Multi-Agent Collaboration in Games:

A Survey of Solutions to Achieve Coordinated Behaviour

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Introduction

- **Topic:**
  - Implementation strategies for collaborative game AI:
    - Non-Player Characters (NPCs)
    - Bots acting as Players

- **Approach:**
  - Breadth-first topic search
  - Explore challenges of different behaviours
  - Present realized solutions
    - How did they help?

Topic Introduction

- **Motivations (for writing):**
  - Exploration in creating richer interactions between agents
  - Difficulty finding cited examples

- **Goal:**
  - Provide a reference for future developers, researchers
    - Starting point

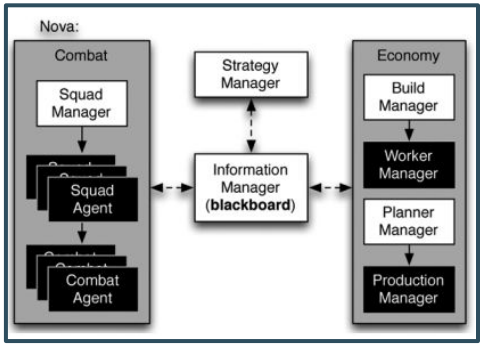
- **Output:**
  - Survey Paper
  - Knowledge!

Multi-Agent Settings in Games

- Settings in games considered in this research have three common components:

- Agents
- Environment
- Collaboration

- **Testbeds for Research:**
  - *Starcraft* (RTS)
  - *Rocket League* (Sports)



Team bot framework for Starcraft.

Behaviour Tasks

- This research explores implementation strategies for:

1. Movement
2. Communication
3. Decision-Making
4. Learning
5. Player Interaction

1 - Movement

- Coordinating movement between independent agents portrays a sense of togetherness

- **Challenges:**
  - Agents can get in each other's way
  - Sudden changes in movement possible
  - Tight environments are difficult to navigate

Steering Behaviours

- Simple movement behaviours for agents
  - Use agent velocity and orientation

- Steering can be made relevant to a target

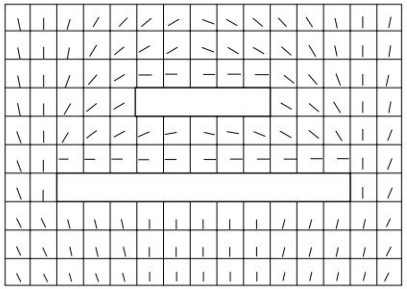
- Examples:
  - Pursuit (Chase a target)
  - Evasion (Avoid a target)
  - Alignment (Match orientation)
  - Velocity-matching (Match velocity)

Crowd Simulation

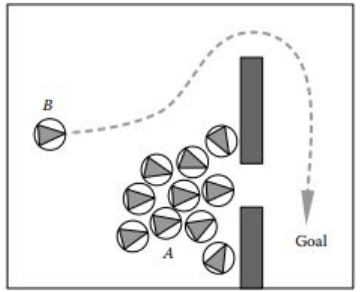
- Large-scale strategy
  - Simulate crowd-like formations
  - Avoidance steering behaviour

- Issues can arise:
  - Densely packed crowds
  - High storage cost for paths

- Solutions?
  - Flow vectors
  - Congestion Maps



A map of flow vectors for traversal



Congestion points emerge with individual pathfinding

Tight Coordination

- Techniques for coordinating tighter dependent movement

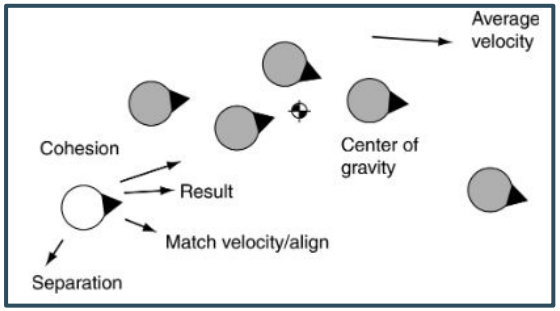
- Agents need full knowledge of other agents' position and movement

- Applications for strategic movement
  - Squad-based formations
  - Flanking strategy

Flocking

- Large-scale strategy
  - Simulate movement patterns of animals
  - Flocks of birds, swarms of insects
  - Fictional creatures (Pikmin)

- Combination of steering behaviours
  - Steer towards average position of neighbours
  - Match the directed movement of the flock
  - Avoid getting too close to other agents



Top image: A flocking group of Pikmin creatures.
Bottom image: Flocking steering behaviours.

Multi-Agent Pathfinding

- Pathfinding strategies for multiple moving agents
- Goal positions may be shared or separate

- Cooperative pathfinding
  - Agents are aware of each other's movement
  - **Centralized**: One entity plans movement
  - **Decentralized**: Each agent plans movement

- Non-cooperative pathfinding

2 - Communication

- Agents need to share information to collaborate
  - Store knowledge internally
  - Acquire knowledge from the environment
  - Share knowledge with agents

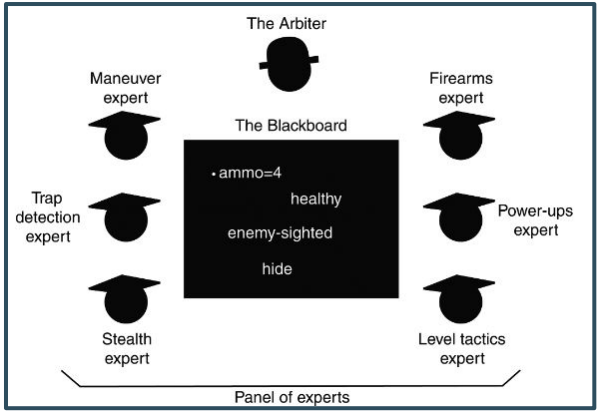
- **Challenges:**
  - How is information stored?
  - What types of data need to be stored?
  - When is data communicated?
  - Which agents can communicate?

Blackboard Systems

- Method for knowledge storage
- Provides a unified access point for information

- Three components:
  - Dedicated section of memory (blackboard)
  - Set of read/write processes (experts)
  - Program to control write access (arbiter)

- Easily extended for use by multiple agents



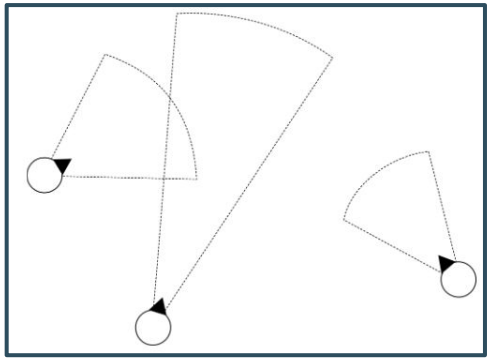
Single Agent Blackboard Architecture

Environment Perception

- Agents need to perceive the environment
- Agent sensors - simulate human senses

- Visual information
  - Line-of-sight checks (raycasting)
  - Distance checks

- Auditory information
  - Defined with a radius of influence

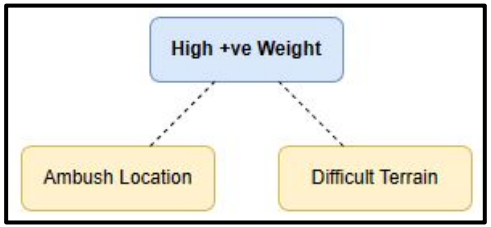


Sight cones for visual perception.

Embedding Information

- Not all information needs to be accessible at all times
- Information can be embedded in the environment

- Waypoint Tactics
  - Extension of waypoint-based pathfinding
  - Define suitable locations for actions



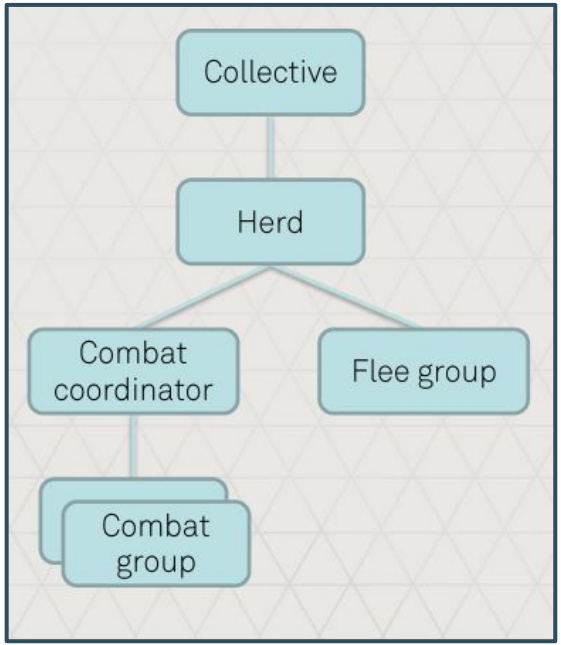
- *The Sims*
  - Objects expose possible actions to fulfill goals

Direct Communication

- Communication can be facilitated by a higher entity

- Agent hierarchies
  - Communication is unidirectional
  - *Horizon: Zero Dawn*

- Agent teams
  - Sports games



AI Machine Hierarchy for *Horizon: Zero Dawn*

3 - Decision-Making

- Behaviour task encompassing the full set of actions that can be conducted by agents

- **Challenges:**
  - Traditional structures aren't designed for collaborative decision-making
  - Agents actions can interrupt other agents

Unified Decision-Making

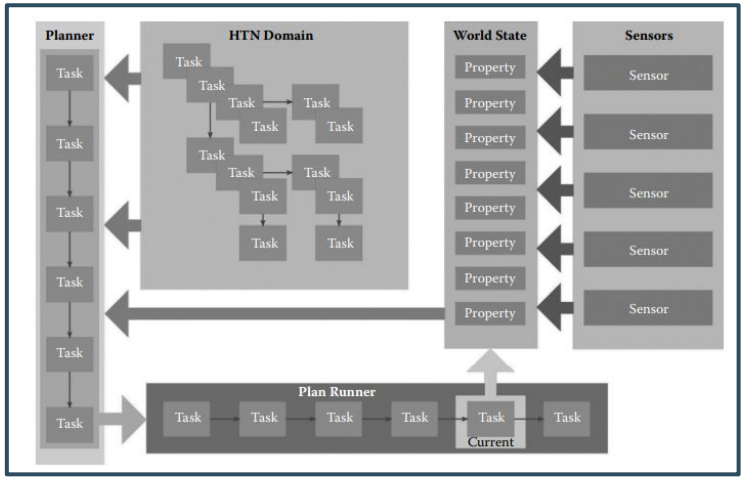
- Control independent agent actions with a higher-level entity

- Streamline decision-making
  - Focus on collaborative actions

- Good fit for strategic behaviour
  - *Total War: WarHammer siege battles*

Unified Decision-Making

- Task assignment to agents
- Unified Planning: Hierarchical Task Networks
  - Decompose an input problem
  - Create a series of actionable steps (plans)
- HTNs used for coordinating agents in *Horizon: Zero Dawn*
- HTNs used in research for team-based strategies in *Unreal Tournament*



An Overview of an HTN Architecture. (*GameAIPro*)

Distributed Decision-Making

- Multi-Agent Systems (MAS) coordinate loosely-coupled problem-solving agents
- Varied levels of intelligence depending on how decision-making is achieved
  - Reflex agents, Model-based reflex agents
- Swarm Intelligence directs groups of autonomous agents that respond to local stimuli
- Honey-bee swarms for RTS battle simulations?

Distributed Decision-Making

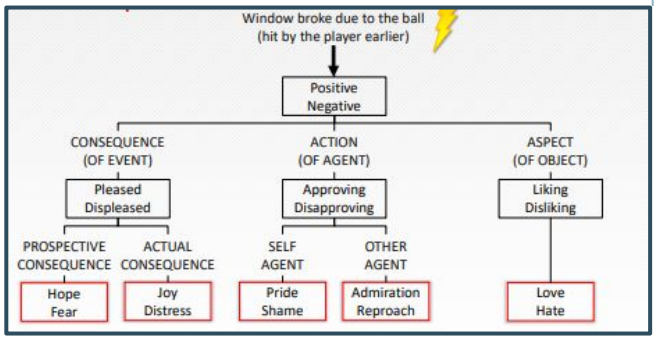
- Collaboration can be conditional according to agent motivation

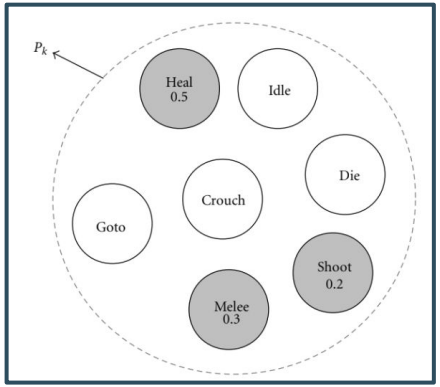
- Utility AI based on utility theory:
  - "Every possible action an agent can make can be mapped to a uniform measure (utility)"

- *Tactical Troops: Anthracite Shift*
  - Squad-based tactics game

Self-Motivated Decision-Making

- Agents can have personal influences to decision-making modelled after human traits
- Emotions & Mood
  - Modelling emotional responses
- Personality Traits
  - Weighted influence to action-selection



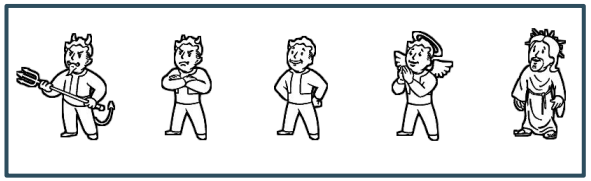


Top image: Emotion Pipeline used in simulating emotional responses.

Bottom Image: Personality model used for tactical decision-making.

Social Decision-Making

- Decision-making influences can stem from agent-agent and agent-player relationships
- **Affinity:** Measures how an agent perceive others
- **Reputation:** Measures how an agent is perceived
- **Trust:** Measure of truthfulness of agent behaviour.



Fallout 3's Karma system for player reputation.

4 - Learning

- Learning for agents supports self-adapting behaviour
- It may be too difficult for designers to plan every possible scenario

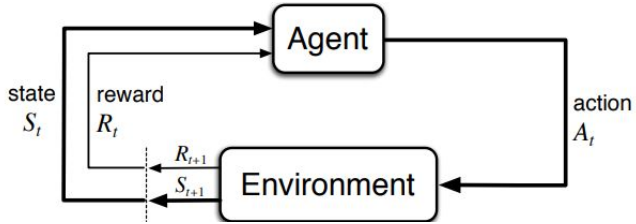
- **Challenges:**
  - Learning results can be unpredictable
  - Learning can create "unfun" behaviour for agents
  - Learning requires a lot of fine-tuning and testing
    - Time not always afforded to developers

Reinforcement Learning

- Have an agent learn what to do when faced with a particular problem

- Agents exist within *states* representing the environment
- Agents select *actions* to reach new states
- Actions learn a *policy* for state → action mappings
- Rewards are generated by states and direct agent behaviour

- Multi-Agent Reinforcement Learning
  - Agents learn joint optimal policies



Key Components of Reinforcement Learning

Imitation Learning

- Type of supervised learning
- Learn by example - expert demonstrations

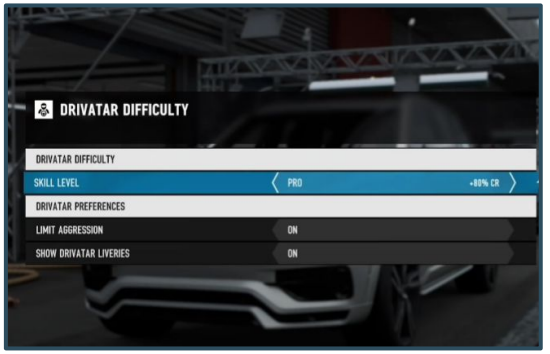
- Agents perceive demonstrative behaviour and process it through classification or regression techniques

- Agent rewards are awarded when replicating demonstrated behaviour

- Good fit for player modelling

Imitation Learning

- **Replicate Player Behaviour**
  - Movement
  - Action Selection
  - Strategic behaviour
- **Anticipate Player Behaviour**
  - Cooperative AI
  - Opponent AI
  - Tutor AI



Forza's Drivatar AI Configuration

Building *Killer Instinct*'s "Shadow Fighters"

5 - Player Communication

- Communication methods for agent-player collaboration
  - Agent-agent methods aren't usable
- Human methods of communication can be used instead

- **Challenges:**
  - Player input is difficult to interpret
  - Some input requires additional hardware

Capture Player Input

- Text-based input
  - Natural-Language Processing (NLP) techniques

- Natural-Language Understanding (NLU)
  - Derive the meaning of text as input

- Natural-Language Generation (NLG)
  - Have agents generate text

Processing Speech

- Speech input
  - Voice recognition processing techniques

- Old technologies:
  - Nintendo GameCube - Microphone Accessory
  - Sega Dreamcast - *Seaman*

- New technologies:
  - WordNet
  - IBM Watson

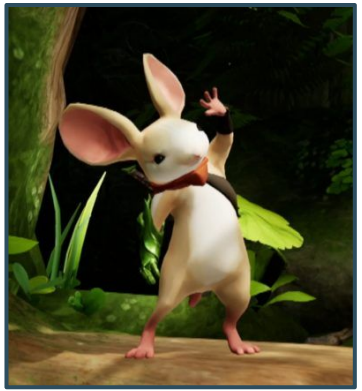
Odama Gameplay

Communicate Agent Intent

- Replicated speech
  - Speaking in the context of actions
  - Stealth Gameplay

- Non-verbal gesturing
  - *Moss* uses ASL gesturing

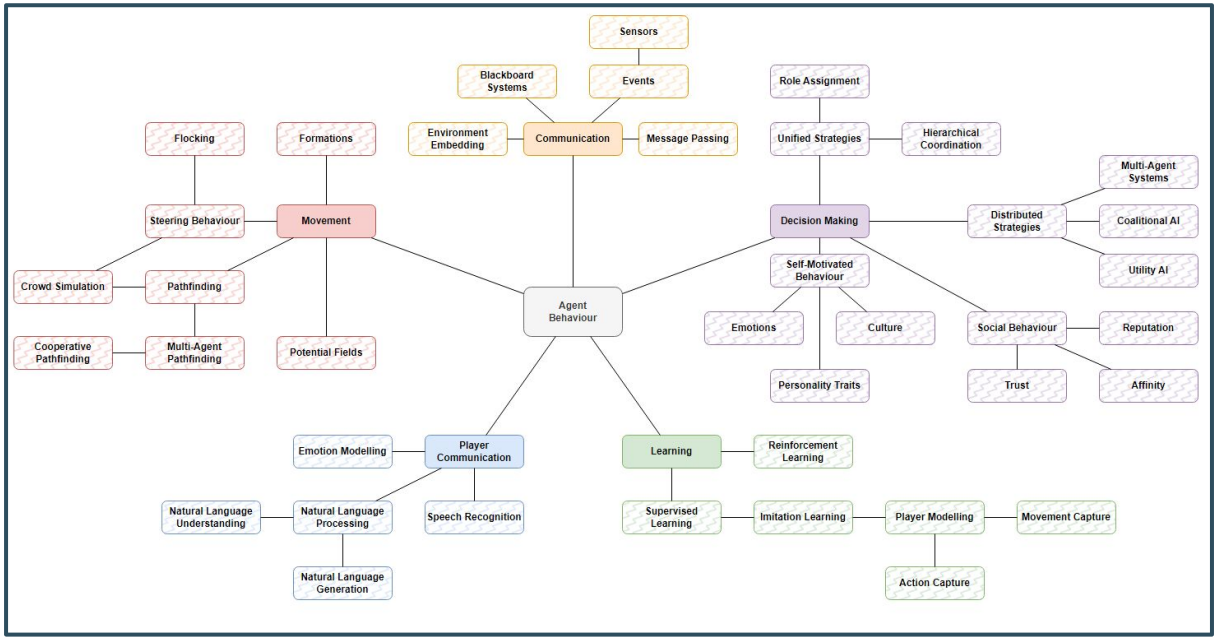
- Emotion modelling



Quill from *Moss*

Summary

- Topics explored in this research



Conclusion

- Implementation of collaborative behaviour for agents is inherently challenging
- Traditional AI techniques for single-agent behaviour doesn't always work
- Interesting and intelligent AI behaviour can arise by experimenting with new technologies
- Hopefully this survey provides a starting point

Thank You!

- **Images Used:**

GDC Vault - Designing AI for Competitive Games

GDC Vault - AI Summit: Driving Emotionally Expressive NPC Animations and Behaviors with a Designer Friendly Pipeline

Karma (Fallout 3) | Fallout Wiki | Fandom

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