# Animat Project Proposal

***An Exploration of Robotic Scouting and Communication Techniques in Swarm vs Search-Party Paradigms***


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With SpaceX sitting on the horizon of human development, effective techniques for exploring, assessing, and even populating distant planets will be required to advance scientific understanding of the universe. In the case of colonization, it is plausible to imagine that robotic intervention may be necessary to prepare a planet for human inhabitants. The present study seeks to explore the explorers by ranking various robotic scouting techniques on efficiency (speed of finding vital resources) and robustness (finding resources before running out of power or breaking down) in a communication- and visibility-inhibited environment.

**Hypotheses**: Communicating search-parties of scouts will be able to find resources of interest more quickly than swarms due to dead-end path pruning from more efficient associative learning. Swarms may be similarly successful if their home base is capable of data storage.

**Goal**: Successfully discover (and in some conditions, mine) vital resources on the planet's surface including water, minerals, and soil.

**Metric**: How quickly vital resources are discovered and what effect the environment, communication, and grouping techniques have on the speed of discovery, if any.

**Overview:**

- Robotic scouts will explore an environment in a given time window while attempting to discover vital resources; their exploration techniques will vary and be ranked based on efficiency and robustness
- Learning from environment [across all experimental conditions]: scouts will associate certain environmental cues with temporally adjacent desirable (found resource water recently near vegetation) or undesirable (found nothing recently near desolate rocks) outcomes; these are assessed via the scouts' visual apparati. Associating certain landscape elements (moist soil around water, shiny material around minerals, etc.) will weigh that scout's desire to explore more in areas that have higher likelihoods of resource saturation.
- In each of 7 different experimental conditions, the bots will acquire (via the experimenters) new abilities to test, including: communication of learned associations, group-search behavior, and use of a home-base mainframe for learning aggregation.

**Foreseeable Issues**:

- Developing successful techniques for merging individual scout experiences into a shared associative learning
- Developing an effective method for having scouts decide when to return back to base and, in the structured group paradigm, when to split for individual exploration

- Developing a method for the scouts to realize how far they can go before they need fuel, while taking into account the distance they need to travel to reach the fuel

# Methods

## Design

**Concentration:** The focus of the study will surround the different animat search techniques and the role that communication plays in the swarm versus the structured "search-party" paradigms.

**Programming Languages:** C/C++, Starcraft II Map Editor Modeling

**Environment:** The study will be conducted using the following programmatic choices and environmental characteristics:

- *Stack:* The graphics and physics of the study will be easily handled by the Starcraft II game engine
- *Perspective:* 2.5D with multi-level terrain-height
- *Physics:* Animat collision detection with cliff-walls (if sufficiently high), debris, other animats, and other environmental obstacles--all handled by game engine
- *Home base:* A central base at which the animats begin their mission, can return to in order to regain fuel, and, in one experimental condition, the central data storage for scout learning; in the central storage condition, scouts near the home base will contribute their data from learned associations and receive aggregate data from the base that has been combined from the visits of other scouts
- *Resources (Objective):* Goal resources (and their associative markers) will be randomly seeded throughout the map
- *Constraints:* Constant communication and visibility haze that presents a significant range impediment to each scouts' radio and visual aparati

**Animat Design:** The present project's animats are robots with the following properties:

- *Movement*:
    - Directions: Ability to move in any direction on the ground
    - Mechanism: Two thrusters situated under the scout that allow it to hover above and move across land
- *Sensors:*
    - Vision: 360 degree camera system designed to detect environmental features in a small area around the scout
    - Communication: Radio frequency sensors designed to receive short range radio frequency signals from scouts
- *Communication (in relevant experimental conditions):* Short range radio frequency transmission between scouts to share learned associative clues for more effectively

finding resources
- *Brain Structure:* Neural network with pre-learned set of actions deemed applicable to the scout's assigned tasks, including:
    - Movement direction: Movement modified by group communication, learned environmental queues, and seeded with random choices for exploration
    - Resource marking: A resource discovered by a scout (probabilistically matched via vision sensor) will be marked with a beacon
    - Energy depletion: Decides whether the "find fuel" protocol will be triggered based on remaining fuel
    - Communicate findings (Communication-enabled condition): Sufficient proximity to another scout (or the home base in some conditions) will communicate (via radio frequency transmissions) any learned associations between environmental cues and goal resources
    - Return to group ("Search-party" condition): Scouts will re-group to share learned associations with the other members of the search party
    - Mine resource ("Mining responsibility" condition): Scouts that discover a resource will mine it, report the resource to the central base after storing the resource, and all scouts that visit the base will also mine the found resource until it is depleted
- Adaptation: Animats adapt through learning via experience and communication from other animats, and in some experimental conditions, from the home base

**Developmental Phases:** The following developmental stages mark the various scout behavioral milestones that will be experimentally compared against each other in a test of exploratory efficiency:

1. *Non-communicating swarm*
   Animats go out to explore individually (in a swarm fashion). There is no communication between scouts, and pathway overlap is likely.
2. *Communicating swarm*
   Animats go out to explore individually (in a swarm fashion). They communicate with each other to prevent pathway overlap and share associative experience for nearby-resource environmental cues.
3. *Communicating, structured search-party*
   Scouts are sent out in search-party groups of three. Periodically, or at points of learned interest, they will split up from a demarcated meeting location to look for resources. After a set time period the scouts return to the meeting point, communicate their findings, and reach consensus for the next exploration direction based on the information that they have learned previously and gathered from their immediate environmental clues.
4. *Resource Mining*
   Scouts will now be not only responsible for discovering new resource deposits, but also for mining them. After discovering a resource, a scout will mine it and report its location to the home base after returning from its first mining trip. At this point, the home base will redirect all other returning scouts to mine the resource until a returning scout reports that it is depleted, at which point scouts will resume their exploration. The dependent

measure in these experimental conditions will monitor amount of resources mined.

# Procedure

The experimental procedure for the present study seeks to compare resource finding efficiency (dependent variable) between combinations of the following manipulations (independent variables): communication capacity (radio vs none), group organization (swarm vs search-party), home-base data storage (home-base stores and communicates associations learned from scouts), and mining duties (scouts must also mine the resources they find, or not). There are 7 separate conditions to test (the cases in which there is no communication capacity precludes both a search-party paradigm and data storage within the home base, and so these are omitted; additionally, home base data storage has been deemed a prerequisite of the mining capacity due to centralized coordination needs; the first condition serves as the control):

| Communication Capacity | Group Organization | Home-base data storage | Mining Capacity and Duties |
|---|---|---|---|
| No | Swarm | No | No |
| Yes | Swarm | No | No |
| Yes | Search-party | No | No |
| Yes | Swarm | Yes | No |
| Yes | Search-party | Yes | No |
| Yes | Swarm | Yes | Yes |
| Yes | Search-party | Yes | Yes |

The precise procedure will go as follows:

1. Start all bots in the center of the map at the home base; there will be a countdown clock begun at 15:00.
2. Bots will perform their exploration routines based on the current condition (swarm vs search-party) and will similarly communicate with each other based on the condition.
3. During the scouts' exploration (in all conditions), low fuel will raise the bot desire to find more, typically resulting in a return to the home base to recharge. In the home-base data storage conditions, bots returning to the base will also contribute their gained associations as well as assimilate those stored by other bots.
4. A single condition trial will end after the 15 minutes have elapsed, and total amounts of resources gathered will be recorded as the dependent measure.

**Analysis**
Upon completion of a statistically appropriate number of trials per condition, a 2 x 2 analysis of variance (ANOVA) will be used to find any statistically significant differences within communication capacity and between group organization and home-base storage in order to assess the degree to which each factor influences the efficiency of the scouts' search. T-tests will be conducted based on the control of no communication capacity in order to see if communication provides any benefit in the scenario at all.

# FAQ

- "Swarm" may have a variety of different definitions and may elicit notions of ant-like pheromone trails; additionally, on what planet is this scenario meant to take place?
    - *There are no pheromone trails or markers other than beacons indicating already-found resources, and the scenario is indeed on another planet; see our contextual definition of "swarm" below*

- What is meant by the term "swarm"?
    - *Swarm, defined in this context, is a large number of bots operating individually except for (in some experimental conditions) some communication when they happen to meet*

- What are the differences between the search-party and swarm conditions, including what number of bots in each, and what is being compared?
    - *Consider each experimental condition consisting of some m number of scout bots where m is a number divisible by the size k of a search-party, i.e. m % k == 0. Our proposal is to make the size of the search party k = 3 in the experimental conditions--this too could be another manipulated variable, but was not in our project outlook.*
    - *In the search-party condition, there are still m bots on the map, but they operate in close communication groups of size k (again, k = 3 in our proposed experiments); e.g. 4 search-parties of 3 bots each = 4 x 3 = 12 bots on the map*
    - *In the swarm condition, there are still m bots on the map, but they are NOT operating in close communication groups -- they scout individually and on their own autonomously chosen paths*
      *e.g. 12 bots individually explore on the map, not divided into closely communicating parties*
    - *As such, the number m is constant between conditions, but the groupings of the m bots are not -- this is the key manipulation: the frequency of communication*

- What is the scout learning mechanism?

- *There are three main learning mechanisms, some dependent on the experimental condition:*
    - *Learning from environment [across all experimental conditions]: scouts will associate certain environmental cues with temporally adjacent desirable (found resource water recently near vegetation) or undesirable (found nothing recently near desolate rocks) outcomes; these are assessed via the scout visual aperatus*
    - *Learning from other scouts [across conditions where communication is enabled]: scouts will share their learned associations via short distance radio; these associations will be something like: "hey, I tend to find this type of vegetation near water, maybe you will too!" These communications will then modify the neural nets of the communicating bots such that the movement direction neural structure will tend toward reinforced environmental cues (e.g. vegetation) and movement direction away from discouraged environmental cues (e.g. desolate rock)*
    - *Learning from the home base [in only the condition where the home base serves as a communication hub]: acts in the same way as the scout communication except all scouts will communicate with the base because they'll eventually need to refuel there; this might elicit some interesting behavior in their exploration techniques*

- What are the specifics of the scout movement mechanism?
  - *The exact specifics of their movement mechanism is actually abstracted; the environment in this scenario is 2.5D. To specify, though, the purpose of the thrusters is to enable the scouts to hover above the terrain as they move along it.*

- What do they communicate to each other? Is it broadcast to all or just to nearby bots? When do they decide to communicate? What are their sensors/motor-actions?
  - *Scouts will share their learned associations via short distance radio; these associations will be something like: "hey, I tend to find this type of vegetation near water, maybe you will too!" These communications will then modify the neural nets of the communicating bots such that the movement direction neural structure will tend toward reinforced environmental cues (e.g. vegetation) and movement direction away from discouraged environmental cues (e.g. desolate rock)*
  - *In our scenario, there is interference on the planet, and so the communicative broadcast is local to nearby bots. In the swarm condition, bots will communicate whenever they are within visual range of another bot. In the search-party condition, they will communicate their individual findings whenever they regroup to continue in their search pattern*
  - *Full sensor and movement neural structures are described in the animat description of the proposal*

- What are physics of a beacon (can any bot spot a beacon from anywhere)?

- What is a beacon?
    - *A scout places a beacon in the ground once it has found a resource of value in its visual vicinity. The beacon continuously broadcasts a short range radio frequency signal notifying other bots that the current location has already been marked. This method of communication is identical to that which the bots use, as is the broadcast radius.*

- What do scouts do themselves (vs under control of experimenters)?
    - *Once an experimental condition has been initiated, the experimenters do not have any control over the scouts. The only portions decided by the experimenters are the capabilities of the scouts before a trial has begun (whether or not they can communicate, whether they will group up or explore individually, and whether or not the home base has communicative capacity). Once a trial is begun, scouts will move according to two factors: (1) a non-deterministic random movement of random distance and orientation, which is less likely to trigger if (2) the scout notices environmental cues learned to be proximal to resources of value (or notices environmental cues learned to be indicative of a lack of resources).*

- What parts are fixed/procedural and what parts are adaptive/neural?
    - *Procedural/Fixed*
        - *Moving, communicating, marking resources*
        - *The point in which the scout needs to refuel (percent of fuel left)*
    - *Adaptive/Neural*
        - *Learning in what direction to move based on environmental cues learned from experience, other scouts, or the home base (dependent upon the experimental condition and its capacities)*
        - *The rate at which the scout consumes fuel*

- Since you are a team of 2 more is expected. How about a phase 2 in which they execute a "mine resource" motor neuron and transport that resource back to home base
    - *A Mining phase has been added in the* ***Developmental Phases*** *section*