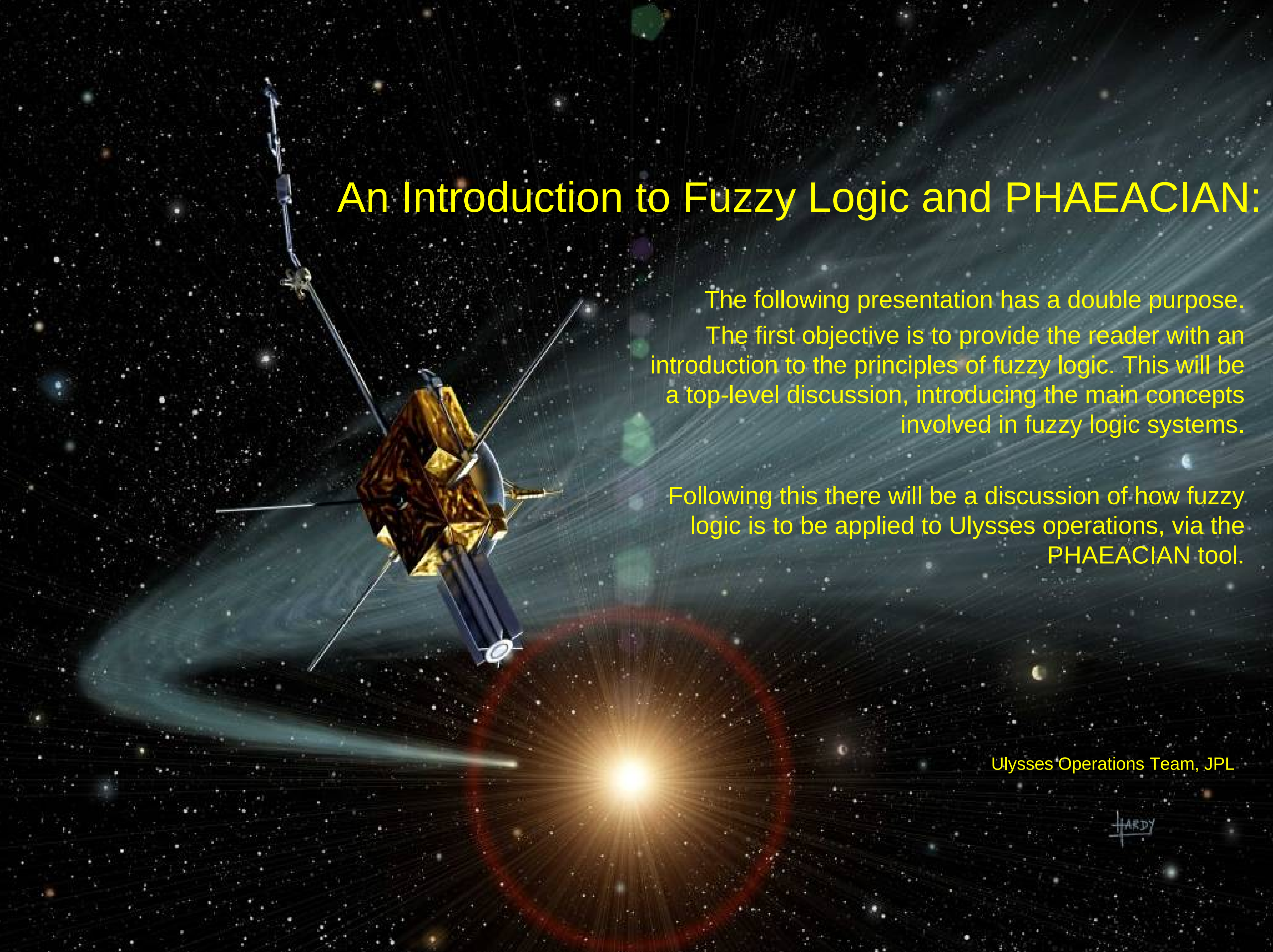

An Introduction to Fuzzy Logic and PHAEACIAN:

The following presentation has a double purpose.

The first objective is to provide the reader with an introduction to the principles of fuzzy logic. This will be a top-level discussion, introducing the main concepts involved in fuzzy logic systems.

Following this there will be a discussion of how fuzzy logic is to be applied to Ulysses operations, via the PHAEACIAN tool.

Ulysses Operations Team, JPL

Fuzzy Logic- Computing Shades of Grey

The concept of Fuzzy Logic (FL) was conceived by Lotfi Zadeh, a professor at the University of California at Berkley, as a way of processing data by allowing partial set membership rather than crisp set membership or non-membership. Professor Zadeh reasoned that people do not require precise, numerical information input, and yet they are capable of highly adaptive reasoning.

Fuzzy logic starts with and builds on a set of user-supplied human language rules. The fuzzy systems convert these rules to their mathematical equivalents. This simplifies the job of the system designer and the computer, and results in much more accurate representations of the way systems behave in the real world. Additional benefits of fuzzy logic include its simplicity and its flexibility. Fuzzy logic can handle problems with imprecise and incomplete data, and it can model nonlinear functions of arbitrary complexity.

Fuzzy Logic- Computing Shades of Grey

Fuzzy logic models, called fuzzy inference systems, consist of a number of conditional "if-then" rules. For the designer who understands the system, these rules are easy to write, and as many rules as necessary can be supplied to describe the system adequately.

In fuzzy logic, unlike standard conditional logic, the truth of any statement is a matter of degree. (How cold is it? How high should we set the heat?) For example, for the rule *if (weather is cold) then (heat is on),* both variables, *cold* and *on*, map to ranges of values. Fuzzy inference systems rely on membership functions to explain to the computer how to calculate the correct value between 0 and 1. The degree to which any fuzzy statement is true is denoted by a value between 0 and 1.

Fuzzy Logic Applied to Ulysses

Between February 2007 and February 2008, the Ulysses spacecraft will once again enter a period of solar-heating induced nutation as it traverses perihelion. Further details on nutation can be found on the nutation page of the Ulysses website.

During a period of nutation, the Flight Control Team (FCT) may have a number of options open to them as they try to minimise the nutation angle, this includes altering the deadbands of the onboard conical scanning system (CONSCAN), or performing specific manoeuvres designed to provide a large one-off offpointing that the CONSCAN system may be able to damp more easily than ongoing nutation.

At any time, one option may or may not work as expected, due to the inherent unpredictability of nutation. Further, multiple options may offer similar results and levels of success. The selection of these options comes down to the experience and knowledge of the FCT.

Prior to the 2000-2001 nutation season, a tool was envisioned that would aid in the decision making process. Trying to translate human language rules such as “If the nutation angle is quite large then…” the potential for using fuzzy logic rules became apparent.

Fuzzy Logic Applied to Ulysses- PHAEACIAN

This tool became known as **PHAEACIAN** (Program Handling Argos Estimates And Calculating Intelligent Actions for Nutation), the basic goals of which are:

- Recommend actions based on past and current experience of the Flight Control Team in similar situations, using Fuzzy Logic techniques
- Assist the Flight Control Team during nutation anomaly monitoring and trend reporting (by automating the extraction from ARGOS output files and graphical plots of the parameters involved in the nutation operations)
- Assist the Associate Cognizant Engineer (ACE, NASA spacecraft controller) in preventing real-time contingencies, thus reducing the need for continuous spacecraft operation's engineer support.

Fuzzy Logic Applied to Ulysses- PHAEACIAN

Created with MATLAB, using the Simulink and Fuzzy Logic Toolbox modules, PHAEACIAN consists of a model and GUI, taking its input from another program, ARGOS (Attitude Reckoning from Ground Observable Signals). This was a JPL/ESOC produced piece of software, currently being reingineered for the upcoming nutation season.

PHAEACIAN can be used in two modes:

- The off-line mode allows the user to read and replay historical ARGOS files. It has been used to develop and test the application. It can be used to support the PHAEACIAN rule-base fine-tuning.
- The on-line mode reads incoming ARGOS files and imports the necessary data into the application. PHAEACIAN recognizes invalid data and interpolate the data to provide the necessary inputs for fuzzy logic (FL) system.

Fuzzy Logic Applied to Ulysses- PHAEACIAN

Data is imported from ARGOS via text output files every 60 seconds, in the form of the following variables:

- Nutation Half Cone Angle (NUTH)
- Earth Aspect Angle (EAA)
- Spacecraft Spin (SPIN)
- Meridian Antisymmetric (MA)
- Earth Receive Time (ERT)
- Spacecraft Event Time (SCET)

Evaluating these variables over a programmable interval called 'Nregime' produces a number of trends- described below- which can be output as graphical displays.

- Nutation trends:
- Nutation trend (NUTHt)
- NUTH growth rate (NUTHgr)
- Nutation percentage of MAN (NUTHpMAN) (**MAN: Maximum Allowable Nutation)**

And similarly regarding Earth Aspect Angle (EAA):

- EAA trend (EAAt)
- EAA growth rate (EAAgr)
- EAA percentage of MAN (EAApMAN).

Fuzzy Logic Applied to Ulysses- PHAEACIAN

For clarity, it should be stated that PHAEACIAN will be used by the operations team as an *aid* in decision-making, not as the sole decision maker. This tool is not intended to define or schedule operational tactics, but to assist the on-scene FCT personnel in identifying their options, and providing a level of confidence in each option.

This is achieved through the trend evaluation. Possible activities, such as changing Conscan deadbands, or SOLACE manoeuvres are displayed with a confidence level ranging from 0 to 1. These confidence levels are based on interpretation of the incoming data via a series of programmable rules. These rules can be tailored based on experience, making for a system that can be constantly adapted and improved.

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  - R. Clivio, A McGarry (VEGA Group gmbh)
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Feedback/ questions
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