$$m(S, t+1) \geq m(S, t) \cdot \{f(S)/f_{av}\} \cdot p_s \quad ...(23.6)$$

23.7.6 Effect of Changes on Schemata Due to Mutation

We assume that p_m is the mutation probability of a bit in a solution string. If a solution string 1010111 of length 7 belonging to the schemata S_1 = 1*****1 mutates at one bit position to become 1010110 then S_1 is lost. Thus p_m is actually the probability of a bit being destroyed. The survival probability of an individual bit would be $(1-p_m)$. In a schema we need to take into consideration only the changes in the constant bit positions defined by the order of the schemata $o(S)$. Since there are $o(S)$ number of such bit positions, each having a survival probability of $(1-p_m)$, the overall probability of survivability of the schema due to mutation would be $(1-p_m)^{o(S)}$. Since p_m is generally chosen to be a small value, this probability may be approximated to $1 - p_m \cdot o(S)$.

Taking this effect too into account we modify the equation for $m(S, t+1)$ as

$$m(S, t+1) \geq m(S, t) \cdot \{f(S)/f_{av}\} \cdot p_s \cdot \{1 - p_m \cdot o(S)\}$$
$$\geq m(S, t).) \cdot \{f(S)/f_{av}\} \cdot \{1 - p_c \cdot \delta(S)/(L-1)\} \cdot \{1 - p_m \cdot o(S)\}$$

Neglecting the product of p_c and p_m,

$$m(S, t+1) \geq m(S, t)\cdot) \cdot \{f(S)/f_{av}\} \cdot \{1 - p_c \cdot \delta(S)/(L-1) - p_m \cdot o(S)\}$$

This equation speaks of how the schemata survive over generations and signifies the fundamental theorem of genetic algorithms called the Schema theorem.

23.8 ANT ALGORITHMS

As a tail-ender and food for thought we take a brief look at the manner in which one of nature's creations—Ants—can trigger our search for new algorithms. Ants are capable of navigating complex terrains in search of food. They also find their way back to the nest. Over a period of time a colony of ants are able to find the best or shortest path between the food source and the nest. So how do they achieve this? As they navigate they keep laying pheromones which tend to modify their environment and serves as a means for communication amongst them in the colony. Pheromones are chemicals that are volatile and give way over a period of time. All ants choose to move over tracks of high pheromone concentration. In the beginning each ant goes in search of food and as they move the pheromone is laid along the path. When an ant finds the food source it starts its return journey along the same path and adds to the pheromone concentration along it. Since the colony comprises a large number of ants, a parallel search ensues. Chances are that several of them discover the food source through different paths. Naturally the ant that found the closest path (out of all those discovered so far) would over a period of time shuttle up and down more number of times than its counterparts. This increases the pheromone concentration of the shortest path and forces other ants too to choose it. Over a period of time only the shortest path exists while other paths fade away due to pheromone volatility. Figure 23.13 depicts two ants A and B using this technique. Ant A will definitely reach back to the starting point faster than ant B, thereby depositing more pheromone over a period of time forcing the other to also follow the shortest route discovered. This algorithm can be easily ported onto the well known Travelling Salesman problem. While it may be seen that GAs and Ant Algorithms have not much in common, what is being emphasized here is that the most efficient and yet simple algorithms may be formulated by looking into nature's vast repositories.

23.8.1 Pheromone Trail and Update

A typical Ant Colony Optimization (ACO) algorithm can be used to find the shortest path between a pair of nodes A and B in a simple connected graph G = (N, E) with |N| nodes. A certain amount of pheromone ζ_0 is associated with each arc initially. The movement of the ants is governed by the intensity of the pheromone trail which in turn is updated by the traversing ant(s). The updates done are proportional to the estimated profits gained by the ant. Gains depend on how good the solutions are from the perspective of the ant. Movement from one node to another is decided based on the information about the outgoing arcs. In its simple form, the probability of an ant a at node i taking a path to its next immediate neighbour j is given by

0 if j does not belong to the set O_i of the immediate neighbours of i

$$p^a_{ij} = \zeta_{ij} / \sum_{j \varepsilon O_i} \zeta_{ij}$$

Trails are updated by ants by depositing a constant value of pheromone on the arcs every time they traverse it. Thus as ant moves from node i to node j at time t, the value of $\zeta_{ij}(t)$ changes to $\zeta_{ij}(t) + \Delta\zeta$. This tends to increase the probability of this arc being used by other ants. To avoid overcrowding due to high pheromone concentration on sub-optimal paths (leading to a local minima in this case), the pheromone is made to evaporate at some rate as in the real ants' world. Evaporation is modeled as an exponential curve

$\zeta = (1 - \gamma)\,\zeta$ where γ is a value chosen in the interval (0, 1).

In the real world ants update their pheromone trails on the fly. In the world of optimization, this method may be tweaked or changed to suit the search domain. Trails could be updated after the ant discovers a solution path. Such trails could be updated based on the fitness of the solution found. The pheromone laid along the paths could be proportional to its fitness. This will force other ants to tread along such hopefully better solutions. The reader is urged to survey both technical literature available on these as also the abundant resources existing in the world around.

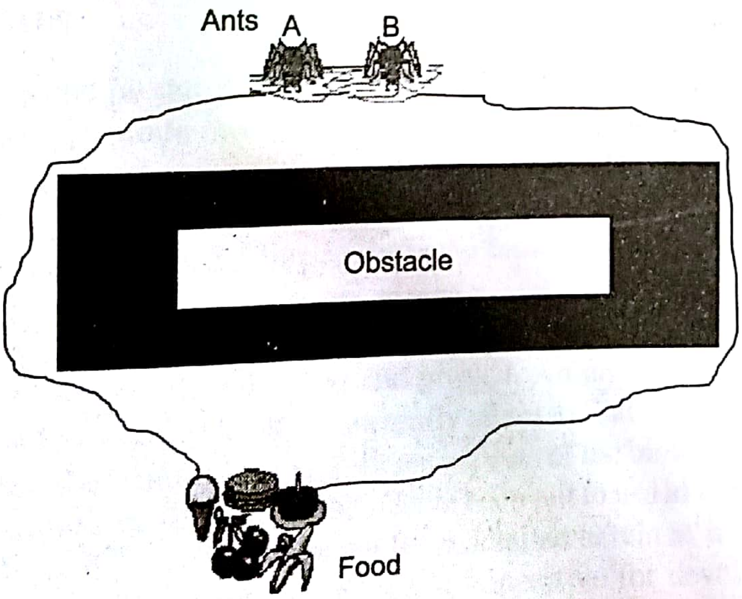

Fig. 23.13

23.9 POINTS TO PONDER

It seems we are all undergoing constant evolution - mentally or physically. Since we are possibly nearing the plateau of change it is difficult for us to easily gauge differences between our previous generations and us. Furthermore, change in nature is not as rapid to be noticeable over short periods (even several thousands of years). ... look the other way at nature we conclude that all living beings as a whole are ... operators doing their job and our survivabili...