INTRODUCTION

Richard Wheeler

- Background in education – teacher in mainland China for five years
- Post-graduate work at the University of Edinburgh in Artificial Intelligence
- Artificial intelligence and adaptive disease control systems for the World Health Organisation in Geneva
- Artificial Intelligence Applications Institute, Edinburgh
- Starlab Research, Brussels
- Public Voice Labs in Vienna, Austria
- Business Development Executive for the School of Informatics, UoE
- Edinburgh Scientific
- Focus: applied AI and machine learning for fault detection, medical informatics, inventing *(9 patents…)*

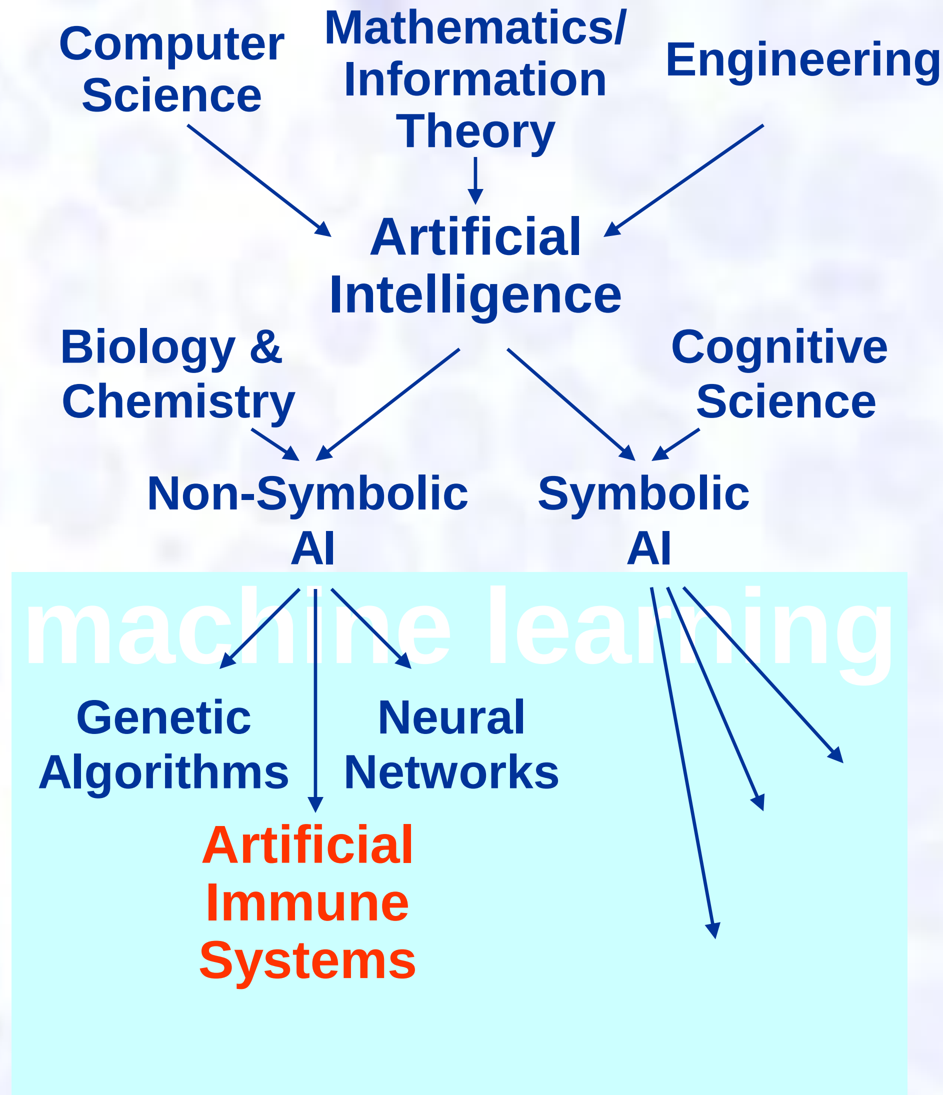
Artificial Immune Systems

Department of Knowledge Technologies, Jožef Stefan Institute, May 31, 2011

This Presentation

- 45 Minutes – feel free to ask questions at any time
- Describe basic concepts and research in artificial immune systems (AIS) and show some applied examples
- AIS for applied knowledge engineering (biological metaphors, not biological modeling)
- For a general scientific audience

"An emerging paradigm for computation and machine learning based on biological immune systems"

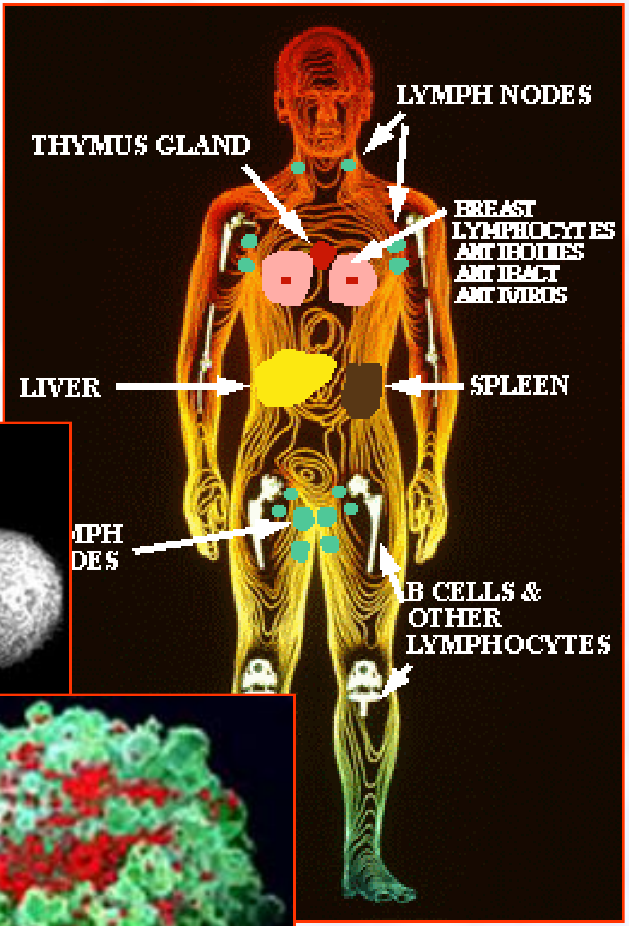


very simple

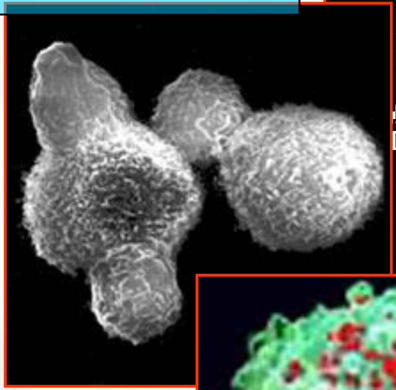
Immunology

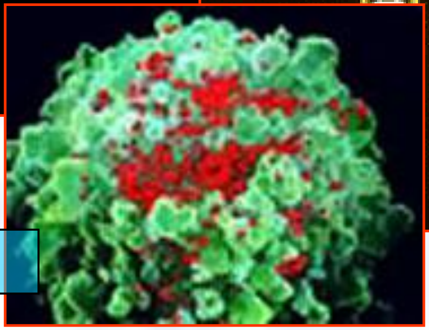
Facts about the human immune system:

- A highly complex massively parallel and distributed system maintaining both innate *(non-specific)* and acquired *(specific)* defenses for the purpose of defense and self/non-self discrimination
- Lymphocytes and phagocytes are the cellular building blocks
- Lymphocytes (B and T cells) created in the thymus and bone marrow interact with *antigens* (things perceived as foreign to the body) and through *recognition* cause an *immune response*
- *B and T Cells have around 100,000 receptors to match a single pathogen, with 10^{12} in the human body!*



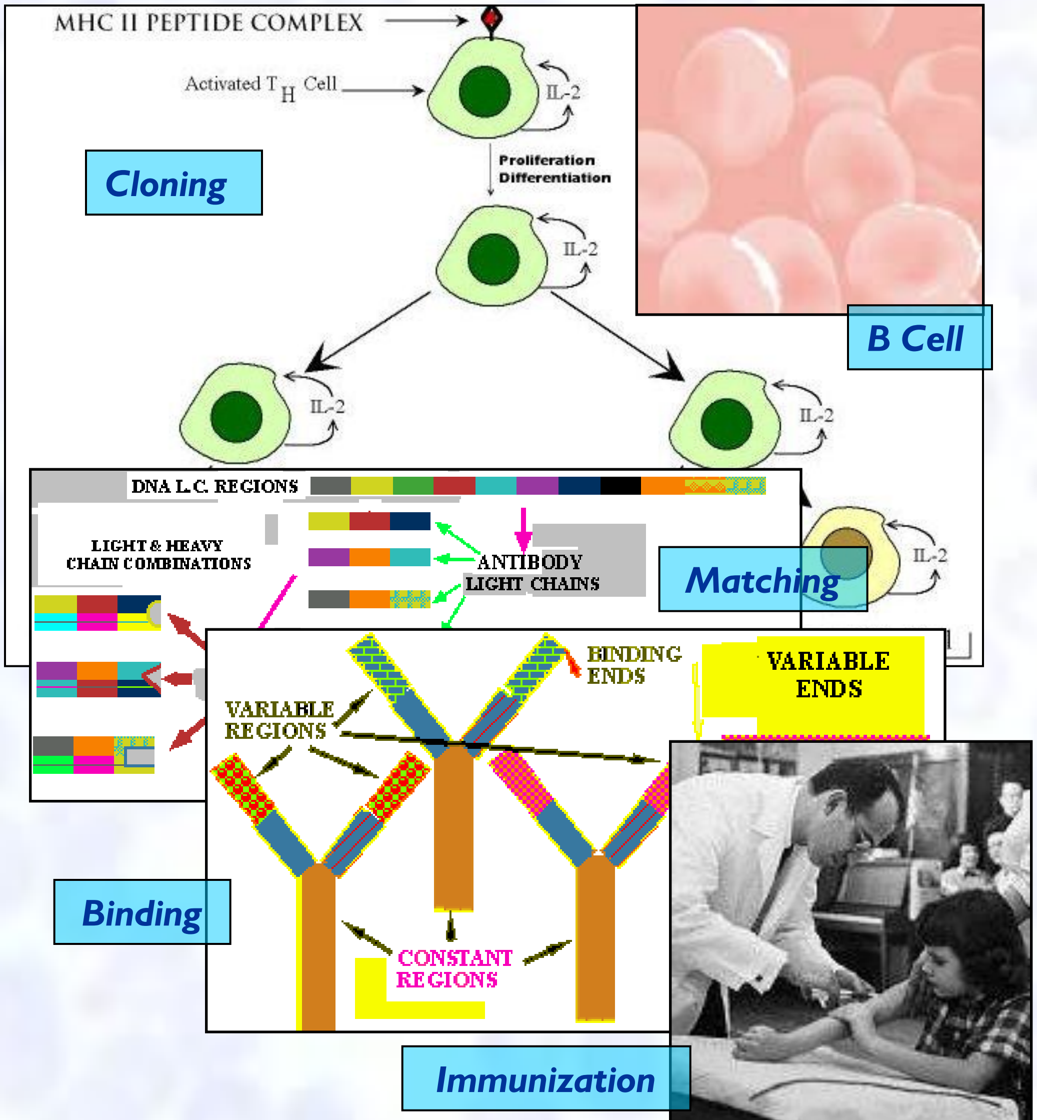
Lymphocyte killing tumor cell





Human lymphocyte

more simple Immunology



- An immune response includes the cloning of activated B cells, with some identical, and some slightly different offspring
- Antibodies recognize dangerous antigens through a complex matching and interaction process in their “binding regions”
- Once a foreign antigen is recognized, an *immunological memory* is created, which is the basis for modern vaccination
- Key concepts: matching, cloning, morphology, negative selection, self/non-self discrimination (Parham 2000)

Artificial Immune Systems

A very young subfield in artificial intelligence

Generally software based

Biologically inspired

Often applied to intractable fault detection problems

What are they good for?

- Anomaly detection in dynamic and complex environments
- Physical and network security applications
- Evolutionary and distributed information processing
- Scheduling and planning, constraint satisfaction?
- Modeling and design optimization

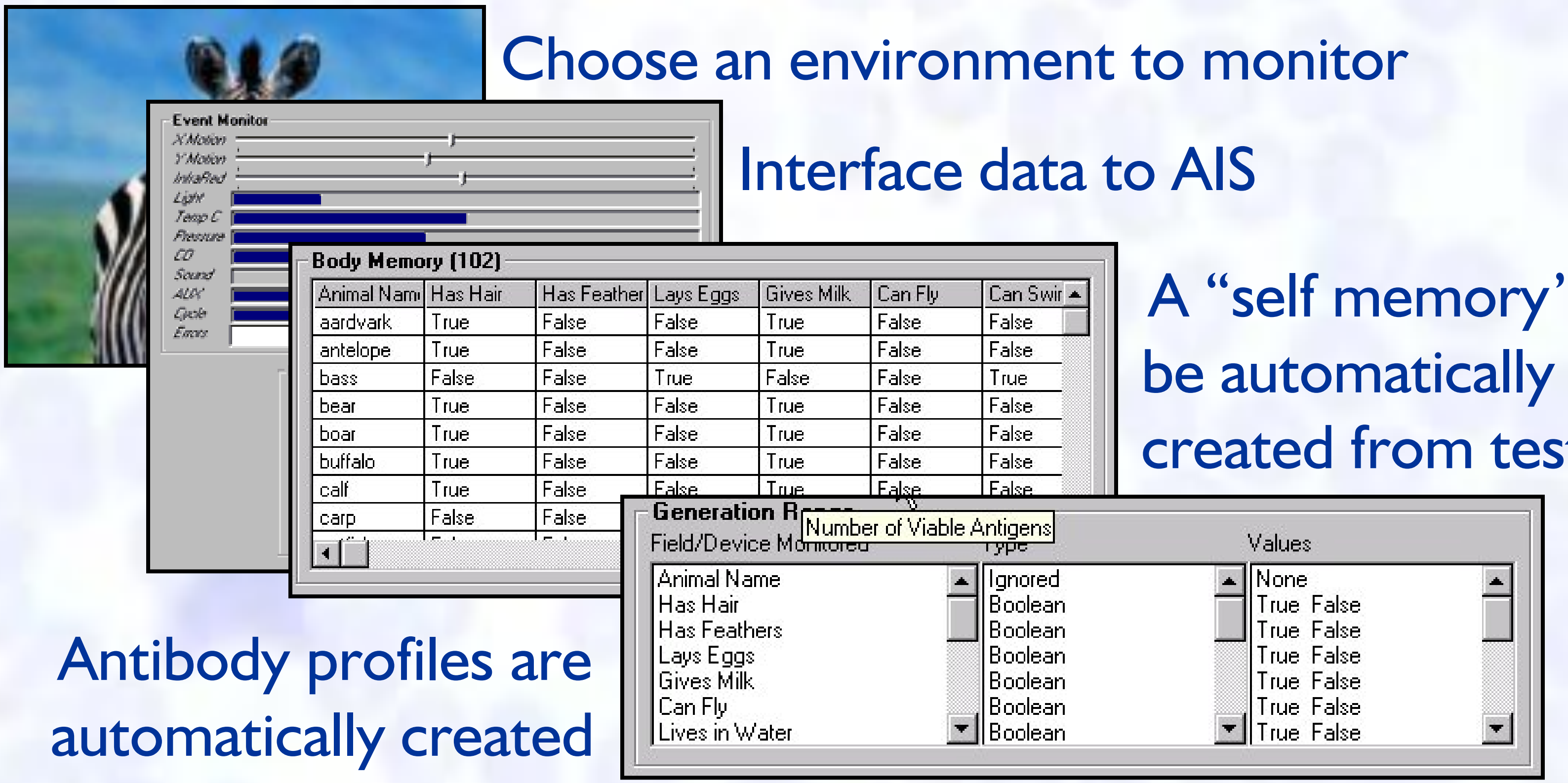
How do they work?

Learn an environment and generate antibodies → ***Interaction between antibodies and environment*** → ***Immune response*** → ***Cloning*** → ***Interaction between antibodies and environment***

Learn an environment and generate antibodies	Interaction between antibodies and environment	Immune response / Cloning
create the 'self'	*diagnosis*	*action* / *reproduction*
innate immunity		*acquired immunity*

How Do You Build Them?

- Like many AI systems, AISs are a technique for learning and reacting to an environment
- A cycle of observation, training, monitoring, and response…



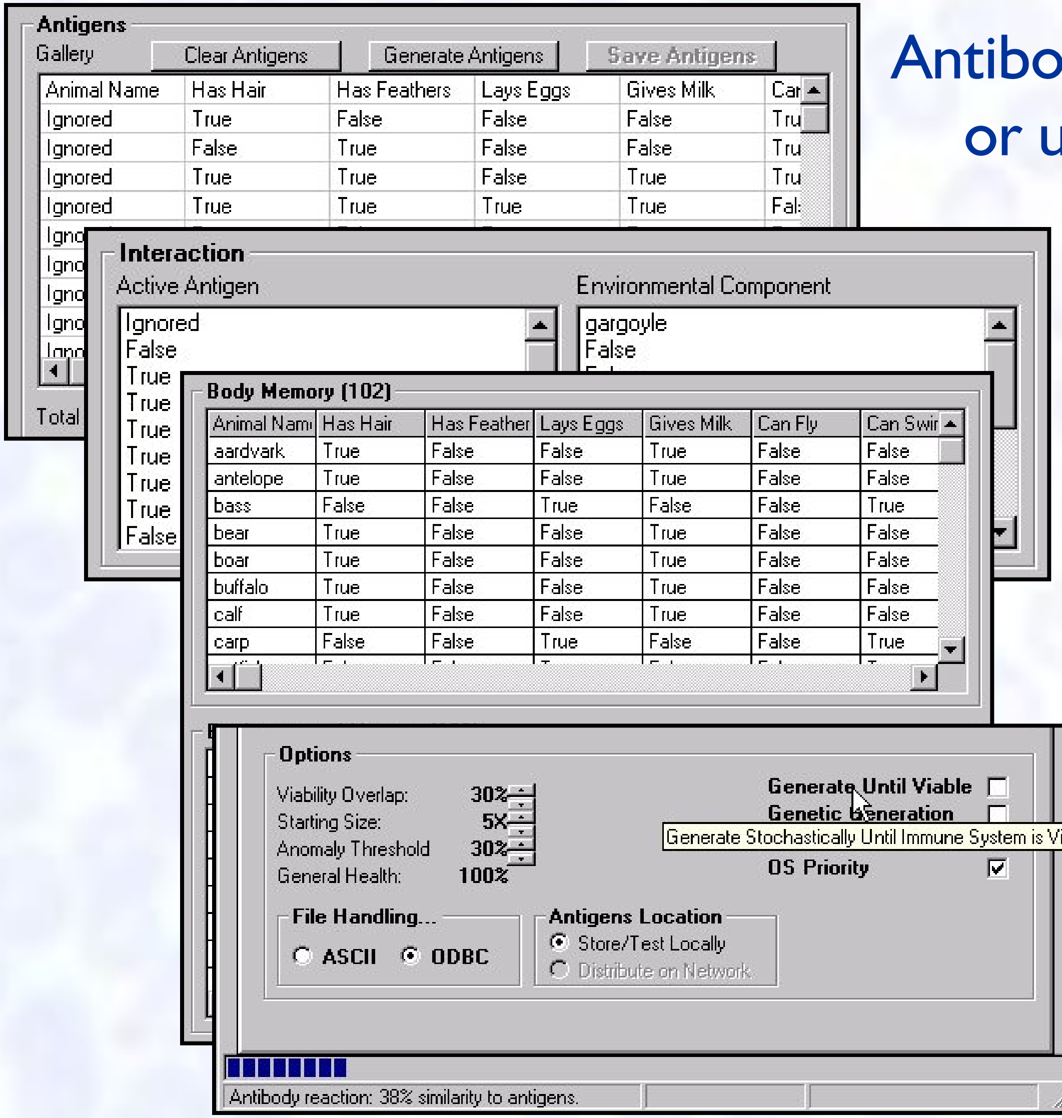
Choose an environment to monitor

Interface data to AIS

A “self memory” can be automatically created from test data

Antibody profiles are automatically created

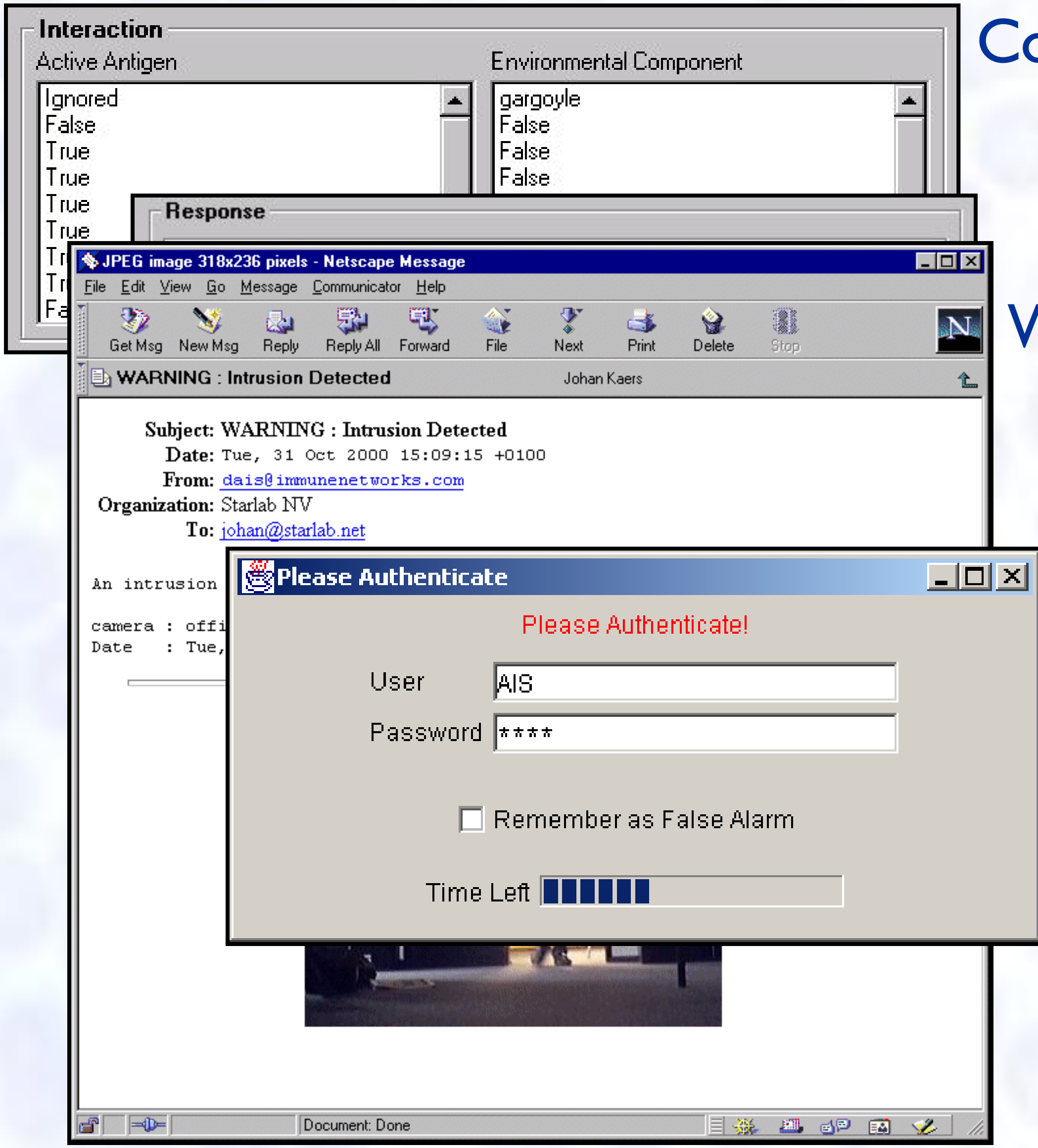
AIS as Semi-Unsupervised Classifier (needs no negative examples) with Continuous Learning



Antibodies are created at random or using a genetic algorithm

- Antibodies too closely matching the "self" or normal system states are killed off during training
- During monitoring the environment (represented as antigens) is compared to the self (represented as antibodies)
- According to immunological principles, an "immune response" may occur

How do they react?



Comparing "self" to the "environment" may trigger an *immune response*

Which may store the warning, contact an administrator, or react automatically

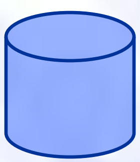
Immune response may also include the generation or network dissemination of advanced antibodies or *clones* with even better detection skills providing *acquired immunity*

What Are the Basics? Representation

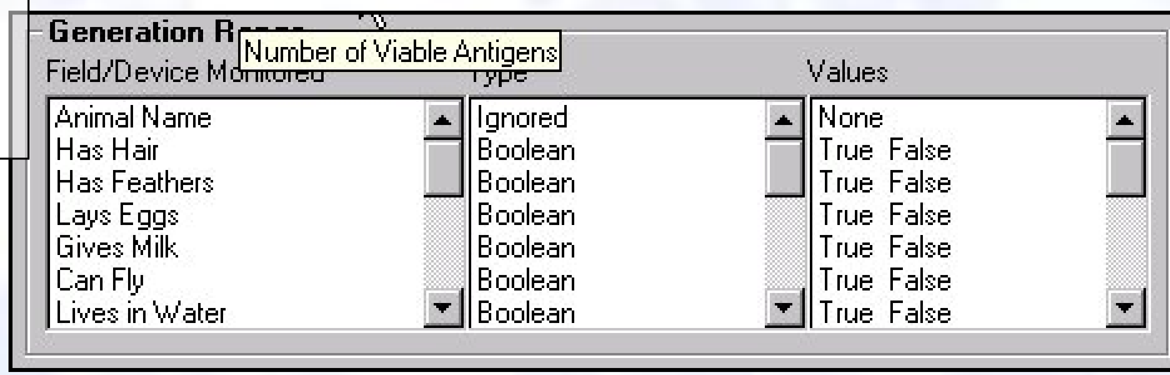
AISs systems in software are usually built like this:

- Decide upon a representation of the problem domain (direct, binary, symbolic, fuzzy) and solution ranges, and establish communication standards for the environment monitored *(all examples in this presentation are taken from the AIAI AIS Shell System)*

Database of animals in the zoo



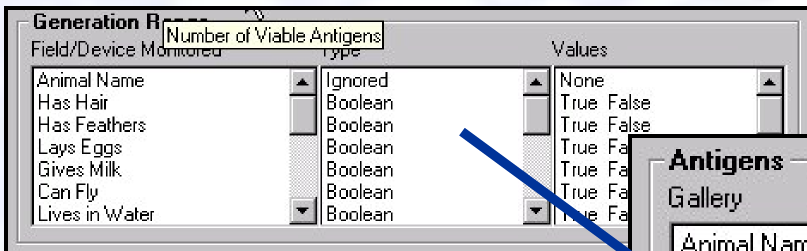
ZOO.DB



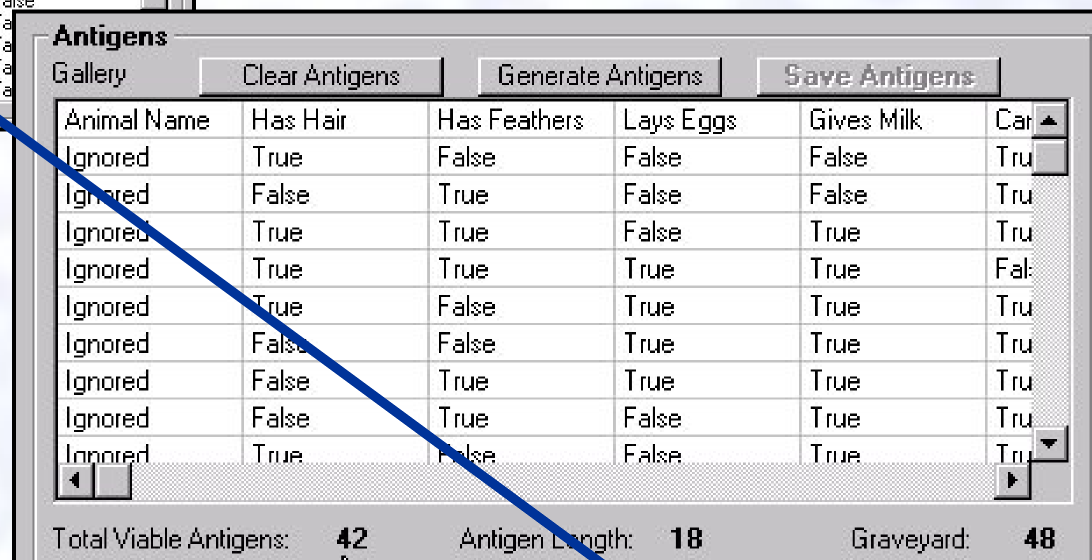
How can we protect the animals in a zoo (database) when we are introducing new, unknown animals?

Basics: Database of Antibodies

- Create an initial population of antibodies either randomly or using statistical or GA methods and remove antibodies too closely matching the “self” (here, animals in a zoo)

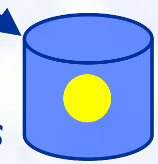


Creation of antibody database



Animal Name	Has Hair	Has Feathers	Lays Eggs	Gives Milk	Car
Ignored	True	False	False	False	Tru
Ignored	False	True	False	False	Tru
Ignored	True	True	False	True	Tru
Ignored	True	True	True	True	Fal
Ignored	True	False	True	True	Tru
Ignored	False	False	True	True	Tru
Ignored	False	True	True	True	Tru
Ignored	False	True	False	True	Tru
Ignored	True	False	False	True	Tru

*Antibodies form the collective memory of natural interaction with ‘self’; **autoimmunity** is the failure of an organism to recognize its own constituent parts as self, which allows an immune response against its own cells and tissues.*

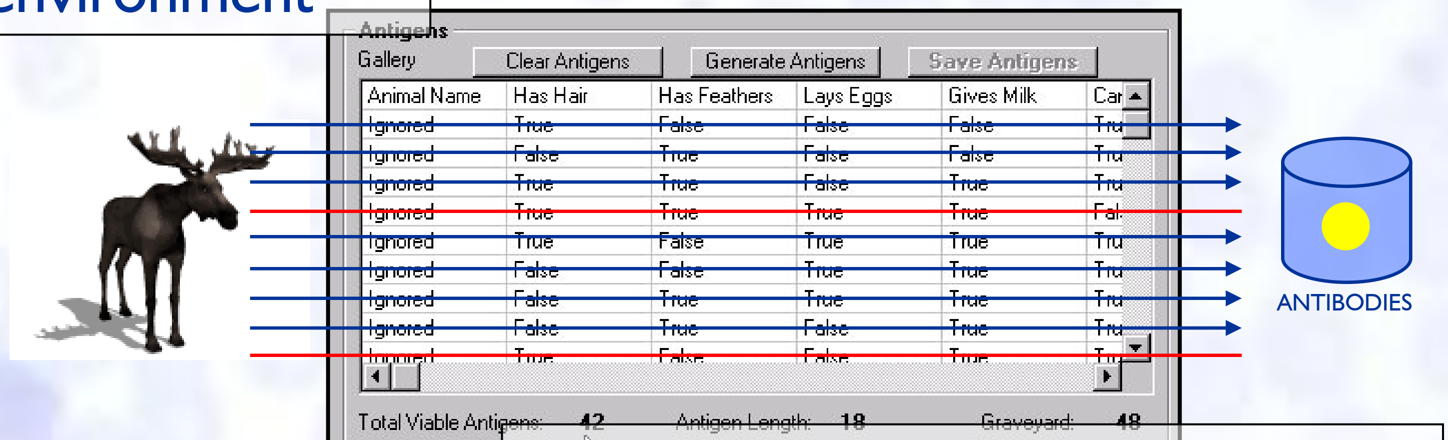


ANTIBODIES

Basics: Learning & Matching

- Monitor the environment (which creates data samples for learning), and remove any antibodies which match the environment samples too closely
- As in other ML methods, we are looking for the smallest collection of classifiers (antibodies) which abstract the system’s knowledge or logic. In AIS, too many antibodies = overfitting.

Learning of a normal environment



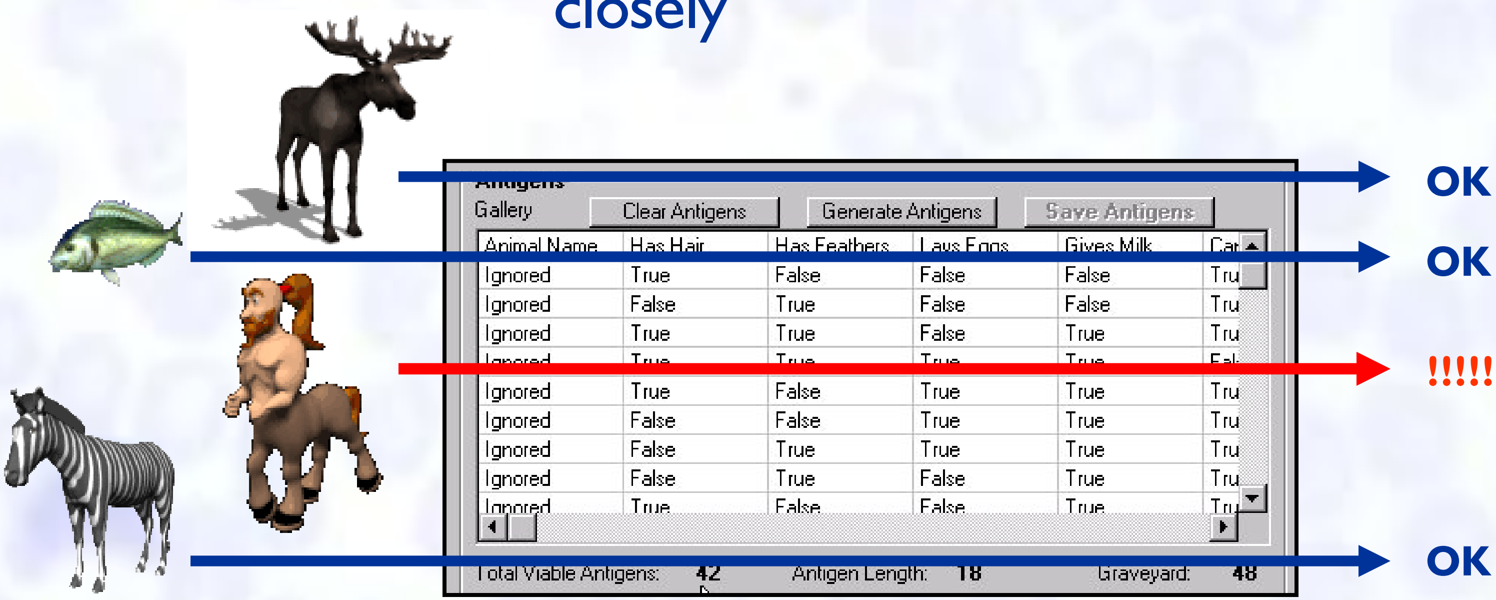
Animal Name	Has Hair	Has Feathers	Lays Eggs	Gives Milk	Car
Ignored	True	False	False	False	Tru
Ignored	False	True	False	False	Tru
Ignored	True	True	False	True	Tru
Ignored	True	True	True	True	Fal
Ignored	True	False	True	True	Tru
Ignored	False	False	True	True	Tru
Ignored	False	True	True	True	Tru
Ignored	False	True	False	True	Tru
Ignored	True	False	False	True	Tru

Database of environmental knowledge = innate immunity

Basics: Monitoring

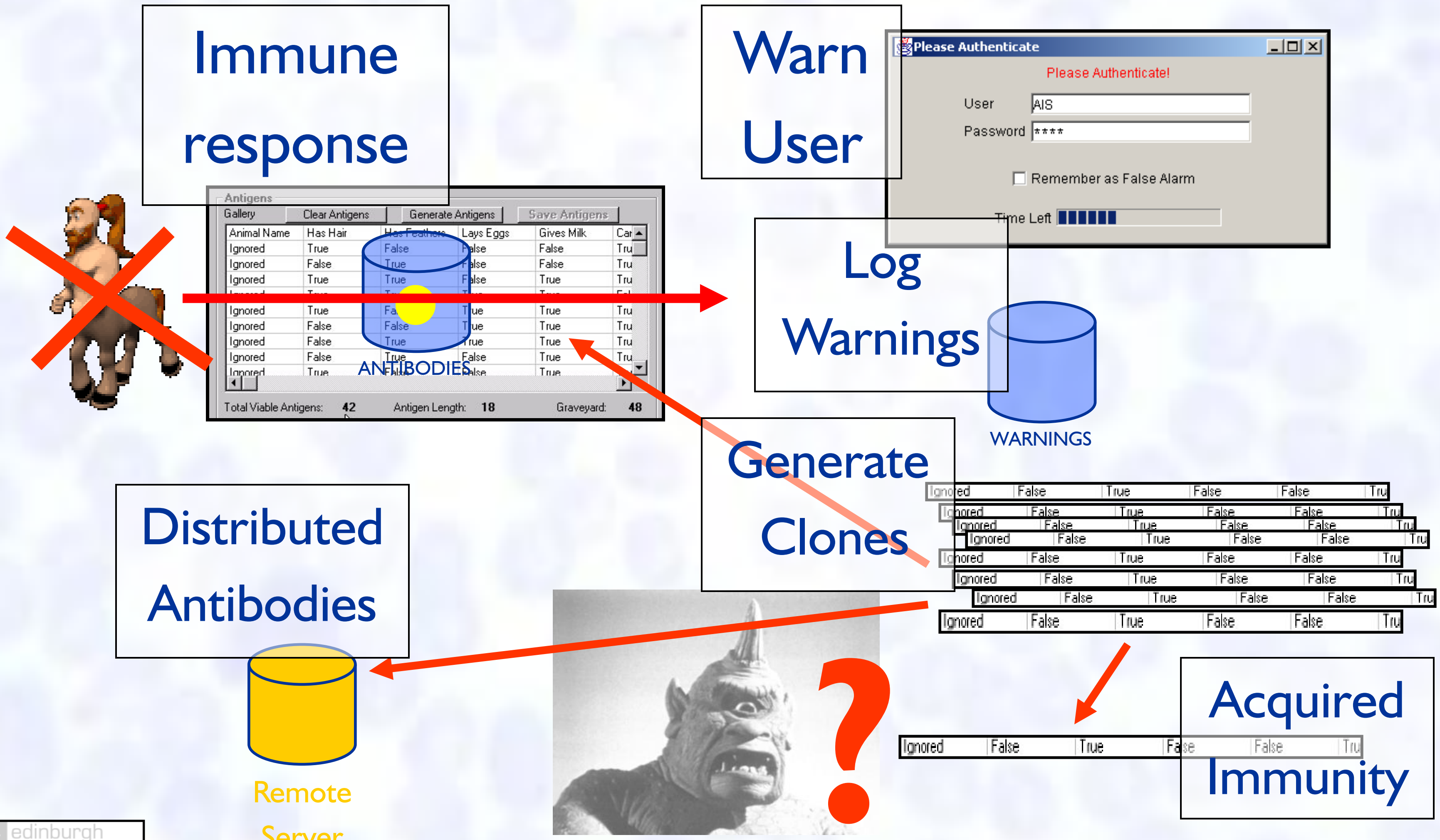
Monitoring of 'live' environment

- After a suitable length of time, allow the remaining antibodies to begin monitoring their environment and generating an *immune response* when they match the environment too closely

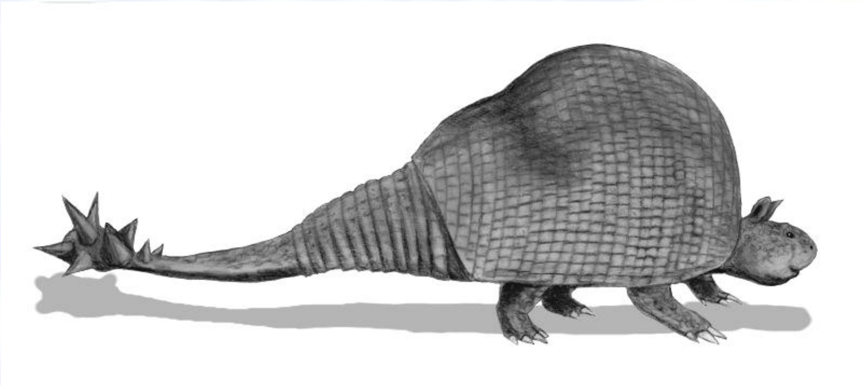


Basics: Immune Response

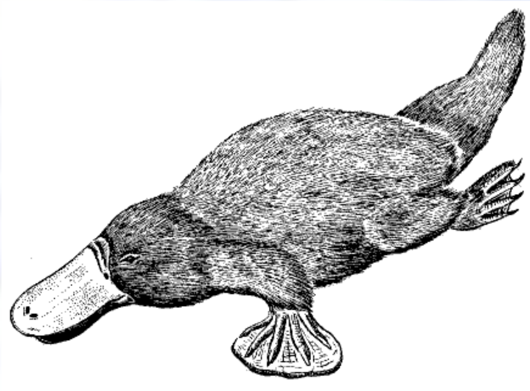
- Create clones and mutations of antibodies which caused an immune response and distribute them throughout the system; also create occasional random new antibodies and introduce them into the population



I know! What about…



Doedicurus clavicaudatus (prehistoric glyptodont): enormous armoured mammal. *Normal.*



Platypus (monotreme): egg-laying, venomous, duck-billed, beaver-tailed, otter-footed mammal. *Outlier.*

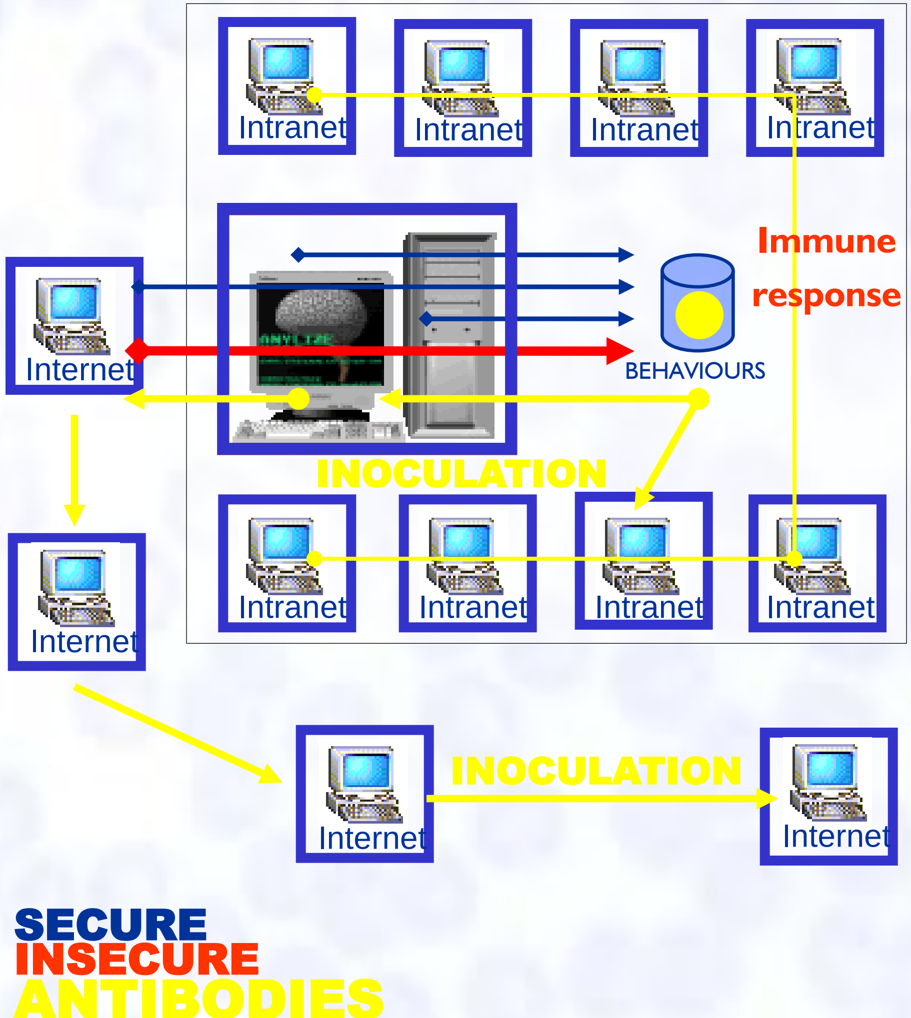
Did the AIS learn some of the basic stable states of earthly biology?

Some practical and applied examples…

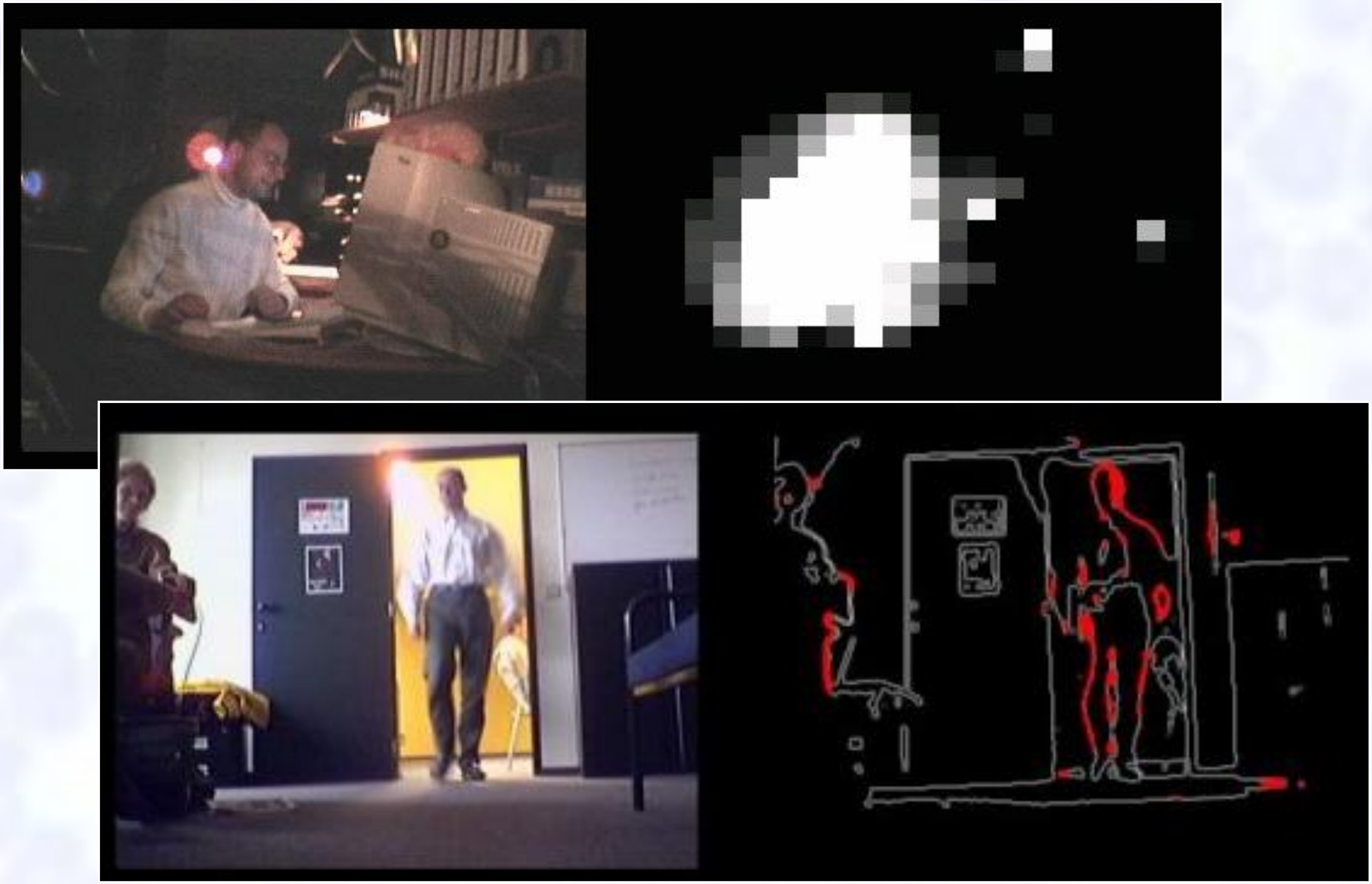
A More Practical Example
Behavioural Based Network Security

- Java VM or OS embedded profiler creates database entries linking processes, threads, and resources to *behaviours*
- AIS system learns normal behaviours and blocks unusual behaviour (after asking user or administrator to verify)
- Antibodies which caused an immune response clone to the local neighbourhood and internet instantly giving protection against new viruses and attacks; clone diversity ensures vigilance against attack polymorphism
- **No virus signature needed for recognition**

(Hofmeyr 1999, Kim, Bently 1999)

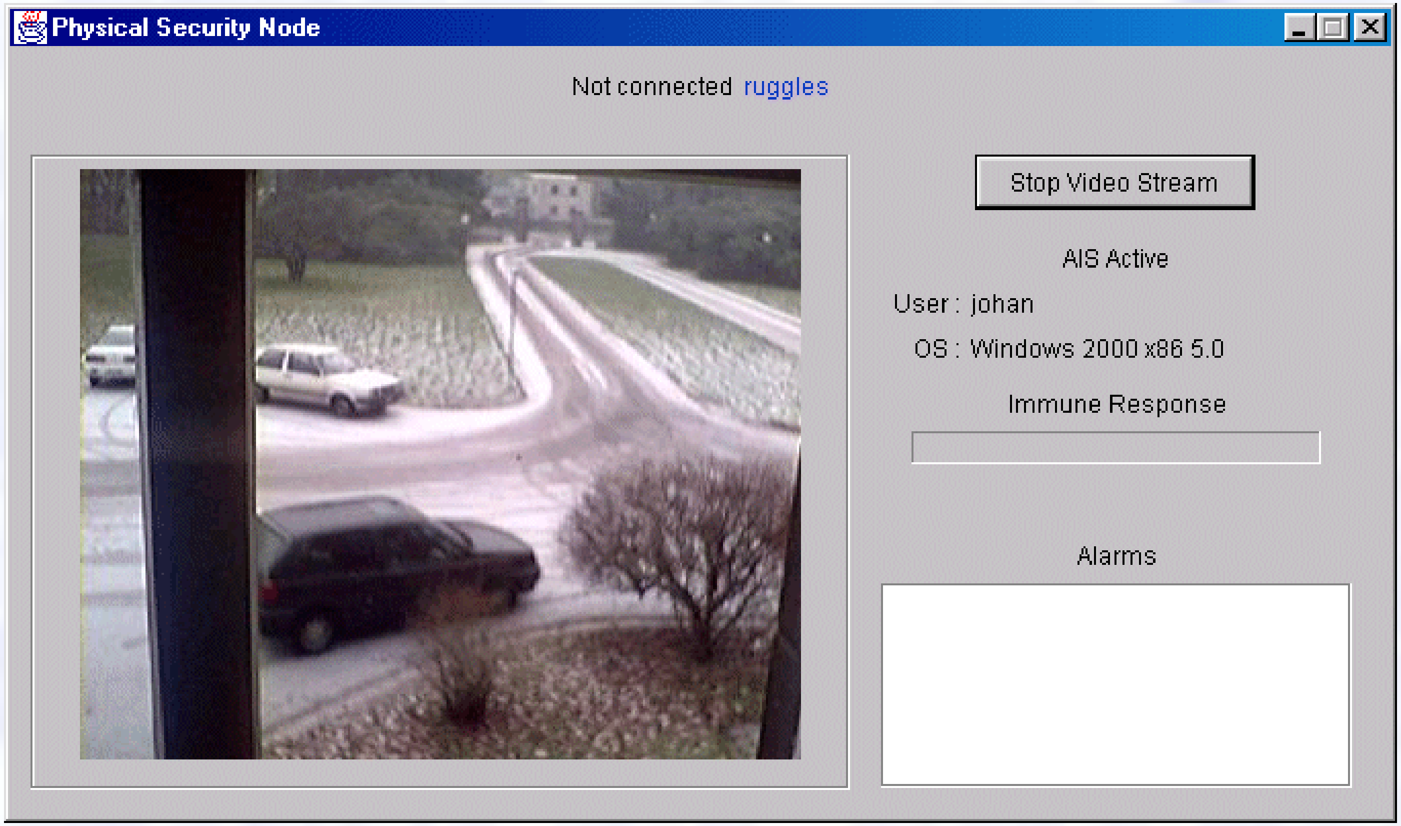


AIS Research: Physical Security



Advances in AIS based video motion detection and learning

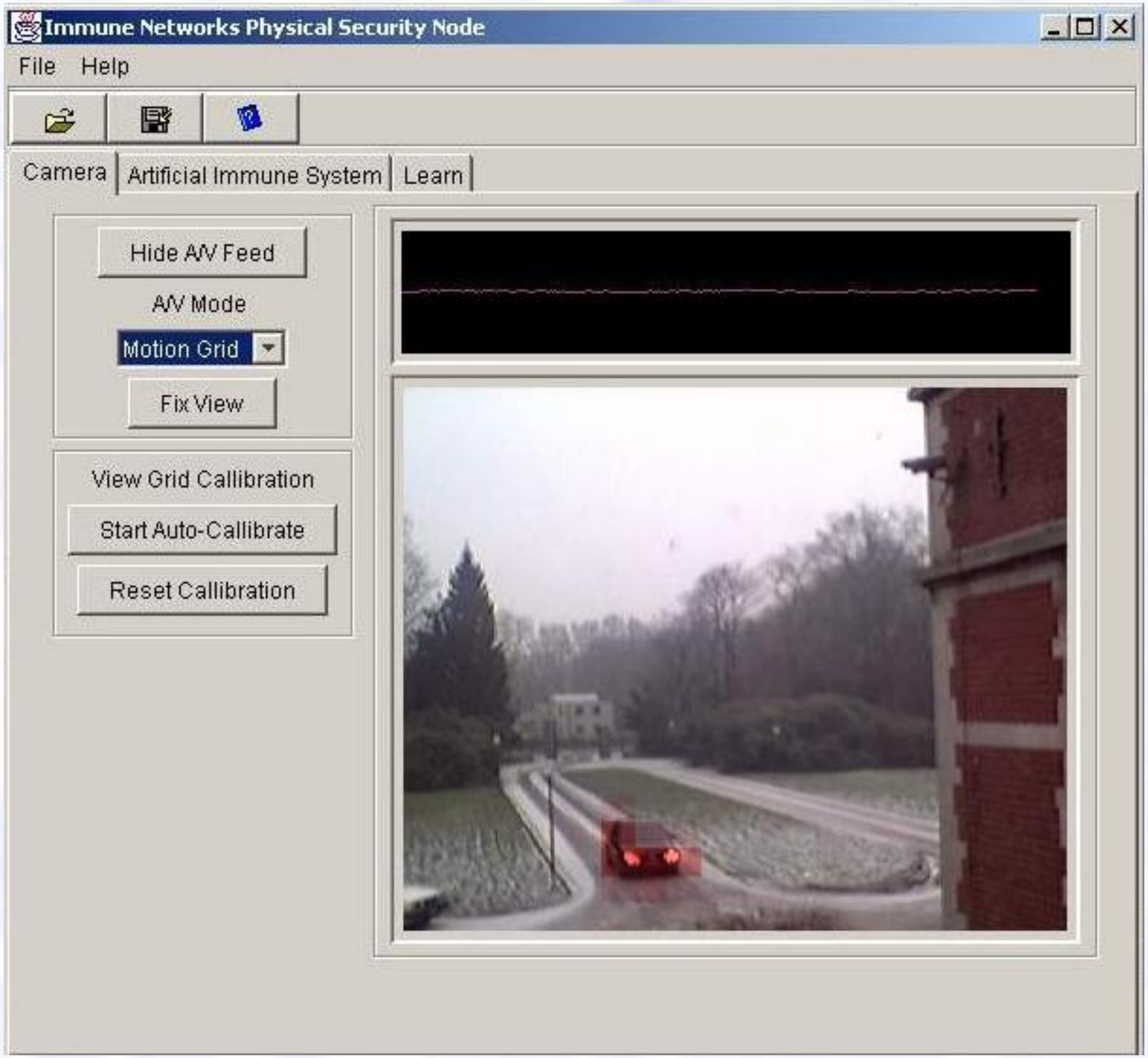
AIS For Advanced Video Motion Detection



Multi-site real-time streaming video and sound integrated over standard networks and across platforms; video transformed into a variable cellular automata grid that encodes behavioural and regional information

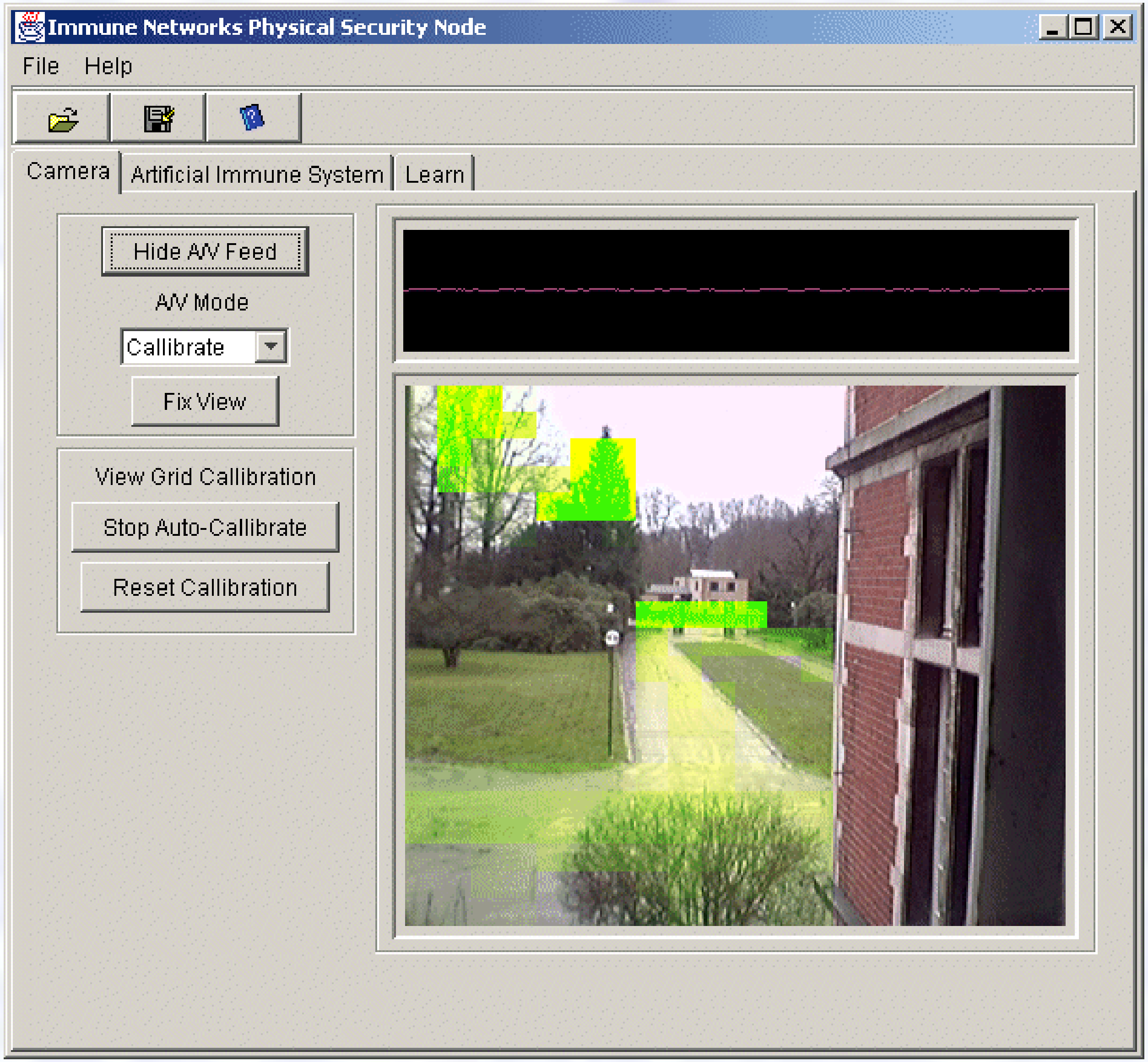
AIS For Advanced Video Motion Detection

- Behaviours are compiled (compressed) in CA structures and mathematical grids and form the input to the AIS shell which is generalizing across cameras and sites



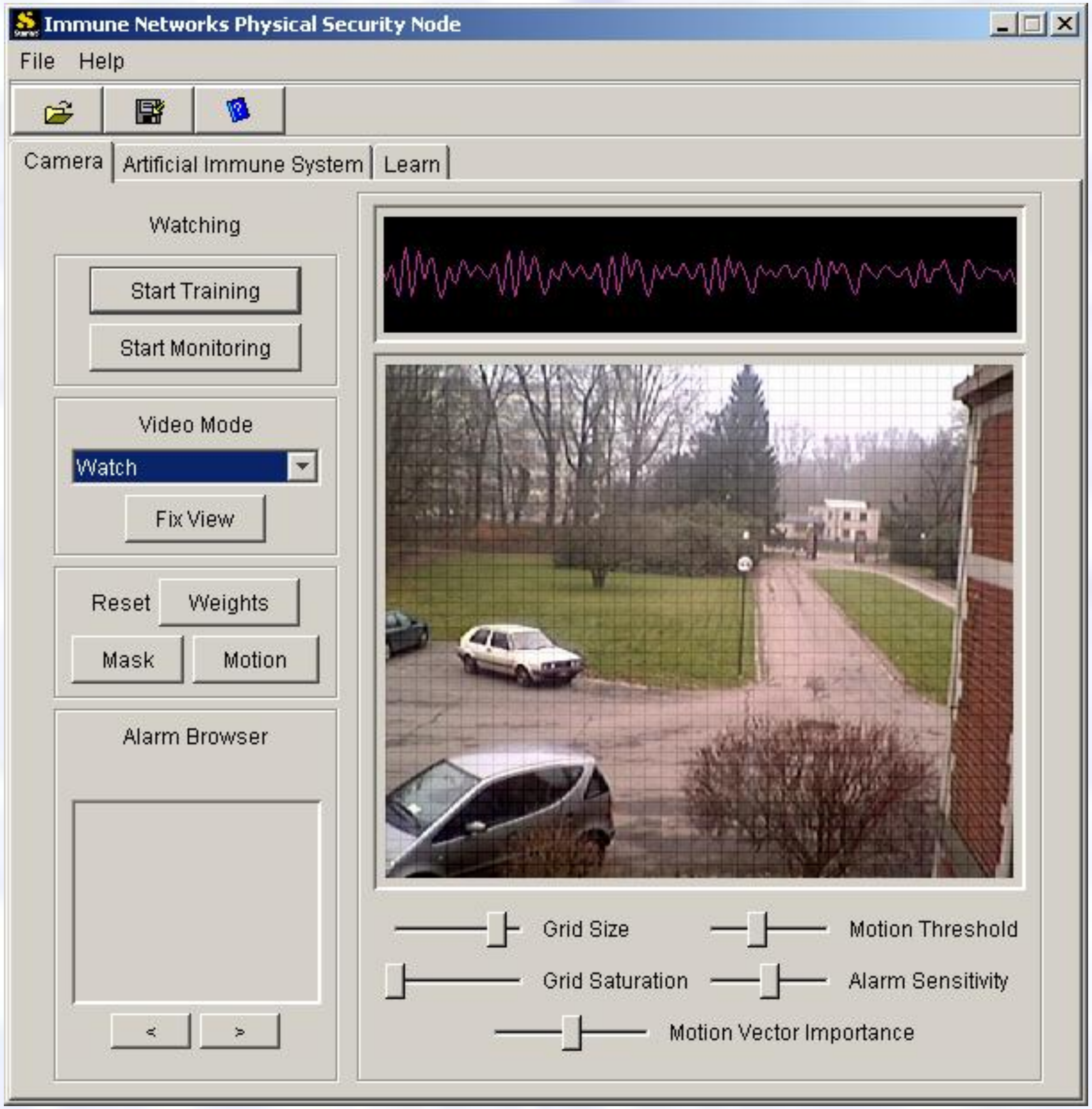
AIS For Advanced Video Motion Detection

Advanced environmental learning (e.g. abstracting of behavioural primitives, time series sensitivity, sound analysis)



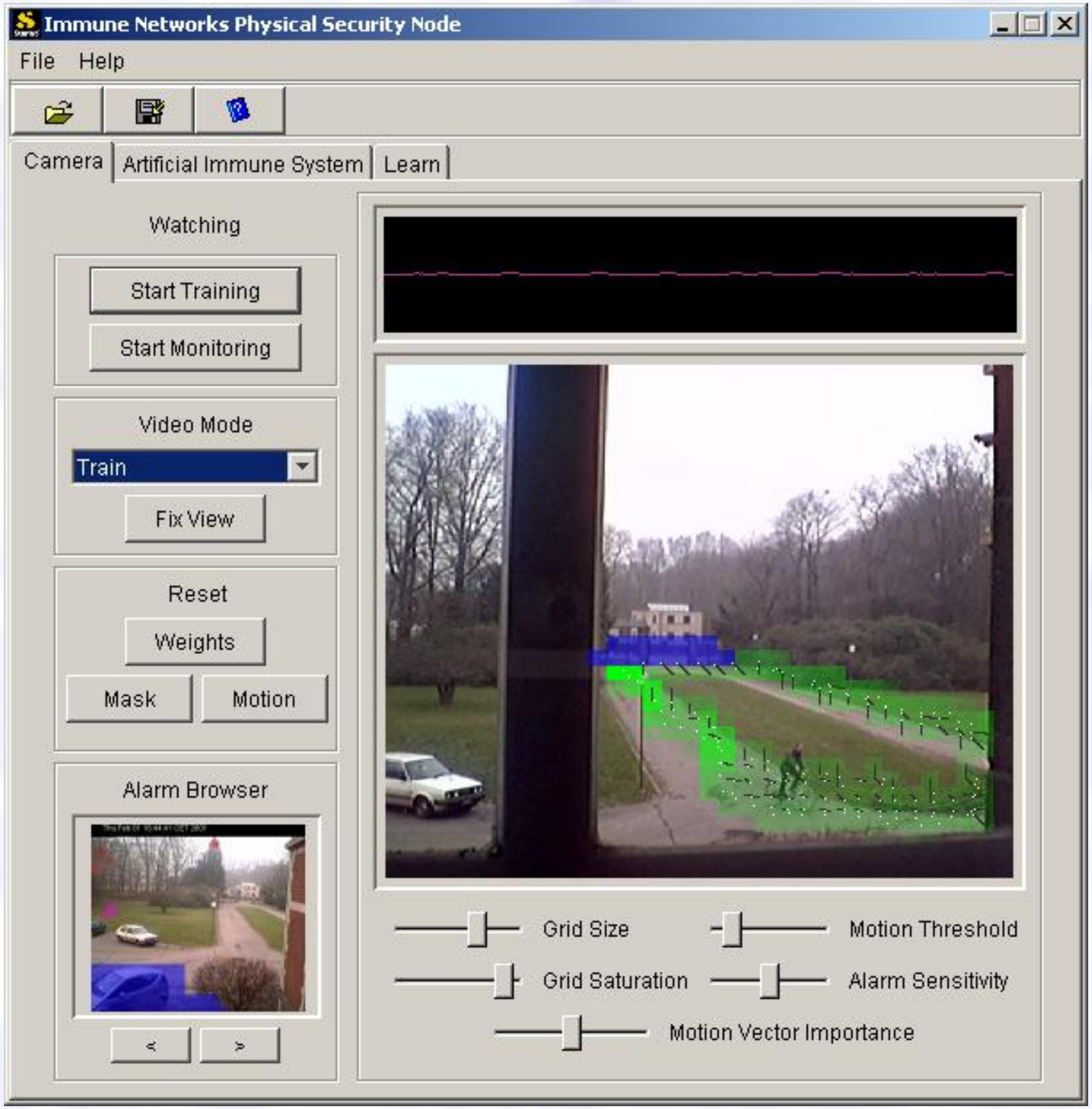
AIS For Advanced Video Motion Detection

Variable overlay grid and user controls added



AIS For Advanced Video Motion Detection

CA/Grid-based motion vector analysis and weighting developed; mask blocking, magnification, and alarm browser added



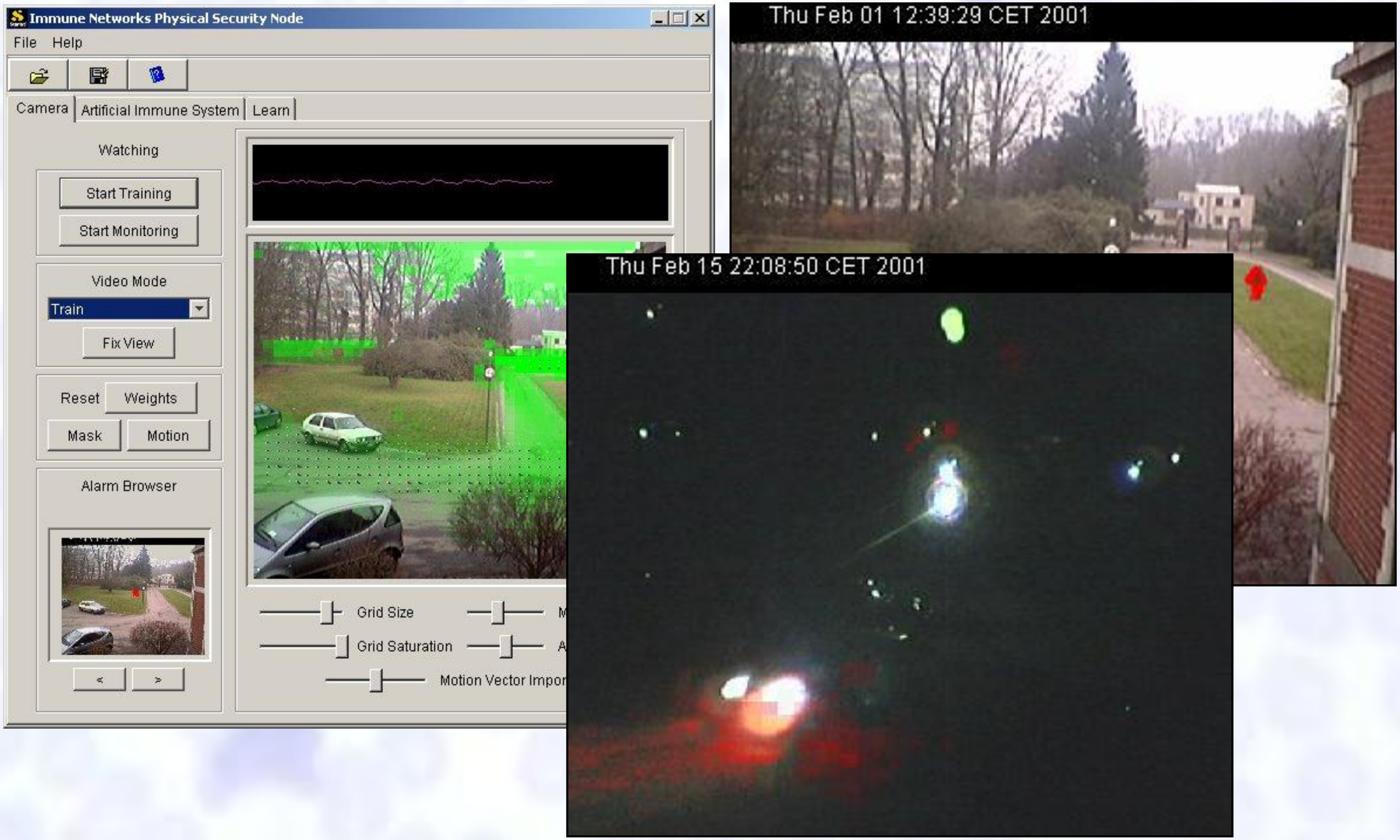
AIS For Advanced Video Motion Detection

Some alarms

AIS For Advanced Video Motion Detection

More alarms

AIS For Advanced Video Motion Detection



Complete installation testing and validation including office settings (examples?) and 3D camera/CA synthesis trials

AVMD: Some More Examples

Warehouse: AIS learns workers take shortest path to targets, intruders take edge paths and pause at junctions…

Museums: AIS learns where people stand and how quickly they move and what areas are forbidden…

Office: AIS learns that people come and go and sit and talk and eat and drink, but people do not come in through windows or ceiling, do not shout or stand on tables or fire guns or smoke…

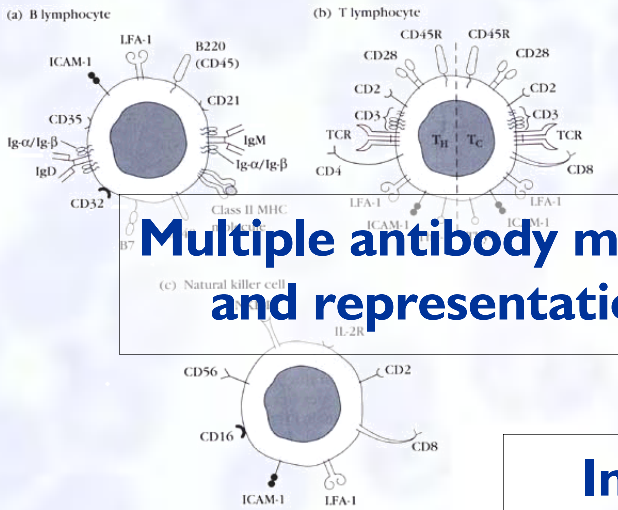
Airport: AIS can learn speed and angle of approaches for different size aircraft, and watch for strange behaviours on the aprons and runways (birds, runaways, planes off the apron guides, people running, errant luggage, fires)…

Military…

Research: Building a Better Shell System

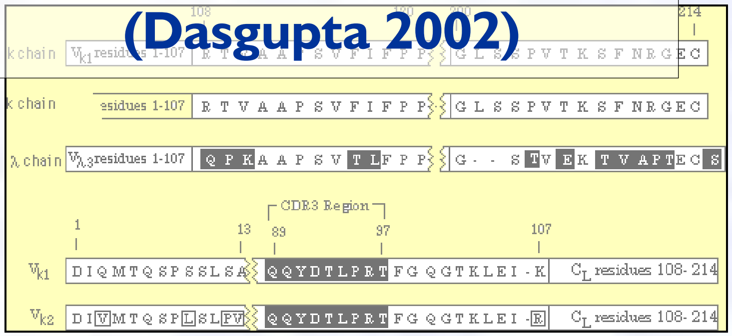
AIS Next Generation Shell (NG)

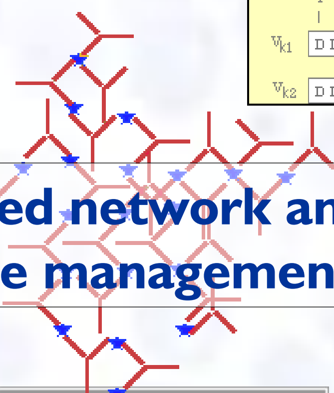
AIS Shell NG features include:



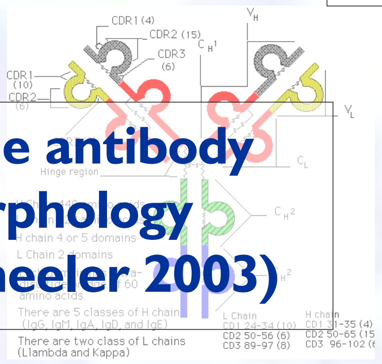
Multiple antibody models and representations

Multiple matching algorithms and fuzzy operators (Dasgupta 2002)

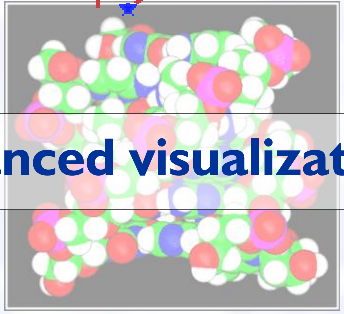




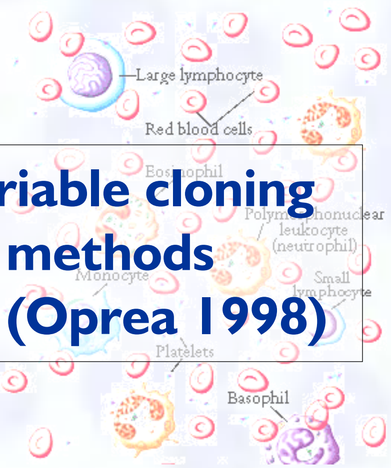
Integrated network and database management



Variable antibody morphology (Wheeler 2003)

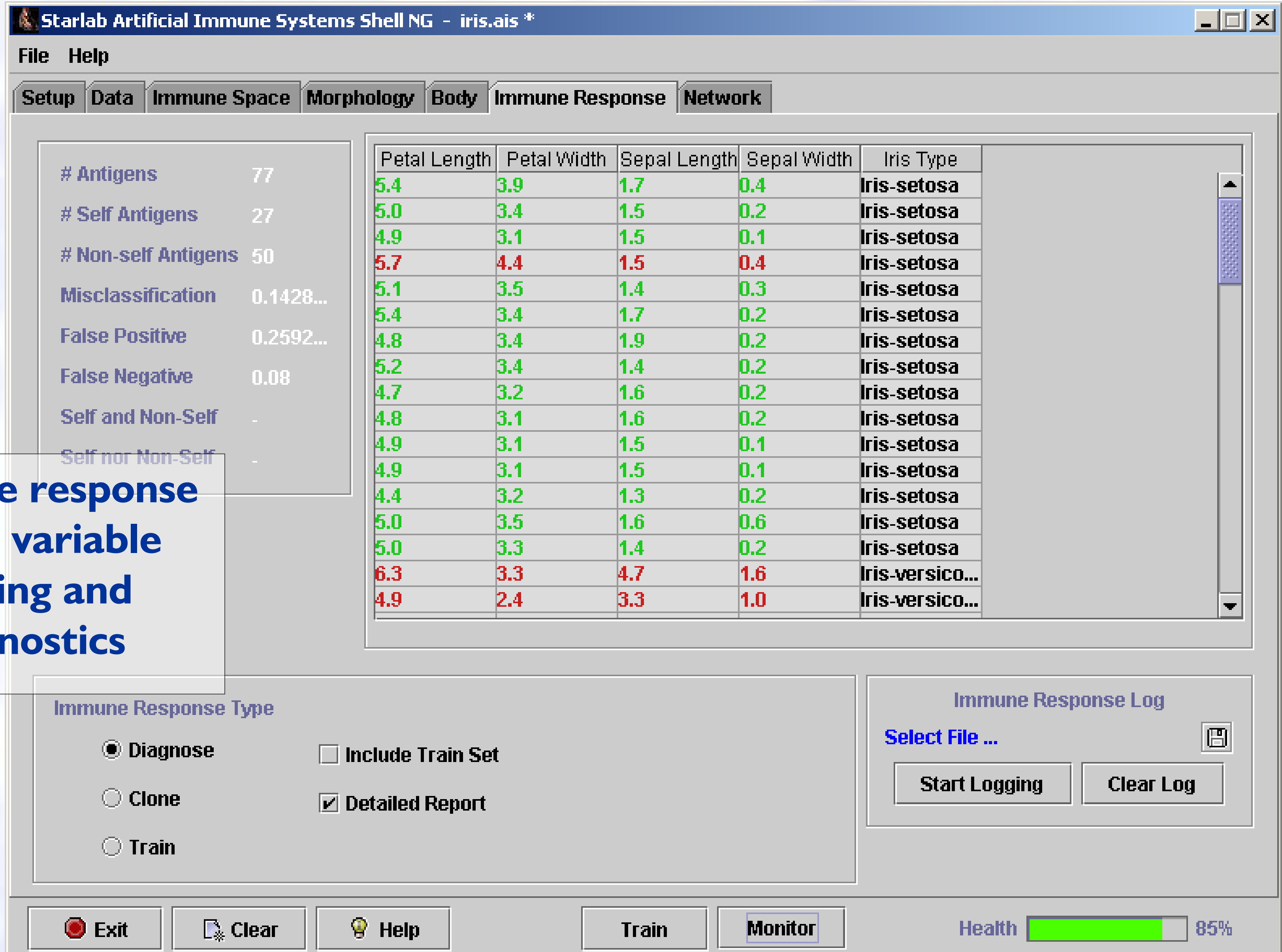


Advanced visualization



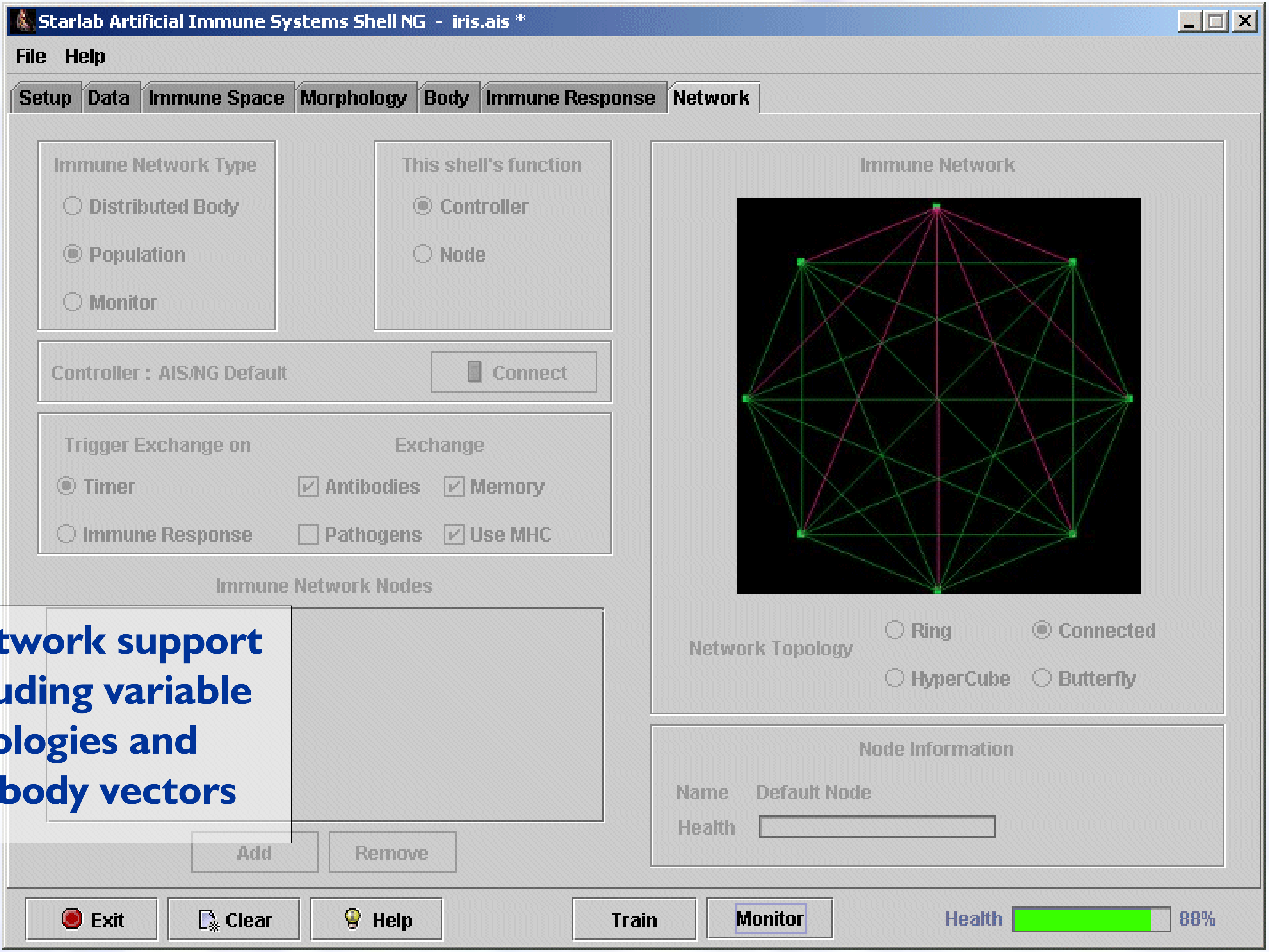
Variable cloning methods (Oprea 1998)

Next Generation Shell



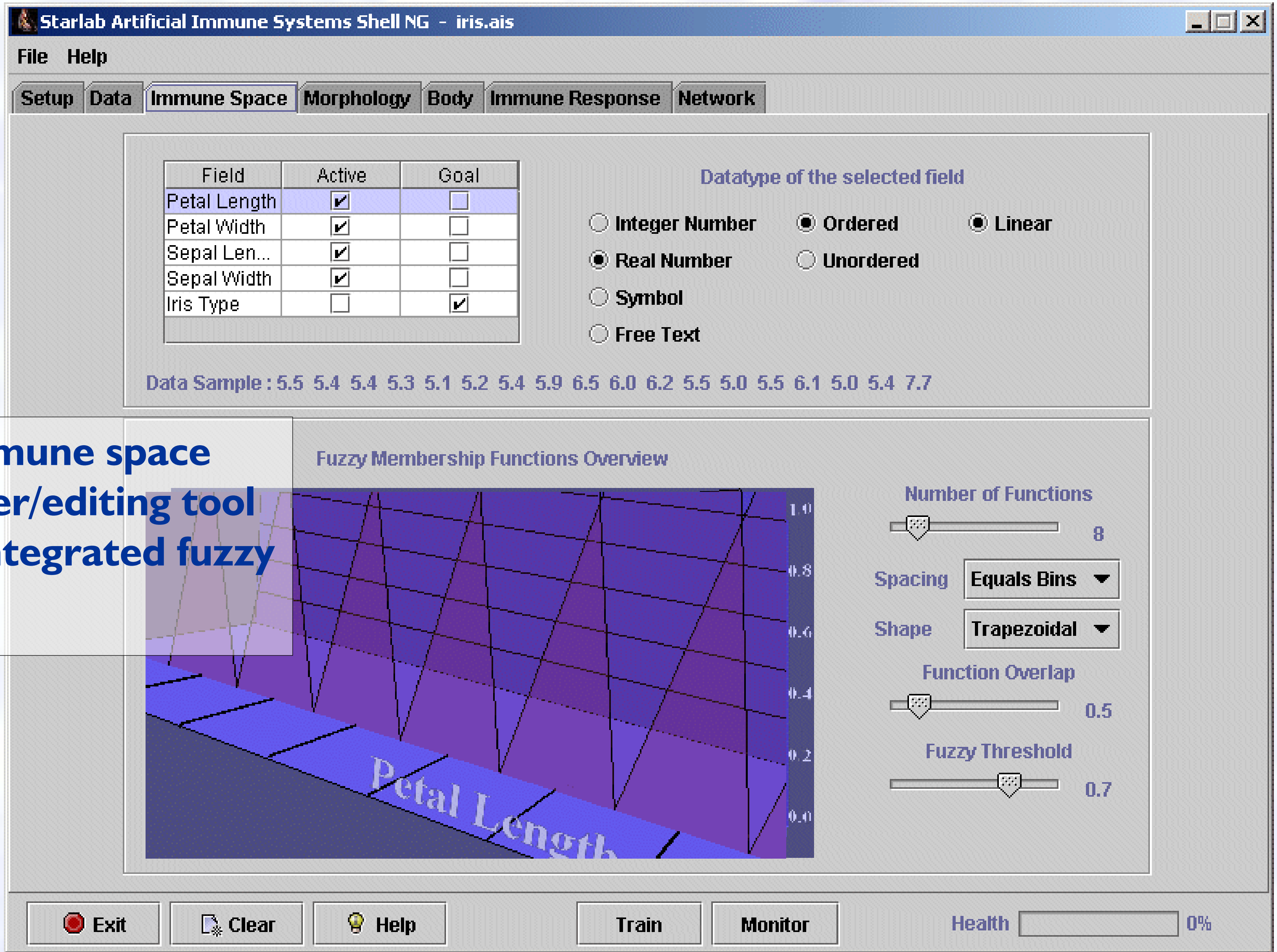
Immune response with variable cloning and diagnostics

Next Generation Shell



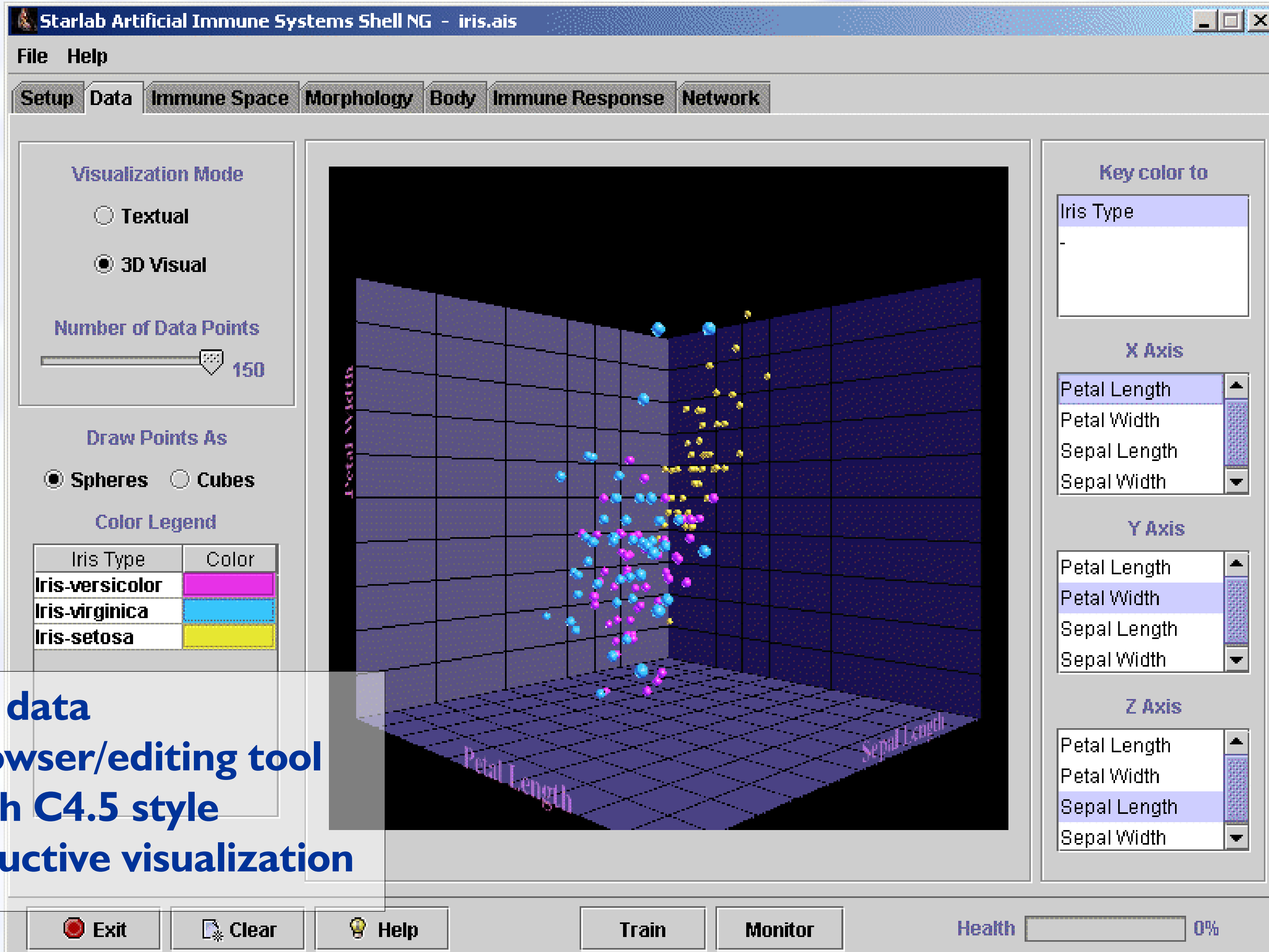
Full network support including variable topologies and antibody vectors

Next Generation Shell



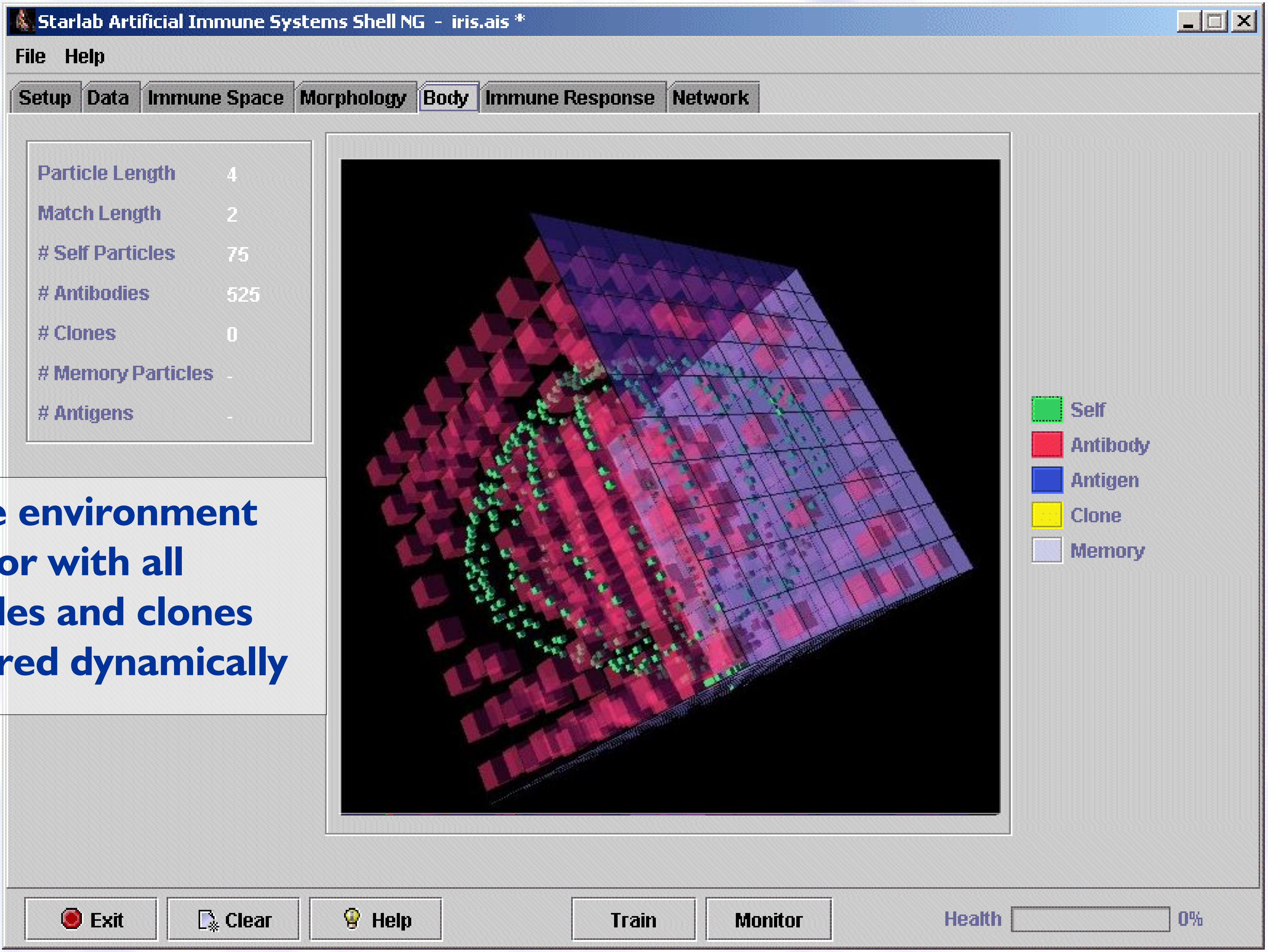
Visual immune space browser/editing tool with integrated fuzzy engine

Next Generation Shell



Visual data browser/editing tool with C4.5 style inductive visualization

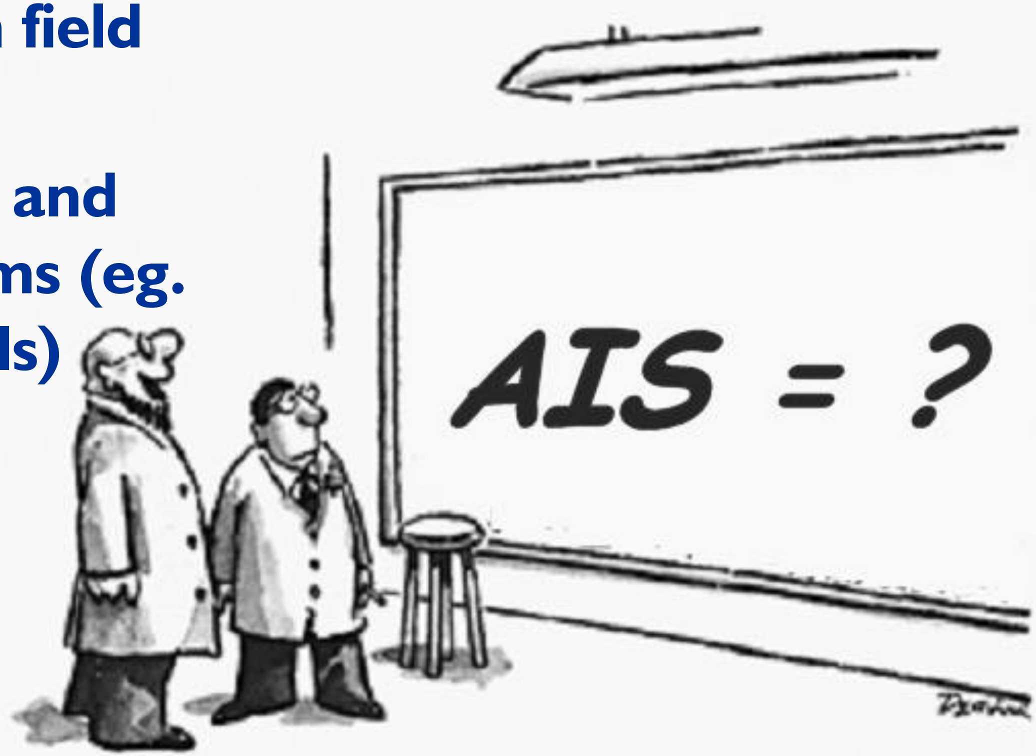
Next Generation Shell



Real time environment monitor with all particles and clones rendered dynamically

Conclusions and Open Questions

- Very young and wide open field (1986)
- Role of biological diversity and plausibility in AIS systems (eg. messenger, memory cells)
- Role of morphology and representation
- Matching algorithms and methodologies
- What applications will AIS systems really excel at?



"Hey, no problem!"

EXCITING: Contributing to the birth of a new field

Thanks to Nada and JSI!

Contact:

Richard Wheeler (rw@edinburghscientific.com)

Download an AIS shell system:

http://www.inf.ed.ac.uk/research/isdd/

AIS Shell NG – email me

Paper "*The Effect of Antibody Morphology on Non-self Detection*" (Kaers, Wheeler, Verrelst 2003) also at http://tinyurl.com/3wbcjct

Questions?