Adaptive Behavior Selection of Autonomous Objects in the Bio-Networking Architecture

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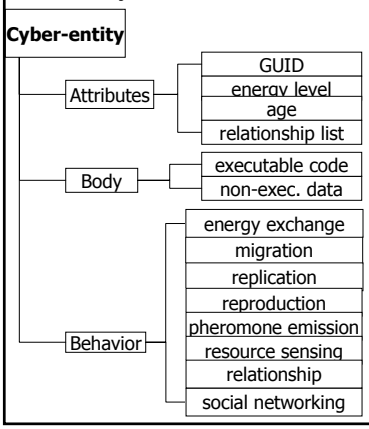
Motivation to the Bio-Networking Architecture

- Computer network environment will seamlessly span locations engaged in human endeavor.
  - at home, workplace, transportation vehicles, public facilities, and even space facilities
- Network services and applications needs to be
  - scalable, adaptable, available/survivable, simple to design/maintain
- Need built-in mechanisms to provide these features
  - large nets: beyond our capability to design
- **Our solution: *apply biological concepts and mechanisms to network service/app design***
  - Biological systems have overcome the desired features.
    - e.g. bee colony, bird flock, fish school, etc.

Cyber-entities and their Behaviors

- Cyber-entity is
  - the smallest component to create a network application.
  - an autonomous mobile object.



- *Energy exchange*
  - Cyber-entities gain, expend and store energy.
  - They gain energy in exchange for performing a service, and expend energy to use computing resources (e.g. CPU, memory).
- *Replication and reproduction*
  - Cyber-entities make a copy of themselves (replication), possibly with mutation in the replica's behavior.
  - Two parent cyber-entities may produce a child cyber-entity (reproduction), possibly with mutation and crossover in the child's behavior.
- *Resource sensing*
  - Cyber-entities sense its local environment. For instance, a cyber-entity may sense which cyber-entities are in the environment and what services they provide.
  - Cyber-entities also sense available network and computation resources (e.g. topology, link bandwidth, CPU cycles, memory space).

Cyber-entity's Adaptation

- Short-term adaptation
  - Cyber-entities autonomously adapt themselves to environmental changes by performing behaviors suitable for the current environment from a variety of behaviors.
    - A cyber-entity may migrate to another platform when resource cost at a platform that it resides on becomes high.
    - A cyber-entity may replicate when it receives a lot of service requests and gains much energy.
- Long-term adaptation
  - by generating species diversity and executing natural selection (i.e. evolution)
    - Diversity is generated through mutation and crossover.
    - Natural selection is controlled by energy level.
  - Long-term adaptation is beyond scope of this presentation.

Behavior Selection

- Behavior selection
  - the process for a cyber-entity to dynamically examine the current environment condition, identify behaviors suitable for the current condition, and decide which behavior to invoke.
- Behavior selection engine
  - Each CE has its own behavior selection engine, and invokes the engine in every certain time period.

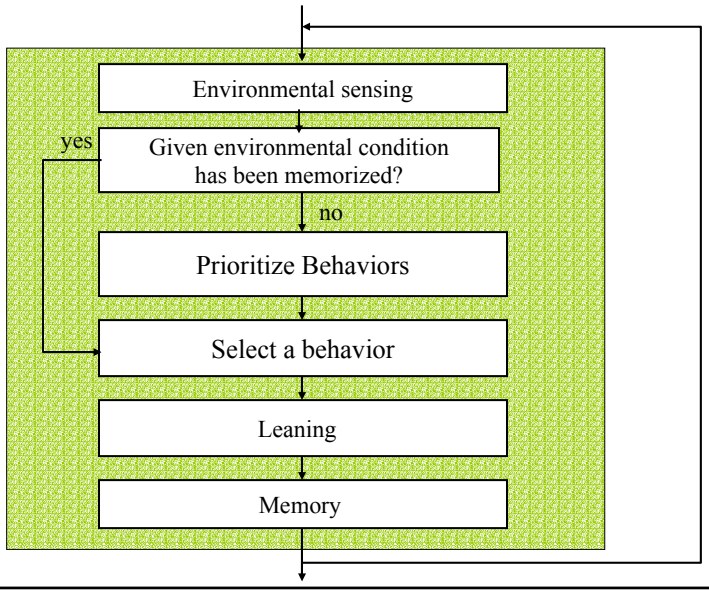
Requirements to Behavior Selection Engine

- Prioritization of behaviors
  - Behavior selection engine needs to select the most suitable (single) behavior to the current environmental condition,
    - even if multiple behaviors are feasible to invoke in an environmental condition.
    - After a CE performs the first behavior, the second one may not be suitable to invoke because environmental condition should be changed by invoking the first one.
- Learning through feedback-based reinforcement
  - Behavior selection engine needs to improve the quality of behavior selection continuously.
    - Environment changes dynamically, and a behavior that was suitable in an environmental condition may not be still suitable.
- Memory of behavior selection history
  - Behavior prioritization may be a heavy task for CEs.
  - Behavior selection engine can make behavior selection process faster by skipping the prioritization phase.

Design of Bionet Behavior Selection Engine

- Bionet behavior selection engine
  - is designed by applying concepts and mechanisms in the natural immune system.
- The natural immune system
  - elegantly meets the three requirements to behavior selection engine.
  - detects environmental changes (e.g. antigen invasion) and responds specifically to the changes (e.g. by producing antibodies specific to them).
- Our design strategy
  - apply the mechanisms of how the natural immune system chooses a specific immune response to an environmental change.

Internal Functional Steps in Behavior Selection Engine



Behavior Prioritization and Selection

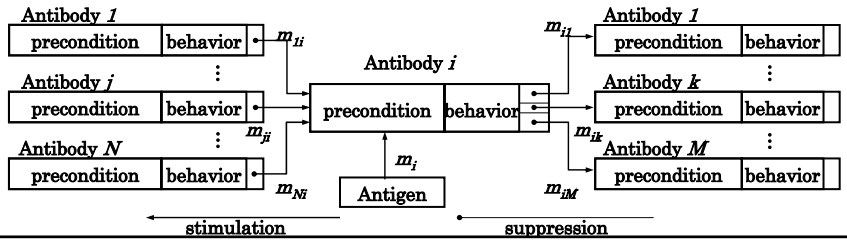
- An environment condition is represented by *antigen*.
  - e.g. request load > 10 msg/s, local resource cost > 100 energy units
- A behavior is represented by *antibody*.
  - e.g. migration, replication, reproduction …etc.
- Each antibody (i.e. behavior) has its own concentration value.
  - Concentration corresponds to the population of a specific type of antibody that exists in the immune system.
  - A behavior corresponds to a specific type of antibody.
  - Concentration value is used as priority in behavior selection.

Antibody's structure

precondition under which this behavior is selected	**behavior**	relationships (pointers to stimulating antibodies)

- Antibodies (behaviors) are linked with each other using stimulation and suppression relationships.
  - Stimulation relationship between behaviors contributes to increase the concentration value.
  - Suppression relationship contributes to decrease the concentration value.
- Each relationship has its own strength.
  - The relationship strength indicates the degree of stimulation or suppression.

- Concentration value is calculated for every antibody as a function of
  - stimulation from linked behaviors (antibodies),
  - suppression from linked behaviors (antibodies), and
  - stimulation from environment condition (i.e. antigen).
- A behavior (antibody) is selected based on the calculated concentration values.
  - If no antibody exceeds a threshold during certain calculation steps, the antibody of the highest concentration is selected, i.e. winner-tales-all strategy.
  - If an antibody's concentration exceeds the threshold, an antibody is selected based on the probability proportional to the current concentrations, i.e. roulette-wheel strategy.



Learning and Memory

- After a cyber-entity select and invokes a behavior, bionet behavior selection engine will evaluate the effectiveness of the behavior
  - in terms of the cyber-entity's fitness (i.e. the degree of adaptation) to environment.
  - Then, relationship strength values are modified based on the effectiveness.
- If a cyber-entity selects a behavior that increases its fitness, the strength of relationships connected with the behavior will be increased.
  - Otherwise, it will be decreased.
- If a cyber-entity invokes a behavior that increases its fitness, bionet behavior selection engine memorizes (i.e. caches) the pairs of the behavior and environment condition.
- This memorized information is used for future behavior selection:
  - when the future environment matches memorized condition, a corresponding memorized behavior will be invoked.