Route Learning and Map Making

(O'Keefe, J. and Nadel, L., "Spatial behaviour", in *The Hippocampus as a Cognitive Map*, Clarendon Press, Oxford, 1978)

Of interest is determining how people actually encode the spatial information used for learning routes and navigating about their environmental. As is often the case, the current theories of human spatial representation is based on animal studies.

Many studies have been performed on the mental processes used by animals for navigation.

For example birds appear to use a "map-and-compass" approach, where it is postulated that birds have an internal map by which it can locate its present position and that of the goal, and a compass which allows it to align the map to determine the direction to the goal.

The compass information is thought to arise from measuring the sun's azimuth relative to time of day, as well as possibly from geomagnetism. Some birds can use the stars to determine direction as well.

Birds do not appear to use landmarks, or follow routes.

Studies of how rats burrow have shown that rats use a complex system of kinesthetic-vestibular cues for orientation, coupled with a previously acquired mental map. Rats will run to a place even if the route using the path originally learned is blocked. Thus they don't seem to be learning just a sequence of actions.

Wolves also appear to use cognitive maps, rather than learned routes. They can take short-cuts or detours, packs can split-up and re-group at distant points beyond communication range, and can return to a rendezvous point from any direction.

Routes

A route is a set of instructions, or stimulus-response-stimulus commands (e.g. at the green house turn left and go forward for 100 meters to the gas station), by which a navigator can proceed from one location to another.

Routes have the following features:

- Routes imply goals, which imply motivations
- Routes direct attention to particular objects and specify actions in an egocentric spatial representation
- Routes are inflexible and must be used in the proper sequence
- The knowledge required to follow a route is usually simple. Routes have little information content
- Routes are reversible

It is easy to get lost while following a route. Cautions should be provided in the route instructions regarding places where mistakes can be easily made.

Corrective measures can also be provided (e.g. if you don't see the gas station, get back on the highway and look for exit 45).

Maps

A Map is a representation of a set of connected places which are systematically related to each other by a group of spatial transformation rules.

Maps should be intrinsically free of reference to any specific object or set of objects. In a topographic map the entities which are located in space are symbols representing objects.

One can locate oneself on a map by looking for several landmarks and looking for these on the map. Two such objects and their spatial relationship will place the observer on the map. Alternatively, one can locate one object together with a direction (from a compass reading or sighting of a distant fixed object such as the north star).

Maps are much more flexible than routes.

Maps have a higher information content than routes (one can derive many routes from a single map).

Maps have the disadvantage of requiring more computation to determine a particular route, or choosing which route out of many possible ones to use. Thus they are slower than route descriptions.

Maps do not rely on particular cues or behaviours and thus are relatively resistant to the effects of environmental change.

Place or Locale Representations

The "Place" hypothesis of cognitive mapping says that there is a neural representation of places in the environment, in terms of the activation of a specific collection of neurons.

Such a place representation can be activated in either one of two ways:

(1) externally, by the simultaneous occurrence of two or more sensory inputs with the appropriate spatial coordinates in ego-centric space;

(2) internally, by an input from another place representation coupled with a signal from the motor system concrening the magnitude and direction of a motion.

With regard to the first, when an observer is at a given location, the cues it perceives have a spatial relationship unique to that location.

If the animal remains in a given location, but rotates in place, these spatial relationships do not change. If the animal translates, however, these spatial relationships do change. Some interaction between the perceived sensory data and the internal movement proprioception is needed to identify and track the procession of places as the animal moves through its environment.

In the case of an internally activated place representation inputs from other place representations are coupled with those from an internal "dead-reckoning" or "inertial-guidance" system. The latter calculated the expected translation/rotation in space concomitant with a potential movement. In the building of a map motor feedback is crucial in assigning representations of things to their appropriate "place" in the place representation.

Active exploration is required to build up a cognitive map. As the animal moves around, different locations in the place representation will get activated and associated with locations in physical space.

Mismatches in predicted and actual sensory input associated with a given place representation location could be used to direct the motor systems used in exploration (please recall the discussion earlier in the course, of the active vision systems of Professor Ferrie's research group that used uncertainty measures in a spatial map to direct further information gathering movements)

Curiosity plays the role of generating actions that serve to construct the cognitive maps!

These place maps have many uses:

- Associating behaviourally important features to places, such as danger, safety, food,...
- Places can be reached from any other place even when landmarks are unavailable.
- New paths can be generated when old ones are closed, as in detour behaviour.

Whenever an organism attends to an object it is encoded in the map. Subsequent attention to that object will not change its representation, hence the system should operate so as to direct the animal's attention away from objects already encoded towards those whose presence is unexpected.

The map can become richer and more detailed but is not altered in any fundamental sense with repeated exposure to the same environment.

It is thought that the locale system is situated in a specific area of the brain, namely the *hippocampus*.

Taxon or Route Representations

The taxon systems generate routes, in terms of lists of guidance and orientation hypotheses.

In a guidance hypothesis an positive or negative action can be attached to a specific cue (approach or avoidance).

The motor system acts as a goal directed device, either increasing or reducing the distance between the organism and its goal.

In orientation, the emphasis is on the specific form of behaviour to be executed in the presence of a cue (e.g. turning of the body in some direction).

Unlike the locale system, the neural locus of the taxon system is not know, and is suspected to involve many sensory and motor areas of the central nervous system.

Again, unlike the locale system, the activation of a representation in the taxon system can elicit a reduction in the threshold for the re-activation of the same representation.

Continued activation of a taxon representation or several successive activations can increase the threshold for re-activation.

The accumulation of activations of any taxon representation over a long period leads to a more or less permanent reduction in activation threshold.

From this we see that, in contrast to the locale system, the taxon system is sensitive to temporal factors.

All things being equal, repeated exposure to a situation in which both place and taxon representations are appropriate will see a shift in favor of the taxon based behaviour with continued training.

The mode of action of the taxon system becomes most evident when the hippocampus is damaged (and in which case the taxon system has to take over the role of the locale system).

The motivation driving the construction of taxon representations is biological need (to obtain a reward or avoid punishment) as opposed to curiosity in the locale representations.