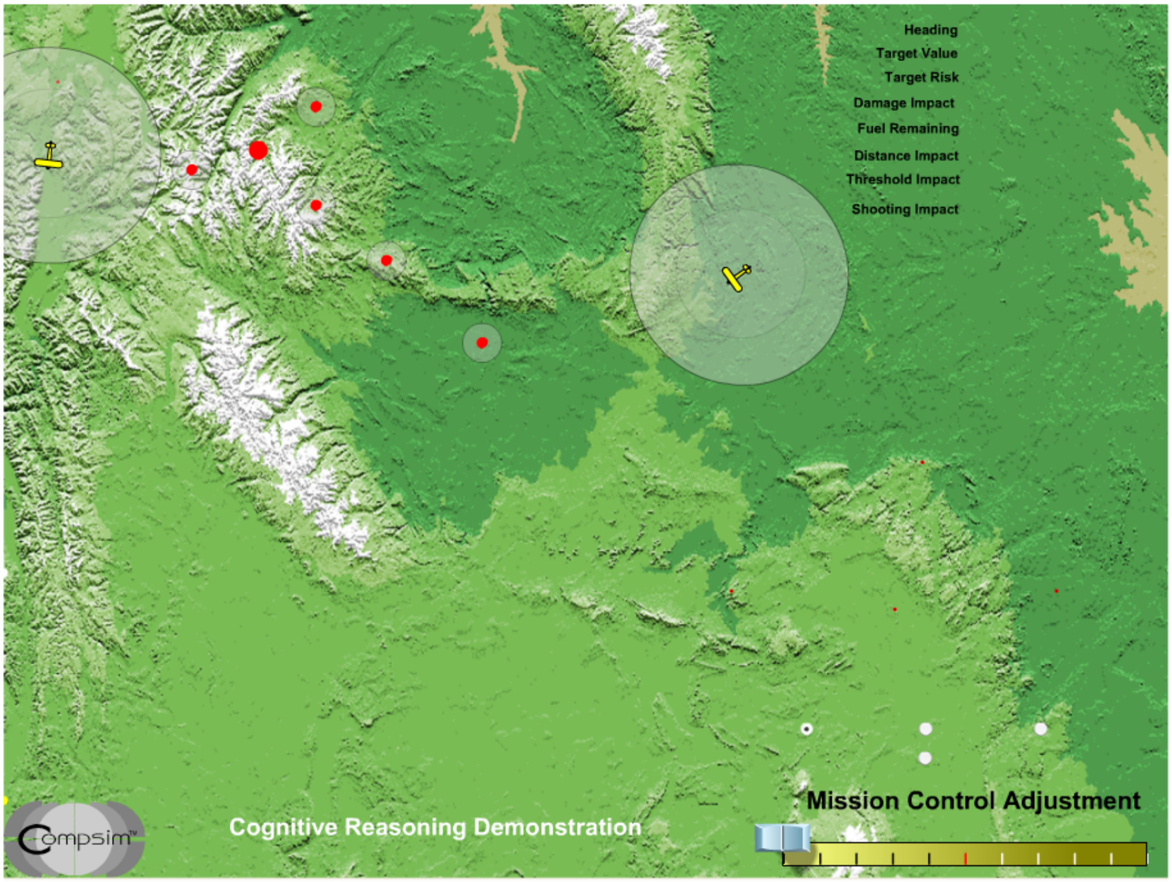
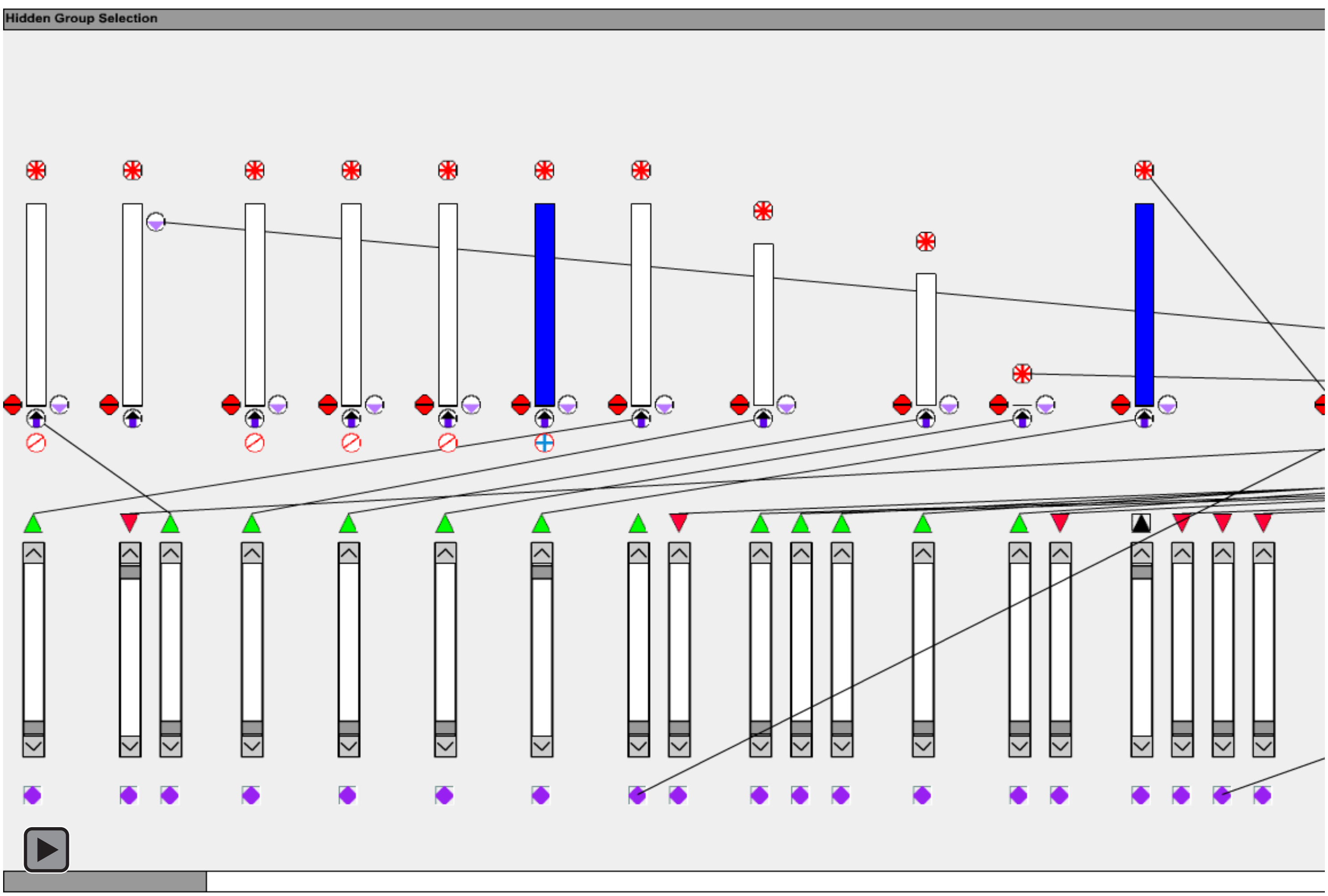



**K**nowledge
**E**nhanced
**E**lectronic
**L**ogic

**Documentation Below**

# Watch UAV1 "think" as it searches for the target



# Unmanned Combat Aerial Vehicles (UCAVs) That "Think"

## Compsim White Paper

**Abstract:**

Asymmetric warfare takes place when opposing forces apply different weapons and different tactics. Unmanned Combat Aerial Vehicles (UCAVs) promise to transform the battlespace and give one side a significant advantage over the other. Initial systems controlled directly by humans have already proven themselves, but they will be immediately outdistanced by those that can think on their own and react on their own. There are legal and ethical concerns about UCAVs that make untraceable decisions about life and death decisions. This paper discusses and demonstrates the use of Compsim's Knowledge Enhanced Electronic Logic (KEEL®) Technology to define policies that describe how the UCAVs interpret their situation and make 100% explainable / auditable decisions. This paper specifically shows how one UCAV can be monitored as it executes the policy.

**Table of Contents:**

**Discussion:**

The objective of this paper is to highlight three aspects related to the use of Unmanned Combat Aerial Vehicles (UCAVs):

1. The way that a UCAV needs to be able to interpret real time information in the pursuit of goals.
2. A way that "humans" can retain "absolute control" over certain functions while still allowing "autonomous behavior".
3. The need to provide a way to monitor the behavior of UCAVs as they pursue their goals.

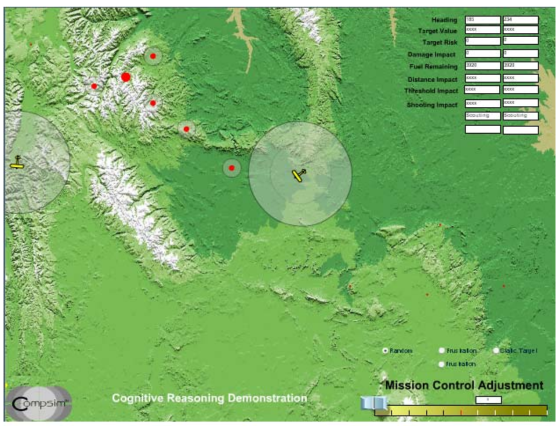



Figure 1

The embedded Flash application at the beginning of this document has two parts. Figure 1 shows two (2) UCAVs. Each of the UCAVs is searching for a Red Force target (larger red dot) by flying random patterns over the map. A "policy" (Figure 2) is described using the KEEL "dynamic graphical language" (DGL) that defines how UCAV #1 is to interpret information as it pursues this goal. UCAV #2 has a policy identical to UCAV #1. While searching for the target, the UCAVs may fly over Red Force defensive positions (smaller red dots). These positions may fire at a UCAV within range and damage the UCAV. Incoming fire to the UCAV will cause it make evasive maneuvers according to its "policy". While pursuing its goal, the UCAV will be using fuel and weapons and potentially sustaining damage from incoming fire. The "policy" describes how it interprets this information in the process of pursuing its goal. A legend in the upper right corner of the map shows updated information as the UCAVs pursue their goals.

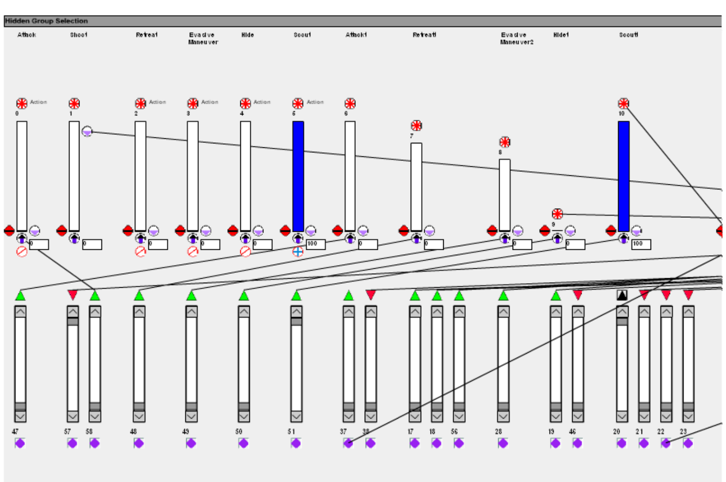


Figure 2

The policy describes how the UCAV interprets Target Value, Risk associated with a specific target, Threats that it may encounter, its Environment that might be used for its benefit if it is threatened, its Fuel Supply, and its own Damage Assessment. The policy also describes how it is to maneuver if it encounters another UCAV in its airspace (Collision

Avoidance). The policy also allows for human commanders to exert some level of control over the UCAV by controlling how it interprets Target Value and its own Risk Tolerance. This allows the human commander to attempt to convince the UCAV that it should attack a target even if the standard policy would suggest that the target should be ignored. The policy also has a "fail safe" provision that allows the human commander to stop the UCAV from attacking the target under any circumstances.

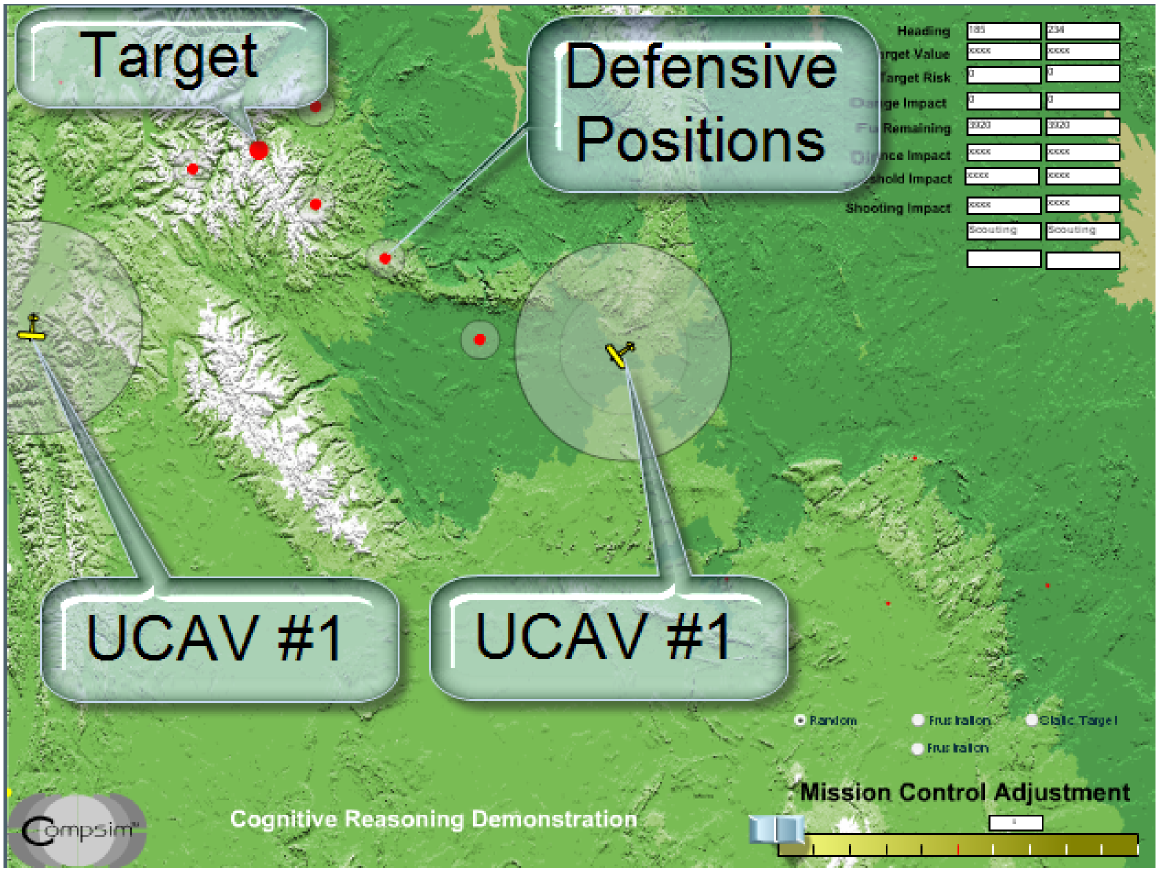



Figure 3

In the lower right corner several controls are provided to demonstrate certain features. Random or Static Target can be selected. "Random" target means that the target will be moving over the battlespace. "Static" target means the target will remain stationary. Two "Frustration" radio buttons run preconfigured patterns (UCAV position / heading, Target location and value, Defensive Position locations) that allow specific scenarios to be repeatedly evaluated.

A Mission Control Adjustment (MCA) provides the means for commanders to send messages to the UCAVs in order to make the UCAVs interpret the value of the target as being more important than the UCAV might interpret on its own using its own sensors (intelligence not available to the UCAV directly). This MCA also advises the UCAVs that the commander wants the UCAVs to be more risk tolerant. This approach allows the

UCAV to use its local knowledge of the situation (weapon supply, fuel supply, self damage assessment) along with remote information to collectively process the policy when making tactical decisions.

This demonstration shows the application of KEEL "Animation" to animate the KEEL dynamic graphical language (DGL). In a real-world application the UCAV would publish the inputs it observes during operation. This information could be saved in a file for after-mission review, or it could be used to drive the KEEL DGL (animation). The "real" KEEL Toolkit provides services to read the input values (packaged in XML files) and animate the language within the Toolkit. KEEL Toolkit services allow specific situations to be "trapped" for detailed analysis. In this specific demonstration, a direct link is provided between UCAV #1 and the DGL. No provisions to "trap" on decisions are provided in this example. The use of Animation is most effective in "after-mission-reviews" and in "simulations" where one may be interested in observing policies in action.

**Interaction with the Demonstration:**

Without any user interaction with the demonstration, the UCAVs will randomly search for the target and shoot at it if it is worthy (by balancing risk and reward). If the UCAV does not find the target until it runs low on fuel, or is sufficiently damaged by red forces, it will return home (upper left corner for UCAV #1 and lower left corner for UCAV #2) for refueling.

You can cause UCAV #1, to fly to a certain point by left-clicking your mouse on the screen. You can direct UCAV #2, by (shift) left-clicking.

Use the radio buttons in the lower left corner of the screen to run the preconfigured patterns.

Use the Mission Control Adjustment to change how the UCAVs interpret the target for attack decisions.

The lower portion of the demonstration is available to allow you to "watch UCAV #1 interpret information". Different "views" allow you to focus on specific segments of the policy. The "graphical" nature of the KEEL language allows you to see how information items are fused to make decisions and take actions (information fusion). Without this capability one would have to spend significant resources (time and money) to create supporting applications to show how information is accumulated. With the KEEL DGL, all aspects of the decision-making process are open for review.

In this application all but one of the inputs is driven by the upper portion of the demonstration. UCAV #1 knows how it perceives the Target Value, Target Risk, Threat Assessment, Weapon Supply, Available Hiding Space, Fuel Supply, and relative Position of the other UCAV for Collision Avoidance. UCAV #1 also knows the information from the Mission Control Adjustment. The sole input that has not been exposed for user control in the upper portion of the demonstration is the "fail safe" control that prohibits the UCAV #1 from attacking the target under any circumstances. In this demonstration you can adjust this value by manipulating the UAV1 Attack Authorization (Input 8) in the KEEL DGL in the lower portion of the display. Normally this value is set to 0. Setting it to 100 will stop any attacks.

**Different "Views":**

The KEEL Toolkit and the DGL in this demonstration allow you to look at selective "parts" of the policy to simplify any analysis.

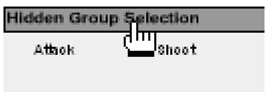



Figure 4

In this demonstration you can select different views by clicking on the "Hidden Group Selection" (Figure 4) bar of the DGL rendering. This opens a window where you can select from different "views" that have been created in the KEEL Toolkit. In this case you can select to view "just" (Figure 5) the logic associated with:

- Attack
- Collision Avoidance
- Control Only w/o Collision Avoidance
- Fuel – items controlled by Fuel
- Attack, Shoot, Retreat, Evade, Hide, Scout
- Inputs and Outputs Only – no Collision

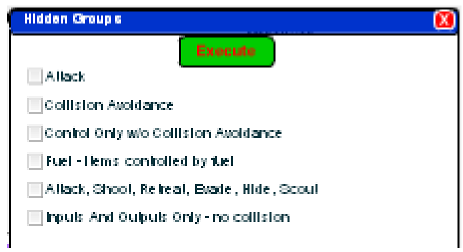



Figure 5

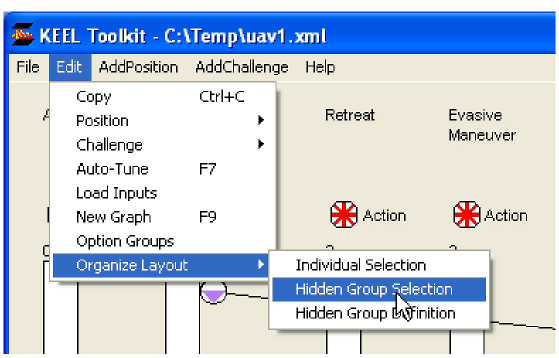



Figure 6

In the "real" KEEL Toolkit you have a more complete menu structure (Figure 6), where you have the option of defining any views that you want. In addition, you can select a "parent view" by choosing an output and looking at all of the logic that drives it. You can also select a "child view", by picking an input and view all of the logic dependent on it.

**Policies for UCAVs:**

Rules are different than "policies". Rules are specific and are not subject to interpretation. Rules can be defined with conventional "IF | THEN | ELSE" logic. Policies are more abstract. They describe how to interpret information. Policies are commonly used in situations where it would be difficult or impossible to explicitly describe all the scenarios that might be encountered, and where actions need to account for changing situations.

Many times a UCAV will be tasked with addressing multiple interacting scenarios. The UCAV will have to account for its own health and tactical value when deciding how best to respond to any situation. The importance of a mission may change dynamically; making it more or less important at any instant in time. Policies for UCAVs must account for a dynamically changing environment.

Policies for humans are commonly described with a written language (English) and depend on the human's "general understanding", morality and training to interpret both the "written policy" and the "situation" collectively. When humans are determined to have "behaved" outside the bounds of the policy, they may be reprimanded or punished.

Unlike policies for humans, policies for UCAVs must be "explicit" and "not subject to interpretation". The UCAVs are / will be mass produced machines. There can be no abstract interpretation of the policies. At the same time, the policies must be defined such that they can interpret complex, non-linear, inter-related, multi-dimensional situations.

Because the UCAVs will be interpreting the policies as they pursue goals that may involve life and death decisions, their decisions and actions must be 100% explainable and auditable. Unlike policies described using the English language, policies described with the KEEL DGL are 100% explicit and auditable.

**KEEL Technology:**

Compsim's KEEL® (Knowledge Enhanced Electronic Logic) Technology can be used to put human-like decision-making in products or software applications. KEEL technology can be considered an "expert" system that uses the decision-making skills of a human as the basis of judgmental decisions. The KEEL Toolkit provides the mechanism to collect and test those reasoning skills before deployment in the final product.

KEEL is:

- A development environment (Click on Figure 7 for a movie introducing the language)
- A model for accumulating supporting and objecting arguments in order to make a decision or take an action
- A small footprint engine that processes sensors or other inputs according to the design of a system created in the development environment
- A method for implementing the cognitive model as an analog circuit

Using the KEEL toolkit, a human (i.e., a "Domain Expert") can document how to analyze problems and take actions. The resulting code can be embedded into a device, a software application or demonstrated on the web. Special characteristics include:

- Decisions or actions are explainable
- Graphical development tools focus on subjective "right brain" reasoning

- Generating  a small memory footprint makes it possible to add human like reasoning to very small devices
- Interactive development environment allows the designer to get immediate feedback in the reasoning process
- A single design can be deployed in a variety of environments
- Architecture independent (simple stand-alone applications, client-server, distributed)
- Easy to integrate into existing systems (simple API)

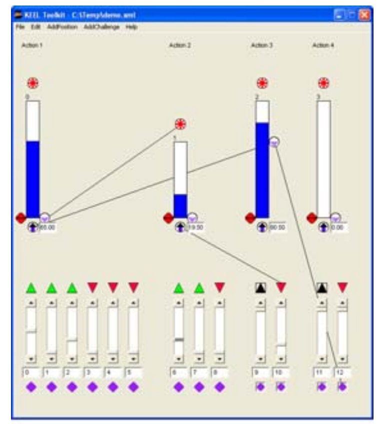


Figure 7
Link to Movie Describing the KEEL DGL

The KEEL Toolkit allows a human (i.e., a "Domain Expert) to interactively model a decision-making process. The designer gets immediate feedback from the design, as the thinking process operates while the design is being created.

A variety of tools assist the designer in documenting the model.  When the design is ready to be integrated into the final product, it is translated from the graphical model to conventional code (C, C++, C++ .NET, Microsoft C#, JAVA, JavaScript, Octave (MATLAB), Python, Microsoft Visual Basic Version 5/6, Microsoft Visual Basic .NET, VBScript, Macromedia's FLASH 2/3, and PLC Structured Text) that can be provided to the software engineer for system integration. The isolation of the decision-making model from the native source code simplifies maintenance.  If a logging function is integrated into the application (according to the KEEL XML schema), any decision that is logged can be read back into the development environment so decisions or actions can be reverse-engineered.

KEEL technology attempts to mimic the way that humans balance input information to make decisions.  In this manner, a KEEL engine operates like an analog computer.  It accumulates supporting information and balances this with objecting or blocking information.  Individual considerations interact with other decisions or actions in a web of relationships that are balanced to achieve the best overall set of actions for the system. In a KEEL system, the importance of information is likely to be constantly changing.

The importance of information can be controlled from external events or can be controlled as part of an internal process.

The output from a KEEL engine can be binary (YES/NO or ON/OFF), or it can be relative (do x amount of action 1 and y amount of action 2…).  Events can be triggered. The number of inputs and outputs from a KEEL engine are limited only by the resources available.

The output of the KEEL Toolkit is two or three small subroutines and a series of tables that define values and relationships between information. There is no textual processing in the KEEL engine itself, only an evaluation of information. Any display and control functions are defined external to the KEEL engine.

**Demonstration Architecture:**

This paper has an embedded Flash application. Flash provides the means of rendering animated graphics that are (in this case) controlled by Flash Actionscript "code". The KEEL Toolkit was used to create the policy for the UCAVs. The KEEL Toolkit was then used to auto-generate the Actionscript code. This code was copied into the Flash development environment (with no change) and accessed by manually developed Flash code.

For this demonstration, the DGL animation is only being called when UAV #1 changes state (Attack, Retreat, Hide, Evade, or Scout), when it changes direction, when it is involved in collision avoidance, and when it is determining the optimal instant to shoot.

**Disclaimer:**

The policies described for the UCAVs in this paper are for demonstration only. They are incomplete and based solely on simulated information. Policies for UCAVs, like policies for any combat situations, need to be described by military personnel.

**Compsim:**

Compsim is a "technology provider" not a "solution provider". Compsim licenses KEEL Technology to organizations that want to provide superior capabilities that can be embedded in devices (like UCAVs) or software applications.

Any application where there would be value in incorporating human-like reasoning and judgment is a potential application where KEEL Technology would provide value; especially for applications that need to have 100% explainable and auditable results.

Compsim LLC is a technology company providing next generation cognitive technology for application in military, medical, transportation, industrial automation, governmental / business, financial, utilities, and electronic gaming markets. Compsim licenses its KEEL® technology for use in embedded devices, software applications and for the Internet. The website is: http://www.compsim.com.

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