Autonomous Intelligent Systems

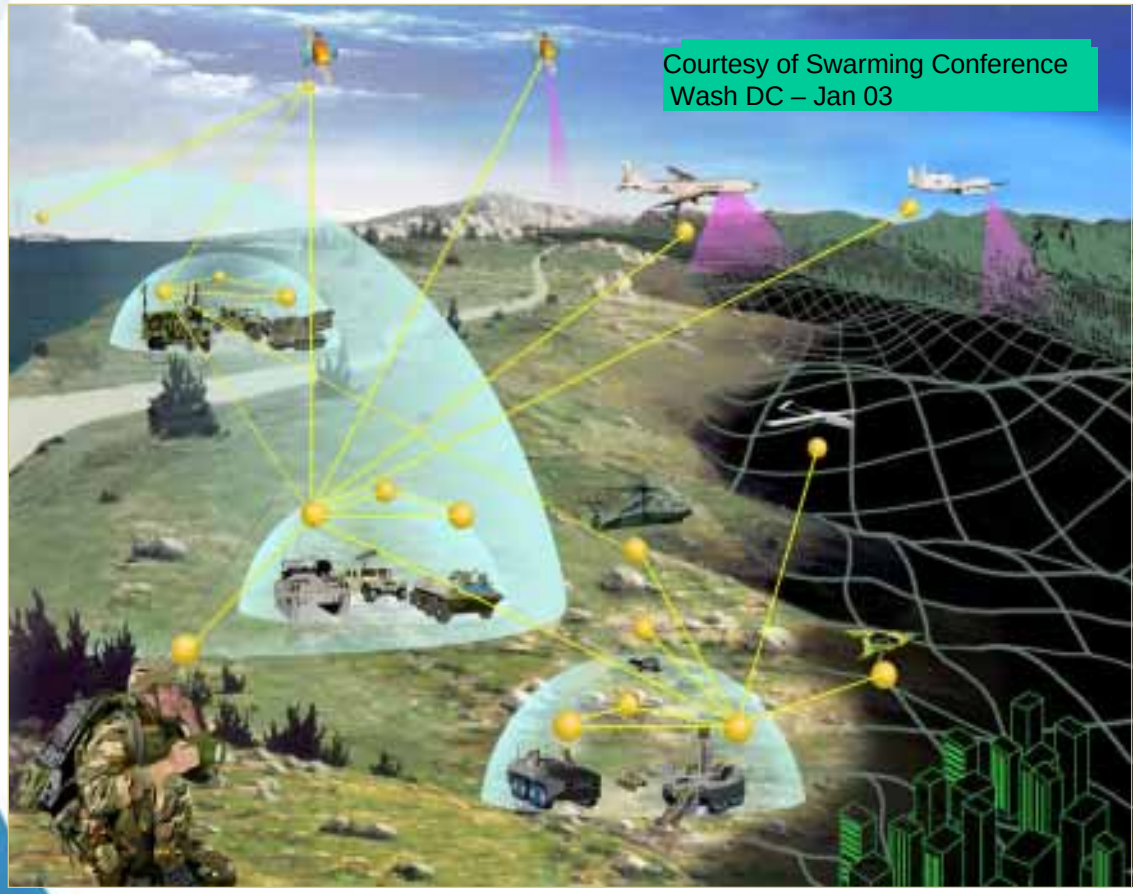
Collective Intelligence in NCW

Bruce L. Digney
Tactical Vehicle Systems Section

Defence Research and Development Canada
Recherche et développement pour la défense Canada
Canada

Autonomous Intelligent Systems in Net Centric Warfare

Network Centric Warfare



The Highly Connected World of NCW

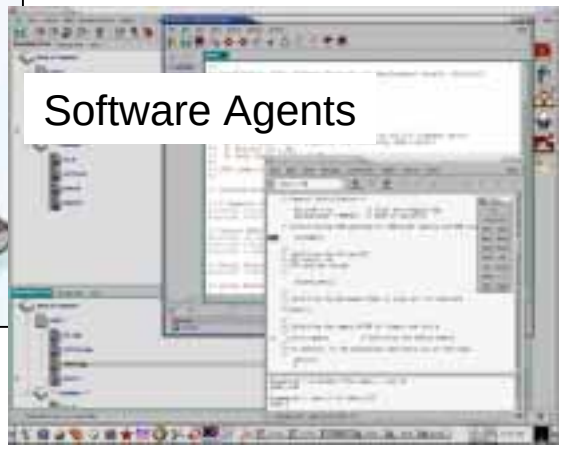
High Connectivity
- Latencies/Bandwidth?
- Observable?
- Controllable?
- Information sharing?

Decision Makers
- Humans
- Intelligent vehicles
- Software agents

Decision Mechanisms
- Human intelligence
- AI planners
- Machine learning

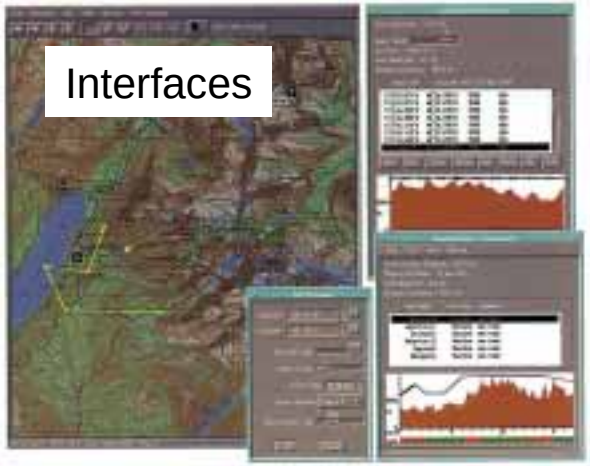
How to Coordinate?
- Centralized
- Distributed
- Hybrid collective

AIS entities in NCW



Develop Vehicles and Systems

- Adaptive
- Coordinated
- Autonomous
- Work with humans within NCW



Roles, Reality and Potential

Why AIS? Will AIS be good enough?

Valued Traits

- Persistent
- Ubiquitous
- Expendable
- No physiological limitations
- Fearless
- Losses more acceptable

Requirements

- Independence
- Adaptive
- Direct able
- Self Directed
- Coordination

Military Requirements

- High level of performance
- Robot must be able to win
- Robots must earn high level of trust

Evolving Roles

Roles 2005

- Remote sensing
- Mine detection
- Planning aids

Roles 2025

- Combat vehicles
- Dismounted solider
- Fast adaptive planning

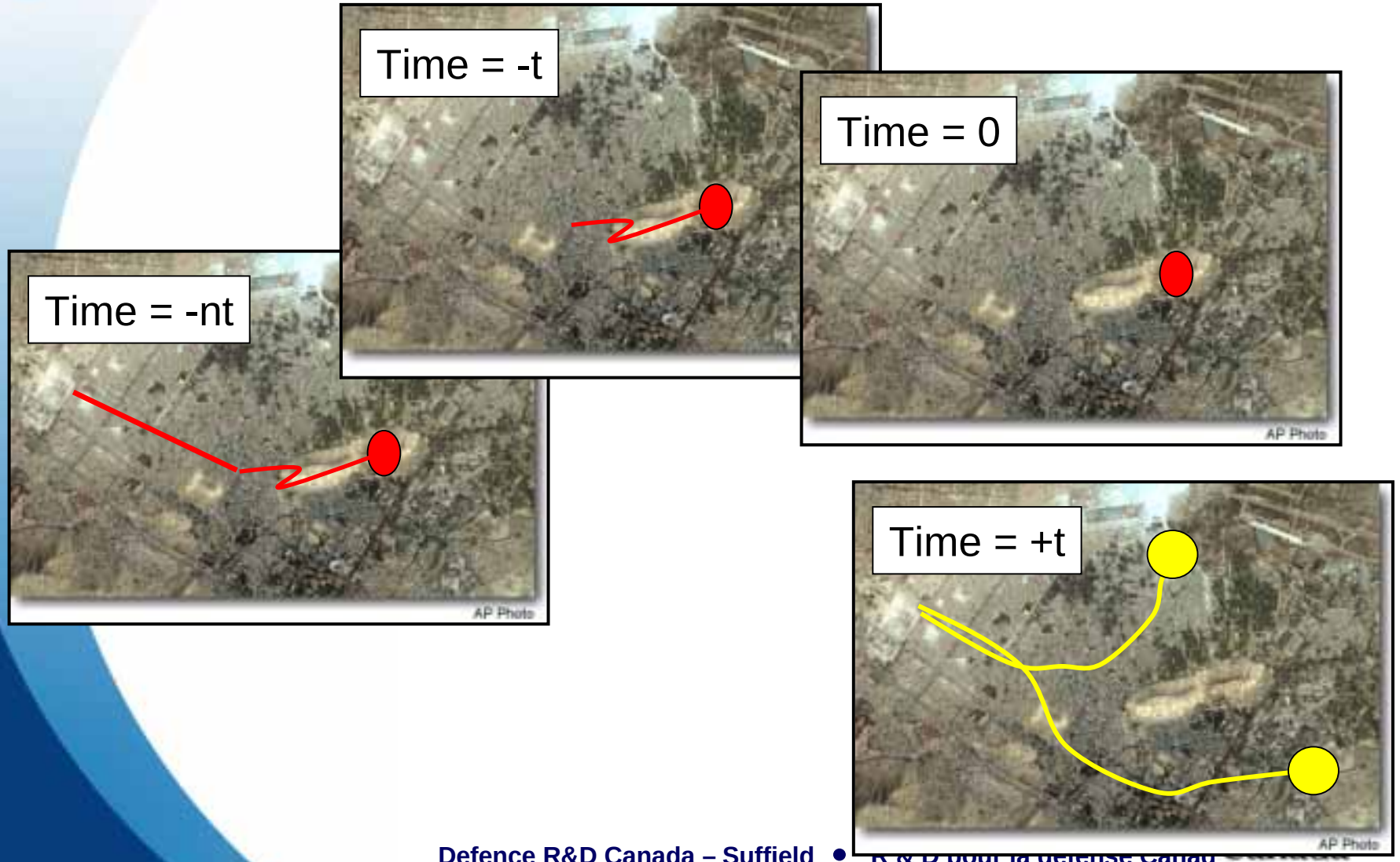
Roles 2010

- Recon
- Urban operations
- Logistics
- Data mining

Potential for AIS Software Agents

- Spatial range of information far greater and at more detail than on human can hold
- Perfect memory of past events
- Persistence of machine recording even what appears mundane but could be important
- Powerful processing and perfect memory combined with flexible, creative interpreting and planning software

AIS Software Agents: Data Mining



Niche Machines

Strength

- D11 Caterpillar
- Mass material movement

Repetitive Calculations

- Deep Blue IBM
- Chess

Hard Realities for Physical Systems

- Even the best are very limited
- Unscripted interaction with unstructured environments
- Require advances in individual and collective intelligence
- Flexibility required for physical world applicable in software world

Hard Realties for Software Agents

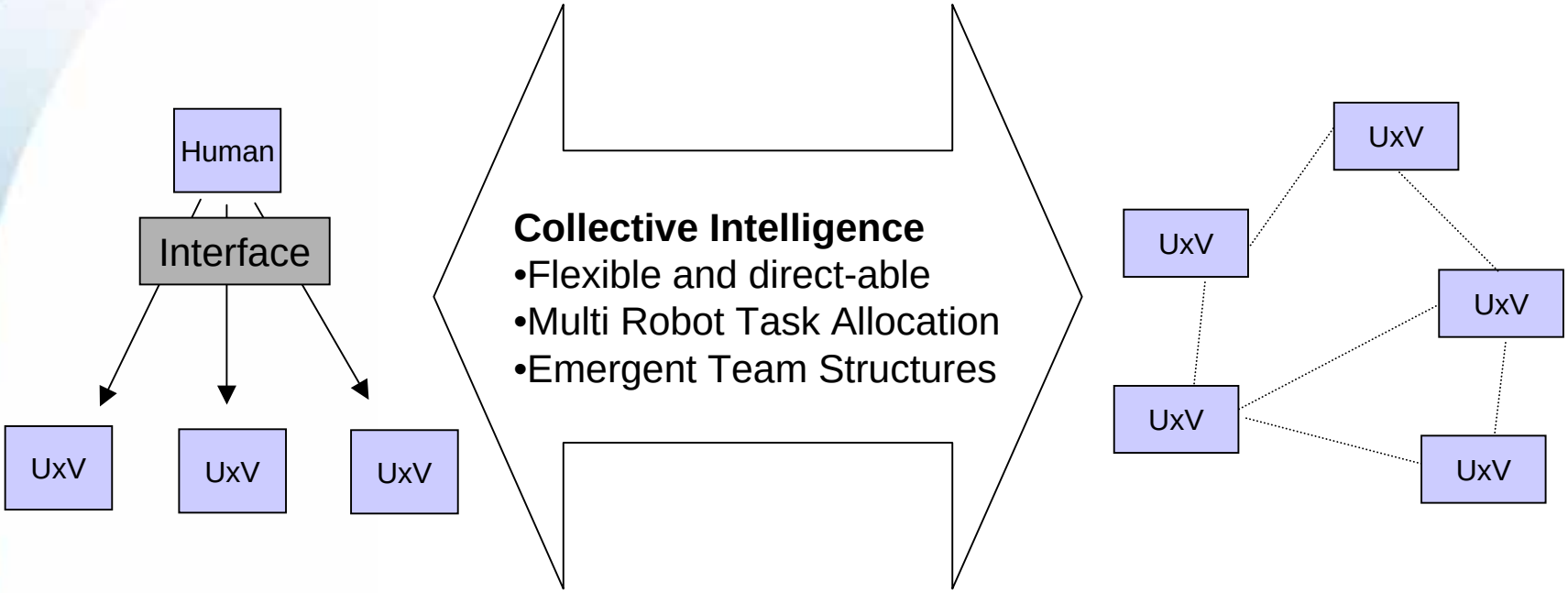
- Software entities eventually grounded in real world
- Knowledge requires handcrafted formatting that:
  - introduces prejudices
  - hides needed detail
  - constrains applicability
- Agents need to understand and counter an agile and adaptive enemy
- Need to be flexible, adaptive, intuitive and creative information processing
- Very similar agile interactions of mobility and navigation

Flexible, Adaptable and Self Sustaining Machine Intelligence

- Generalization
- Intuition
- Learn from mistakes
- Improve in the small (tuning)
- Improve in the large (find new approaches)
- Build background knowledge
- Apply background knowledge in new situations

Path to Collective Machine Intelligence

Collective Intelligence Paradigms

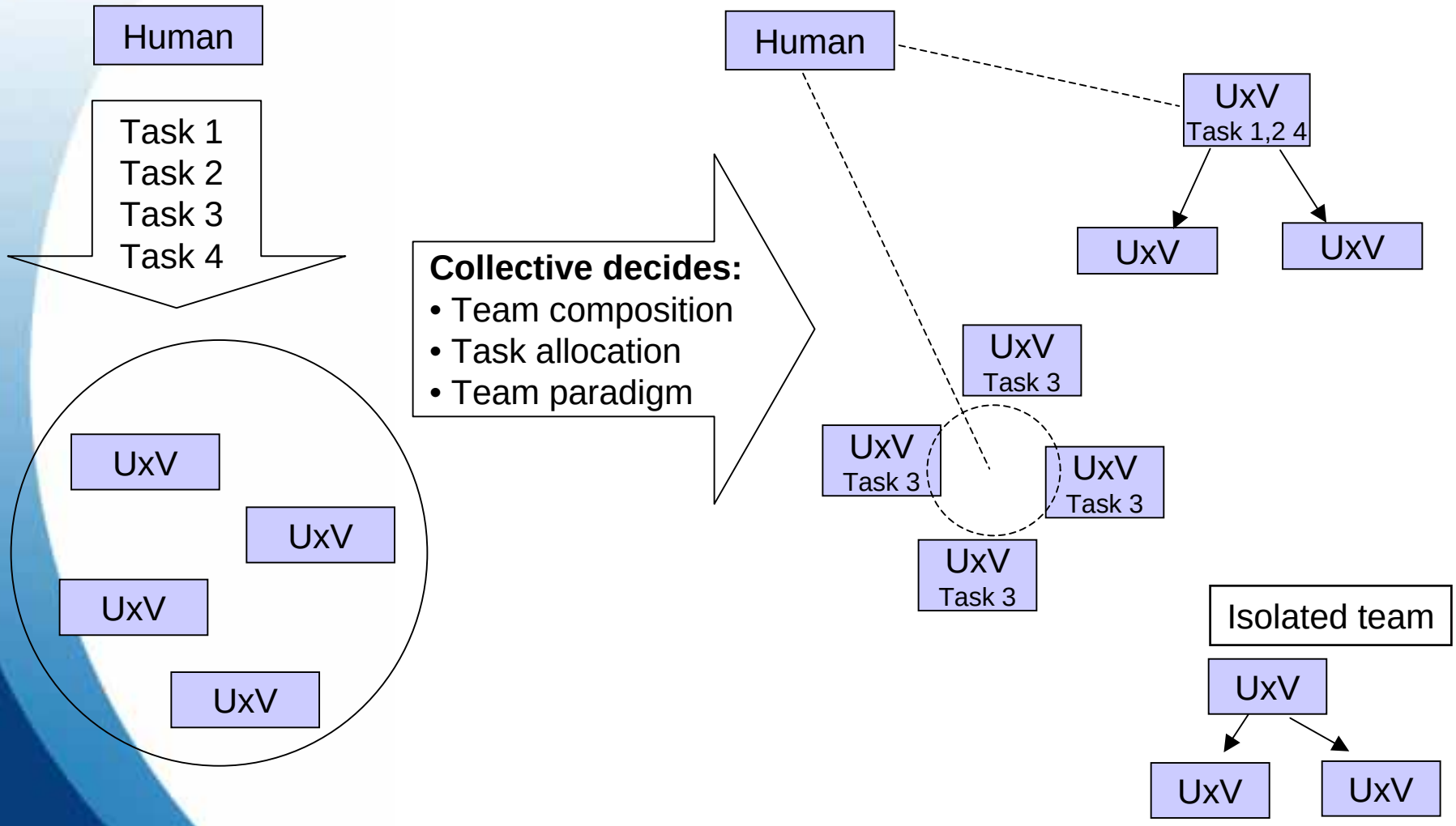


Centralized
- •Fully direct-able
- •Brittle
- •Simple teleop

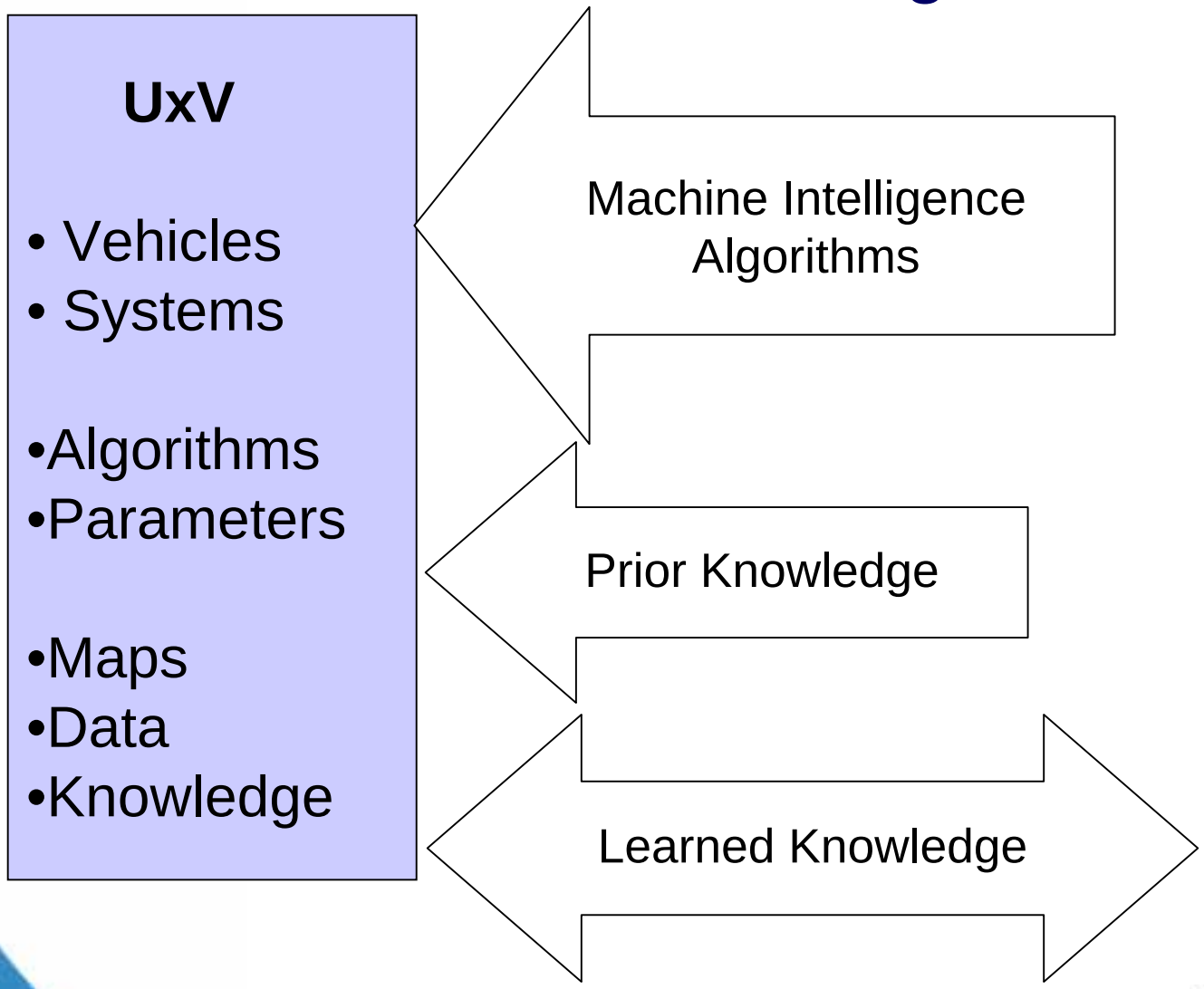
Higher Machine Intelligence Required
- •Higher level decisions made locally
- •Vehicle and software systems
- •Both centralized and decentralized
- •Individual and collective autonomy

Decentralized
- •Difficult to direct
- •Robust
- •*Swarm*

Collective Control



Individual Machine Intelligence



Progression of Machine Intelligence within NCW Connectivity

1. Clever hand crafted algorithms
2. Hand crafted algorithms updated across network
3. Limited learning algorithms for niche applications
4. Learning and discovery for broad applications
5. Communal learning and discovery implemented collectively across networks

Research Strategy

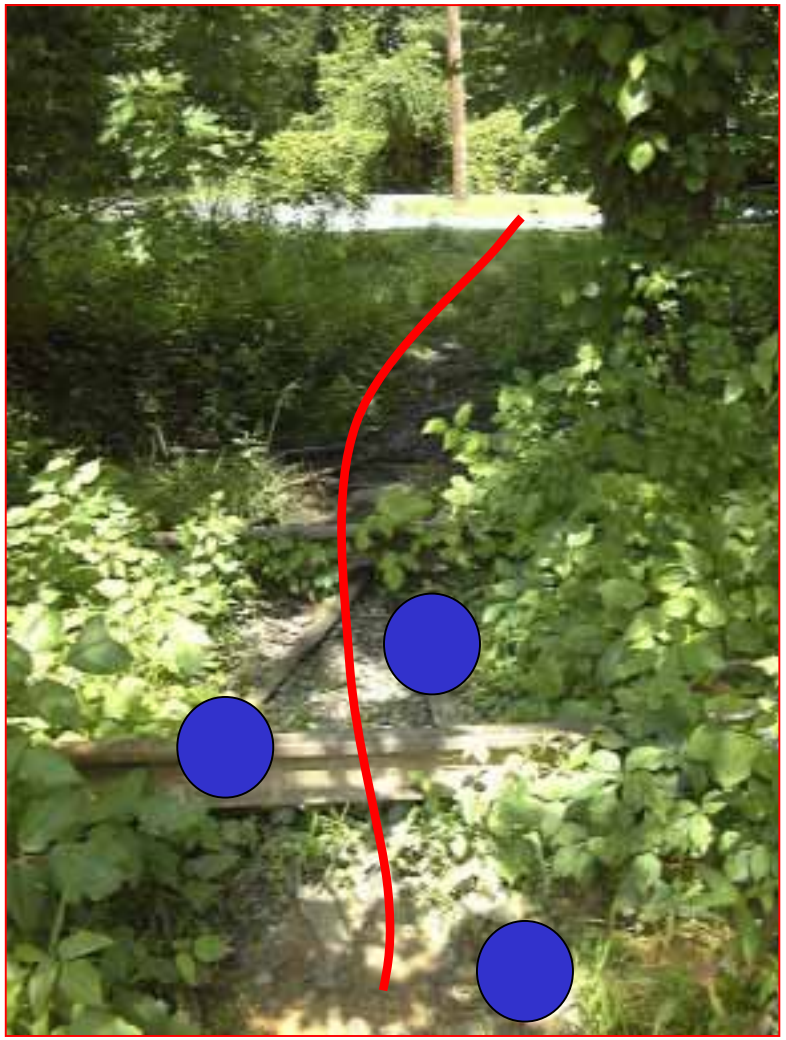
Research Strategy

1. Enabling Research
   - Barriers and grand challenges
   - Transcends many application research areas

2. System Specific Research
   - Aligned with program deliverables
   - Consumers and directors of enabling research

Enabling Research: Reduction of world to Functional Abstractions

- Features detected relevant to purpose at hand
- Neglect irrelevant details
- Generalized object recognition
- Recognize characteristics rather than appearance
- Understanding of use of objects in the world



Enabling Research: Concurrent Learning, Planning and Discovery

Discover new concepts, learn how to perform them and use that capability to plan

- Discover relationships (action->effect)
- Learn the relationships (what causes what)
- Chain relationships together and project to future goal states (planning)
- Refine and correct relationships
- Many concurrent tasks at different time scales

Enabling Research: Self Defining Control Structures

- Automatically decompose tasks and build control structure
- Not just tune within a framework
- Learn the underlying principles rather than just a solution
- Key to reuse of previously learned knowledge
- Life long learning

Enabling Research: Collaborative Learning, Planning and Control

- Function as efficient and flexible teams
- Learn from others, learn to work with others, learn with others and learn to compete with opponents

Enabling Research: Unformatted and Asynchronous Learning

Current learning systems are very constrained

- What to learn, what to learn it from and when to learn it are specified by designers
- Real systems must learn when lessons are presented
- Must learn in many forms
  - Trail and error
  - Teacher
  - Imitation
- Must learn from unformatted data steams

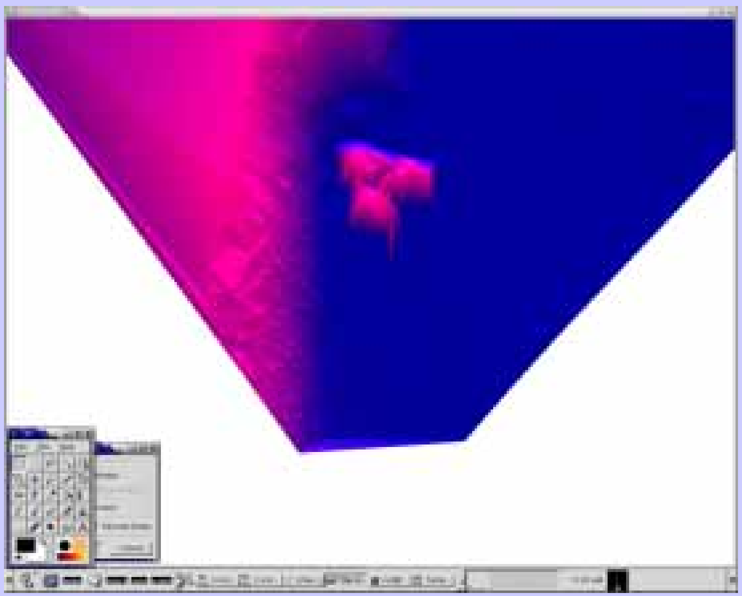
Enabling Research: Unified Representations: Symbolic - Real-valued

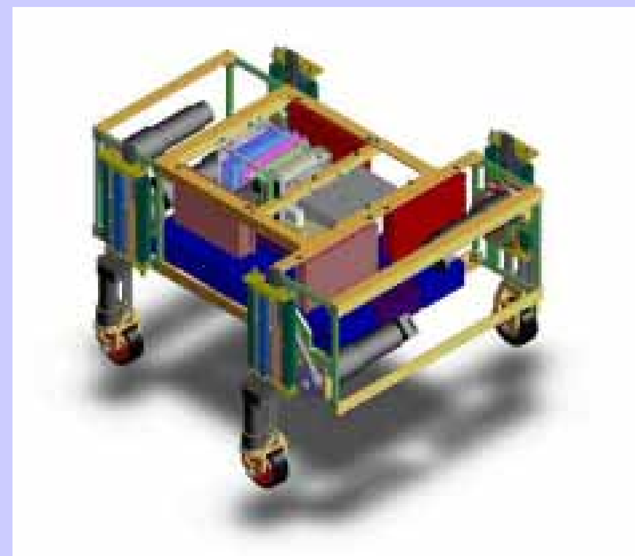
- Intelligence processes are interwoven discrete events and continuous actions
- Intelligence algorithms must cope will each equally well with signals and symbols

Walking and climbing

- Interwoven steps and continuous leg force and sensations
- Control discrete step sequences and continuous forces
- Must also evaluate, adapt and learn in this joint space

	Self Defining Structures …	Functional Abstractions …	Concurrent Learning…	Unified discrete, real and dynamic	Unformatted and Asynchronous Learning	Collaborative Planning and Control	Multi Agent Learning	More
Dynamic aware navigation and mobility		x		x				





Attaining human/animal agility will require exploiting dynamics .

Intelligent Systems Research

Enabling Research Themes

Vehicle Specific Research

	Self Defining Structures …	Concurrent Learning…	Unified discrete, real and dynamic	Unformatted and Asynchronous Learning	Multi Agent Learning	More
Path planning •Geometric						
Path planning •Learned Geometry		X		X		
Mission planning •Hybrid Collective		X				
Mobility •Intelligent Mobility	X	X	X	X		
Mobility •Dynamic			X			

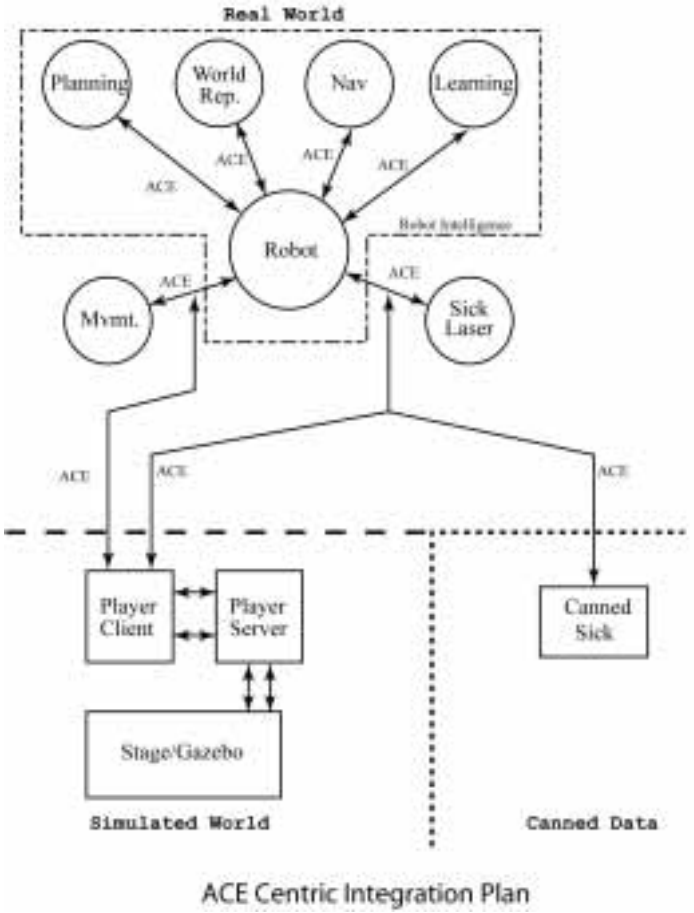
Implementation

Implementation of Intelligence

- **Short Term: Little dependence upon enabling research**
  - Algorithms hand crafted for niche applications
  - Show some limited degree of flexibility
  - Bound-able – not a bad thing
- **Long Term: High dependence upon enabling research**
  - General purpose autonomous machines
  - High degree of flexibility
  - High degree of self direction
  - Surprises and mistakes – not a good thing

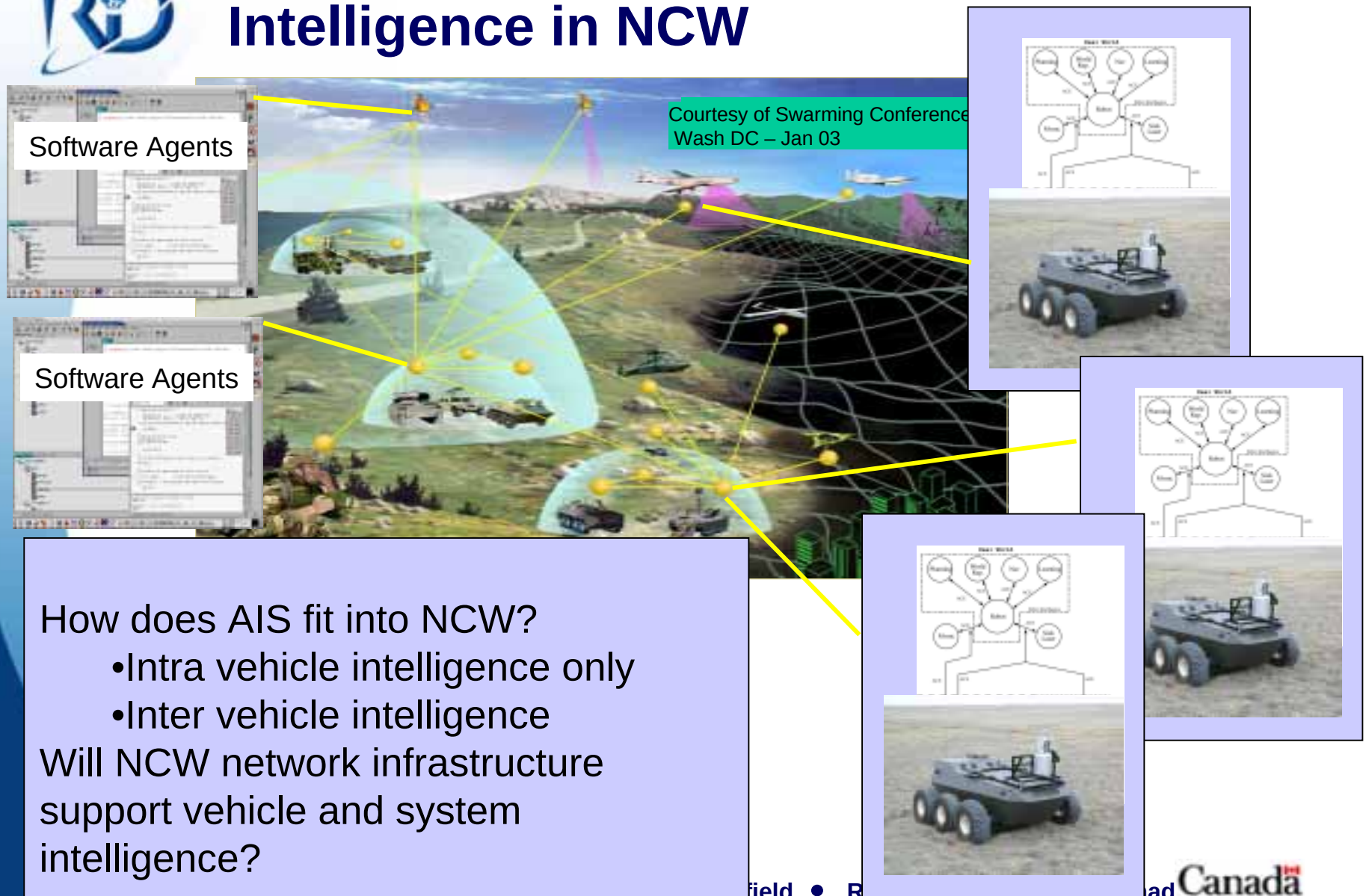
Architecture for Autonomy

- Research architecture
  - Cope with incremental and decoupled nature of research
  - Amenable to machine intelligence
- Operates in:
  - Real world
  - Simulated world
  - Canned sensor data
- Opensource tools
  - ACE/Player/Stage
  - RTEMS
  - Linux/C/C++
- Compatible with research partners



ACE Centric Integration Plan

Intelligence in NCW



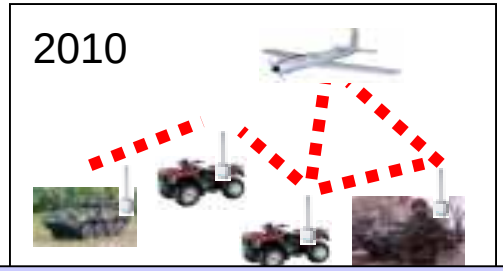
How does AIS fit into NCW?

- Intra vehicle intelligence only
- Inter vehicle intelligence

Will NCW network infrastructure support vehicle and system intelligence?

Way Forward

Looking Forward



Collective Intelligence and Coordination

- Low flexibility
- Low independence
- Scripted teaming
- Limited interconnectivity

- Some adaptation
- Greater independence
- Emergent teams
- Beginning to exploit interconnectivity

- Fast learning and discovery
- Self direction
- Fluid and graceful teaming
- Fully exploiting interconnectivity (BORG-like)

Individual Autonomous Vehicles and Systems

Way Forward

- Research:
  - Implementation of a state of the art
  - In parallel develop advanced algorithms
- Contracting:
  - Guide academia and grow an industry
  - Retain research program continuity in house
- Partnerships:
  - Remain a credible player in community
  - Maintain and expand strategic partnerships
- Practical Development Environment:
  - Flexibility
  - Compatibility

Conclusions

- NCW requires systems that make decisions and collaborate
  - Unmanned vehicles and software agents
  - High performance require – AIS must be able to win
- Joint research: different vehicles and software agents – same problems
- Mechanisms for integrating AIS within NCW need to be explored

The Defence Research and Development Branch provides Science and Technology leadership in the advancement and maintenance of Canada's defence capabilities.