockpits and four fighter controller stations (ground control intercept, GCI). The research activities are mainly focused on training effectiveness and human performance, while the development program conducts simulator-based acquisition studies and tactics development.

Training and Feedback

The importance of feedback and guidance has been identified as an essential part of any training since many years back (e.g., Holding, 1987), and it seems to have grown in relevance over the past decade following an increased use of simulators (e.g., Cannon-Bowers & Bell, 1997; Wickens & Hollands, 2000; Freeman, Salter, & Hoch, 2004). Considering modern simulator-based training, one effective way of delivering immediate feedback is to replay critical situations of a scenario, visualizing the events while discussing different situations. Especially when dealing with teams, the importance and effect of scenario replays during debriefs become critical.

The training concept at FLSC is based on Kolb's Experiential Learning Theory (ELT) and his four-stage cycle of learning: concrete experience, reflective observation, abstract conceptualization, and active experimentation (Kolb, 1983). At FLSC, this basically means that the trainees (i.e., pilots in this case) have a high degree of responsibility and influence on their own training. For example, they plan their training together with the instructors and run the debriefings themselves (even though the FLSC instructors may support with additional comments). By doing so, the pilots, with the support of the instructors, are provided with concrete experiences in the simulator, leading to observations and reflections during execution (pilots flying and pilots not flying) and debriefs. The pilots' influence over the training aims to stimulate them to assimilate their reflective observations into abstract concepts which they can actively test and elaborate with. The experience is that this model supports motivation and deliberate practice among the pilots, which in several domains has been found to be a crucial ingredient for developing expertise (Ericsson & Charness, 1994).

Another important part of simulator training is debriefs and after-action review (AAR), since providing feedback and knowledge of results has been proven important for both motivation and performance improvement (Holding, 1987). Freeman, Salter, & Hoch (2004) declare that feedback in debriefs is particularly important in team training since teamwork itself does not necessarily produce immediate feedback from which the team members can learn during task execution. Further on, feedback offered during performance is normally processed less well than feedback received immediately after completion since attention must be divided in the former case (Wickens & Hollands, 2000).

The experience at FLSC is that effective debriefs can substantially enhance the effect of simulator-based team training. The development of the enhanced scenario visualization is one example of that. Since the pilots hold a high level of responsibility for their own training it provides the opportunity for objective critique and reflections based on an audio-visual replay of the scenario. Examples of proficient or poor performance can be exposed and discussed with the support of the replay and the visualization aids. Several studies have shown that allowing trainees to practice without specific feedback and guidance of good and bad performance can be detrimental (Wickens & Hollands, 2000) and may produce sub-optimal decision-making skills (Cannon-Bowers & Bell, 1997). In that sense, the tool supports the pilots learning process since it facilitates critical thinking about their own performance (Freeman, Salter, & Hoch, 2004) and supports the development of common ground (e.g., Clark, 1996) among the team members while discussing the audio-visual replay of the events.

Even though feedback is critical for nearly any form of skill acquisition, Wickens and Holland (2000) point out that there are characteristics of decision making that can prevent feedback from providing maximum training value. Two of them are that (1) feedback is often ambiguous, and (2) feedback is often delayed. One way of overcoming this could be to immediately provide debriefs using embedded scenario visualization aids making as much information as possible available for observation and critique in an objective manner.

User Needs for Scenario Visualization

Following a growing experience of providing training and conducting simulator-based research and development at FLSC over the past ten years, an emerging need for augmented scenario visualization was identified a few years ago. A previous tool (Figure 1) served some of the basic visualization needs, but was deemed insufficient and inflexible to suit different emerging needs for various user groups. The needs emerged not only from trainees and instructors but also from engineers, operational analysts, and researchers. Experiences from these user groups were collected during workshops and during actual training, research and development efforts, over several years. This section lists the specific needs and intended usage patterns of the scenario visualization system for the three user groups mainly involved with training: pilots, instructors, and training designers.

Figure 1. The FLSC instructor and operator station, and in the background the debriefing facilities using the old scenario visualization tool.

The pilots require a visualization system for several purposes. Pilots not flying may follow the scenario in real-time from the debrief area, including the verbal communication via head-sets and desired visualization presentation aids. The pilots flying would use it for immediate debriefs, as well as for conducting delayed analyses of performance on the recorded sorties from a week of training at FLSC. Hence, the pilots would have a chance of conducting delayed analyses of individual or team performance, using the various visualization aids. This could play an important role for enhancing the effectiveness of delayed debriefs or analyses of individual performance since the memory of execution normally declines if feedback is delayed, hence making it less effective (Wickens & Hollands, 2000).

The instructors at FLSC would primarily use the visualization system to monitor and supervise the scenarios during execution. Further, it could be used for pre-training purposes, before squadrons arrive at FLSC. The idea is that an instructor from FLSC visits the squadron scheduled for training the week before the actual training itself. Such pre-practice tools have been supported by Burke, Salas, Wilson-Donnely, and Priest (2004) who included this approach as one of their ten guidelines for effective team training. The instructor would provide replays and examples of scenarios and events of sorties the squadron or another squadron has previously performed, and a preview of what they can expect during the coming training. The purpose is to prepare the pilots for the training in order to increase the initial effectiveness of the training. Further on, and similar to the delayed analyses of performance for the pilots, the replay and visualization aids also could support the instructors delayed performance assessment. Since many of the exercises at FLSC include eight manned pilot stations, time constraints make it difficult for the instructor to conduct reliable performance assessments during execution, especially at an individual level. Combining performance assessment tools or mission blueprints might enable the instructors to conduct reliable judgments after execution. This also provides enhanced in-depth assessment since the visualization aids embedded in the tool can be used to a higher extent due to lower time constraints.

The instructional designers would use the visualization tool to monitor, analyze, and evaluate the training, for example the exercise management, and the vignettes (i.e., trigger events) that the white force (e.g., role players) and constructive forces (computer-generated forces, CGFs) make. By using a audio-visual replay and the embedded visualization aids they could conduct in-depth analyses of the effectiveness of different vignettes (i.e., if they actually triggered desired reactions).

Needs and intended usage patterns vary between the different user groups. Common for all user groups is the need for visualization of non-physical parameters and composed measures. Non-physical parameters here refer to information or composed measures that are not normally available for observation. One example of a non-physical parameter would be the predicted point of impact (PRIMP). A visualization of the PRIMP quickly shows a pilot how his maneuvers forces the missile to recalculate its PRIMP and change course, thus draining the missile of its kinetic energy. An example of a team related composed measure would be a visualization of a fourship's current radar coverage (given a certain stipulated radar cross section of a target), combined with remaining own armament ranges (given certain target characteristics and behavior), which would represent the fourship's offensive potential at any given moment. The pilots can thus easily see when their offensive potential drops due to their behavior. Focusing on training applications, one could argue that these non-physical parameters represent knowledge that typically differentiates a more experienced individual from a less experienced. Enhancing the scenario visualization with non-physical parameters and composed measures would in this sense make some knowledge normally limited to experienced pilots available and observable, and hence provide a potential for more effective training through enhanced debriefs.

Based on this analysis of user needs and intended usage patterns, the enhanced visualization was developed as a flexible and expandable package using a plug-in architecture.

Enhanced Scenario Visualization System

The enhanced system presents a 3D "God's Eye" view of the simulated world, together with the head-down displays from all eight cockpits. The graphical user interface gives the user full control of the view of the world, with full zooming and control of the view angle. The temporal control of the replay provides up 16 times fast forward or backward playback speed. The functionality to go directly to a specific timestamp also exists. However, the 3D-view not only shows all the aircrafts in a selected area, but also in real-time visualizes data such as status parameters and measures of each aircraft, for example its weapon and sensor systems. Emphasis have been put to the development of visualization of the non-physical parameters (e.g., verbal and datalink communication), and information that wouldn't be visible to pilots in reality (e.g. the missile envelope; or PRIMP, mentioned above). These are a few examples:

- Visualization of radio communication, including statistics such as total air time, percent of air time, and number of step-ons (i.e., when two or more pilots are verbally communicating over the radio at the same time).
- Visualization of tactical data link messages (Link 16) between aircraft and with ground controllers.
- Radar coverage, radar lock-on and target sorting symbols.

- Missile envelope, missile lock-on status and PRIMP.
- Shot logs for missiles, including hits/misses and reasons for missile termination/abort.

During replay, the visual presentation of every parameter or function can be turned on and off as different users have different needs and preferences. The tool also provides the possibility to enter time-stamped observer comments that are shown during replay. It is also possible to web-cast the replay which is a useful feature during distributed simulation exercises.

After a training week at FLSC the visiting squadron receives all the logged files from the week, enabling them to review the recorded material of the sorties on any secure PC. The current implementation represents a modular concept where new plug-ins (e.g., the logging and presentation of Link 16 tactical data link messages) are developed as required. Figure 2, 3, and 4 provide some examples of enhanced visualizations in the new system.

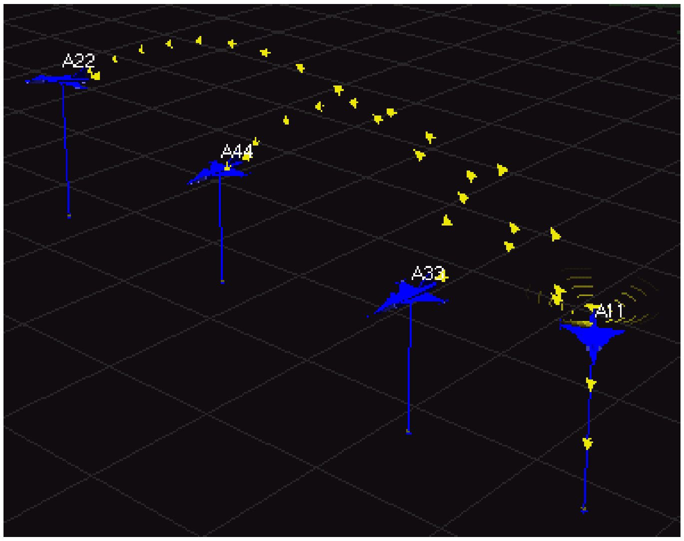

Figure 2. Visualization of verbal communication transmission (yellow arrows) from A11 to A22, A33, A44 and to the ground control interceptor.

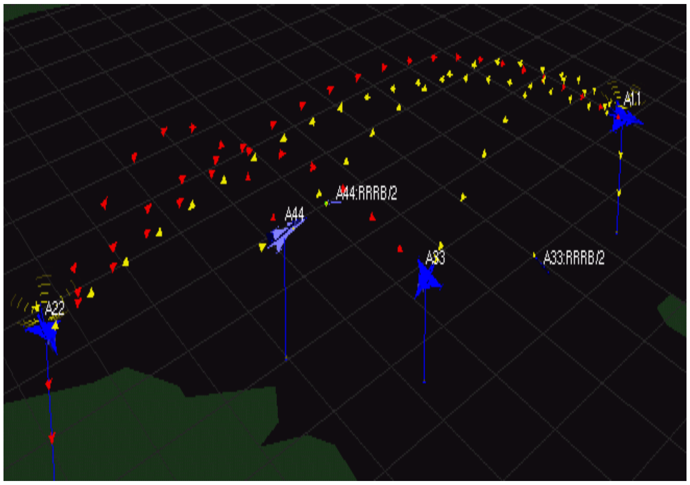

Figure 3. Visualization of verbal communication (yellow arrows) and step-on (red arrows). A step-on occurs when two or more pilots are verbally communicating over the radio at the same time. In this situation A11 is already communicating with the rest of the 4-ship and the ground control interceptor via radio when A22 steps-on.

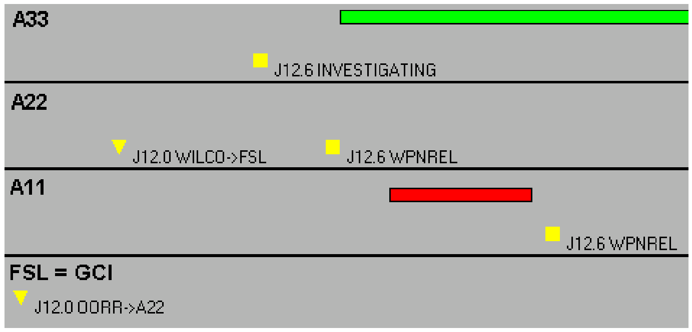

Figure 4. Visualization of verbal communication and data link communication (A11, A22, and A33 represent three different aircraft as can be seen in Figure 2 and 3 above, GCI is the Ground Control Intercept). The green line represents speech, the red line step-on, and the yellow boxes and triangles Link 16 messages.

Development Paths

A number of paths are envisioned for the continued development of this tool. One such path is to visualize historical data from 10 years of previously conducted exercises at FLSC. By processing, filtering and aggregating this data, typical cases of pilot and team behavior in specific situations can be generated. Visualizing such typical cases, and in particular illustrating the deviation from the planned data, could help instructors and training designers in understanding, analyzing and refining the scenarios. In addition, human factors researchers could benefit from such visualizations for analysis of pilot and team performance. Providing such insight into previous experiences and outcomes, could prove beneficial in optimizing the planning and pre-training stages.

Similarly, pilots may benefit from comparative visualizations of their individual performance and such aforementioned typical cases in specific situations. Through direct visual presentation of spatial and temporal deviation from the expected outcome, pilots may be further aided in reflecting on their own performance and decisions throughout the executed sortie.

There are plans to incorporate psychophysical sensors, such as eye trackers, in the pilot stations. This would enable many additional non-physical parameters, e.g. a pilot's physical or cognitive state, in the visualization. Various measures, including fatigue, workload, and attention, can be extracted from such sensors, and be analyzed online or offline in a human factors research context. Additional complex composed measures, such as a pilot's current *intent*, *aggressiveness* or *awareness*, could conceivably be extracted from a combination of the aircraft state (e.g. "determined" or "uncertain" motion pattern), pilot gaze (what the pilot is paying attention to, e.g. surrounding objects or specific data in head-down display devices), and control input (e.g. distinct and clear adjustments vs. constant corrections). With such measures reliably and intuitively visualized, scenarios could be altered in real time to increase difficulty for under-stimulated pilots or ease workload for stressed ones, as appropriate.

Including such additional parameters to the visualization can add significantly to the already visually complex scenarios. Therefore, another direction of investigation is how stereoscopic 3D rendering can aid users in perceiving the visualization. Air combat scenarios are inherently three-dimensional: combat aircraft, missiles, civilian traffic, and CGFs, fly at various flight levels in various directions and attitudes. These items should be unambiguously visualized in 3D space, along with the aforementioned non-physical and composed measures. When this information is rendered on a conventional 2D display, the objects are projected onto a flat image plane, potentially creating visual overlap of multiple objects from various depths in the original 3D scene. This information loss may cause confusion in the interpretation of spatial relationships. The problem is generally reduced by rotating the scene back and forth, generating motion parallax – one of two ways to provide absolute depth information (Cutting 1997). It is not as effective for moving scenes, however. The other way is to provide binocular disparity of the objects in the scene, which is accomplished through stereoscopic rendering techniques. Not only can spatial relationships potentially be better understood; the stereoscopic depth differences themselves may aid in visually isolating overlapping or clustered objects, further reducing clutter and confusion (Parrish, 1994).

Concluding Remarks

This enhanced scenario visualization system is currently being integrated into the training program. Continued development based on operational needs will emerge as the experience of the tool grows, and the development paths outlined in the previous section will be further explored. The effect of the system, at its current state, for the various applications and user groups, is still to be empirically investigated through controlled experiments and studies. Since the development has been carefully driven from user needs and contemporary research findings on the topic, the system is predicted to have a high potential of supporting the training program in particular, but also the research and development programs, and the initial experiences and reactions have indeed been very promising.

The use of the system for research and development is under way. For research purposes it will primarily be used by human factors researchers for studies of human performance, human behavior, and training effectiveness. Researchers working on CGFs have also expressed the potential of using replays and the visualization aids for knowledge elicitation processes. For simulator-based development, operational analysts, and to some extent engineers, plan to use the tool for in-depth analyses of behavior and performance of weapon and sensor models, as well as their effects and implications on tactical behavior, both on an individual and team level.

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