Development of Haptic Perception by Homogeneous Active Elements

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When we move our fingers across the surface of objects, we can obtain tactile sensations of its shape, roughness and material and categorize these sensations into a perception of the object. The feelings of various objects can not be deduced from the instantaneous sensations of our fingers. These sensations exist inside the dynamics of our body and nervous system, that is affected by both the environment and our spontaneous movement.

Gibson discussed the importance of spontaneous exploratory motion in haptic perception (Gibson, 1962). Some simulation models of active perception have been demonstrated previously (Nolfi and Marocco, 2002).

In our simulation model, an agent has a body that consists of six homogeneous active elements connected by springs to a central mass. The body is on toroidal surface in a three dimensional gravitational space. Each active element is pushed or pulled towards the central element according to the state of the element, and the state is affected by the length of the three connected springs (proprioception) and states of the two adjacent elements (signal transmission). Figure 1 shows an example of our simulation. The details of the model are described in (Morimoto and Ikegami, 2006).

In this paper, we present a developmental process of obtaining active perception of the bumps on the surface. The following factors are required for the agent's perception:

- differentiation of the states of active elements to allow spontaneous movement
- sensitivity to the curvature of the surface, which is transmitted as the spatial difference of external forces between elements
- to detect the direction of the gradient through body movement

The agent's control parameters are improved by greedy mutation over a sequence of random hill-climbing tasks. The score at each task is the average height of the agent's central mass. The control parameters are mutated if the score in the same environment improves by using the new values. Each environment has two hills and two hollows, the height (or depth) and radius of each is chosen randomly each iteration.

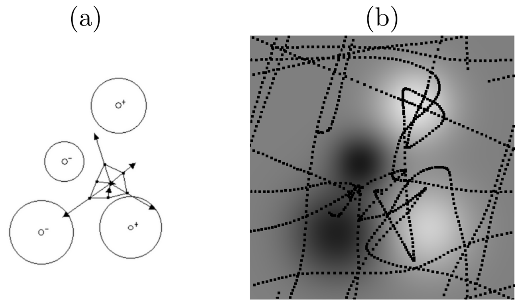

Figure 1: An example of our simulation. (a) Two hills and two hollows with various heights and sizes are positioned in two dimensional toroidal space. Six homogeneous active elements are differentiated. Arrows show forces on elements. This coordination leads to a spontaneous movement towards 2 o'clock. (b) Trajectories of the central element. Lighter shades show higher positions. The well-developed agent, after 20,000 iterations, moves quickly through flat regions and tries to avoid hollows and approach hills.

Figure 2 shows the improvement of the score over time.

At the initial stage of development, the states of all the elements are equal and the shape becomes hexagonal. The agent makes no spontaneous movement and slides down into hollows.

At the early stage (Figure 3), the agent begins passive avoidance of hollows. After about 1,300 iterations, states of active elements differentiate and the equilibrium shape becomes asymmetric, which makes it possible to move straight in flat regions. In addition, if some elements are pulled outside by the external force, the central element pulls them back and the body can avoid hollows.

At the middle stage (Figure 4), two different strategies are observed. One is a slow movement more sensitive to curvature and the other is a fast

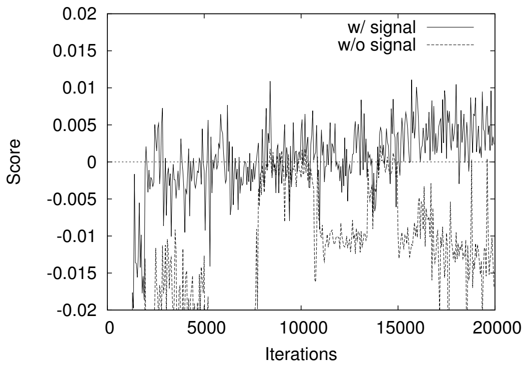

Figure 2: The development of the score of the hill climbing task. At the middle stages of the development, the expected score is close to zero. At the later stages, the expected score is positive, that means the agent can discriminate the hills and hollows while exploring the space through spontaneous movement. If the signal transmission between the adjacent elements is cut, the agent can still passively avoid hollows, but approaching hills seems impossible.

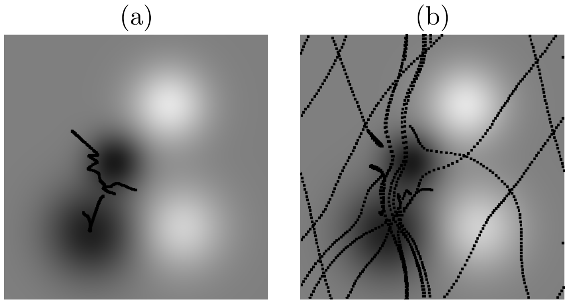

Figure 3: Acquisition of spontaneous movement at the early stage. (a) Trajectories after 1,000 iterations. (b) Trajectories after 1,500 iterations. The agent breaks symmetry and moves almost straight. It is attracted by hollows (the darker regions) and avoids them.

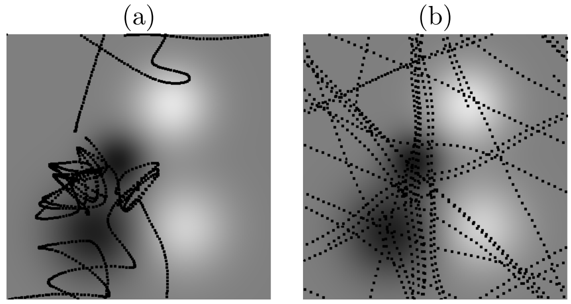

Figure 4: Two strategies competing through the iteration at the middle stage. (a) Trajectories after 5,000 iterations. Spontaneous motion is slow and sensitive to the curvature of the surface. (b) Trajectories after 7,000 iterations. Spontaneous motion is fast and not sensitive to the curvature.

movement that is less sensitive. Expected scores of both strategies are close to zero. Variance of scores by the first strategy in random environments is larger than that by the second strategy.

At the later stages of development, the agent can integrate the two strategies. It moves relatively fast through flat regions. It can also turn direction to try to avoid hollows and approach hills by altering the roles of active elements. Figure 1(b) shows an example of the motion of a well-developed agent. We found that the last step of the development, acquiring spatiotemporal coordination, is possible only if the signals can be transmitted between adjacent elements (Figure 2).

The interesting point is that the model agent has no explicit sensory inputs; environmental information is only transferred to the agent implicitly through modification of the springs that connect the elements. The springs are also modified by the activations of the elements. Implicit coupling between sensory inputs and motor outputs may provide an origin of active perception (Iizuka and Ikegami, 2005). By coupling with the environment the agent's elements are differentiated which allows it to move coherently. Namely, the role of structurally identical active elements is only determined epigenetically.

We may conclude that appropriate coordination of proprioception and self activation can allow an agent to use homogeneous elements for both sensory and motor activities. Without explicitly adding sensations to an agent, it can still improve its performance in an *ecological* context by developing its own active perceptions.

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