Smart Shepherding

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Modification of Swarm Intelligence

- Most swarm systems focus on social animals
  - Bees, ants, etc.
  - Using pheremonal information and communication

- More recent research has expanded to boids
  - Flocking, knowledge only about their neighbors

Both above systems lack certain aspects

- No way to know the goal
  - Swarms are not generally smart enough to manage everything
- There is no interface
  - The swarms work in a vacuum

Shepherding as an Alternative

- Multiple kinds of units
  - Human
  - Sheepdog
  - Sheep
- Top units are the most intelligent
  - There are the least of them
  - Top units are not capable of managing the whole rest of the swarm
- Layering of units
  - Human > sheepdog > sheep
  - Sheepdogs offset the physical

Rules of Shepherding

- Move units from one location to another
  - Any medium is valid
- One set of units is susceptible to another
  - Layers of cognitive ability
- Layering of unit control
  - Humans control one layer of a small number of units
  - Second layer controls a large number of units

Shepherding Concept

- The goal of the swarm is not just to complete an objective
  - The survival of the units are equally important
  - Requires the different layers to be able to understand and predict what the other layers will do
  - Higher layers will adapt to the information and change their tack
  - This involves modifying their inputs to also take in the swarm states

- Layering of knowledge
  - Sheepdogs don’t understand the goal and the sheep know less than that
  - The previous layers use their influence to guide the rest of the swarm in the correct direction

Using Shepherding

Shepherding uses modified flocking

- Use normal flocking
- Add a secondary force to the system to control the flock

Use vectors to simulate motion

- Forces from the flocking motion and the sheepdog motion
- Sum of forces influence the vectors of each swarm member
- Leverages GPU efficiency with vectors

Usages

- Predator-prey
  - Simulate the motion of prey in response to a separate threat (modeled as sheepdog)
- Swarm Robotics guidance
  - Most direct application of shepherding
  - Proximity of sheepdog affects motion of the whole swarm
  - Few swarms controlling many
- Cybersecurity
  - Minimize control data and maximize payload data
- Mission Cryptology
  - Encode the goal of the information transfer by way of few knowledgeable nodes
- Human-autonomy Teaming
  - A small number of manageable units
  - Parallel of real-life shepherding

Reactive vs Cognitive agents

Physicomimetics = research in reactive agents

Reactive agents	Cognitive agents
Model represented as a set of event-condition-action tuples	Model analyses cognitive components such as executive control functions and long term memory
Faster as less computational resources used	Uses more computational resources but more robust to change in environment/mission
Criticised for model simplicity and high level of abstraction	Classic control theoretical or cognitive AI models are widely accepted and used

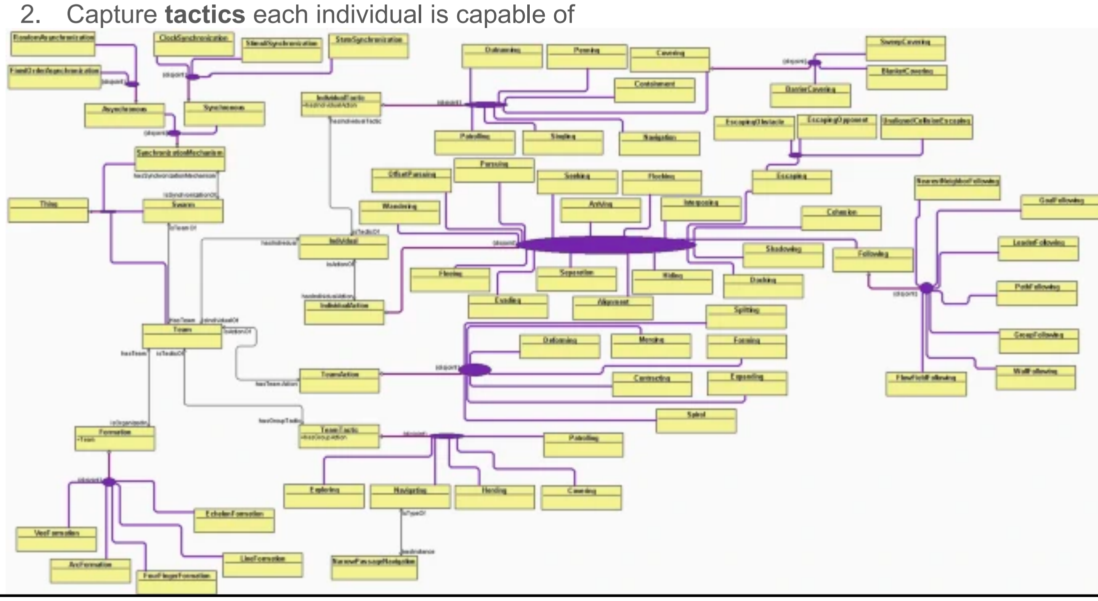
Hybrid agents

- Robust agent capable of operating in complex real-world settings
- Design approach:
  - Utilise required time-scales for responses to determine the switching point between cognitive and reactive control
  - Actions such as immediate collision avoidance: **ECA reactive approach**
  - Determine appropriate path to traverse to avoid known obstacles: **cognitive planning approach**
- **A**dditional parameters, such as computational resources available to the agent, and complexity of the missions the agent is designed for should be considered to determine the switching point

Swarm ontology

- To capture elements across different layers the system is operating on

1. Define **capabilities** of an agent to enable activity recognition
2. Capture **tactics** each individual is capable of



Action/Capability vs Tactic

Tactic	Definition
Outrunning	Moving in a pear-shaped trajectory with a wider arc as the sheepdog approaches the sheep until it reaches the point of balance; the latter is the point where the stressors on the sheep due to the sheepdog position places the sheep in a state of alert, while being at the edge of moving.
Penning	The flock is driven to a small enclosure. The door is closed when all sheep get inside the enclosure area.
Singling	A specific sheep is separated from the flock.
Patrolling	Preventing a group from exiting an area or keeping it at a fixed distance.
Covering	Navigation to multiple goals.
Containment	Motion of the agent is constrained within a region.
Navigation	Localisation in the environment and identification of appropriate routes.

Actio	
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Dock	
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Pursu	
Offset pursuing	Steering near but directly into a moving target. Basically, the predator pursues the prey while maintaining a distance from the prey.
Arriving	Seeking with decaying speed as the agent approaches the target. The speed is 0 at the target location.
Interposing	Predict the centre of gravity among future positions of two or more agents then seek this position.
Escaping obstacle	Similar to flee but only when the obstacle is on a collision path with the agent.
Escaping opponent	Similar to flee but only when the opponent is on a collision path with the agent.
Shadowing	Approach the agent then align to match speed and heading.
Cohesion	Seeking the centre of gravity.
Separation	Steering away from nearby agents.
Alignment	Steering vector is the difference between the average velocity of neighbours and the agent's velocity.
Flocking	A combination of separation, cohesion and alignment.

Advantages of swarm ontology for shepherding

- Important enabler for transparency
- Provide explanation on how an agent makes decisions using concepts humans are familiar with
- Allows mapping of an explanation from one form to another
- Guide machine learner to constrain its search space, gaining efficiency in learning time

Definitions

1. A **team** is a group of organised individuals joined together to execute team-level tactics and actions.
2. A **formation** is a spatial organisation of a team of individuals.
3. A **team action** is a basic building block of what a team can do and is capable of generating an effect/outcome.
4. A **team tactic** is an organised set of team actions to achieve an intent or a higher-order effect.
5. A **swarm** is a team with actions of the individuals that are aligned spatially and/or temporally using a synchronisation strategy

Behavioural synchronisation of swarms

1. Asynchronous
- Use random order to perform actions
- Example: Taking input from one agent which triggers an action in another, the order of actions is independent of any clock
1. Synchronous
- All team members perform the action simultaneously
- Require a common point of reference for members to know when to perform the action
- Two common approaches:
    1. Synchronise clock in each agent on a **common clock**
    2. Trigger actions across multiple entities based on **environmental stimuli**

Questions?