Collective Locomotion

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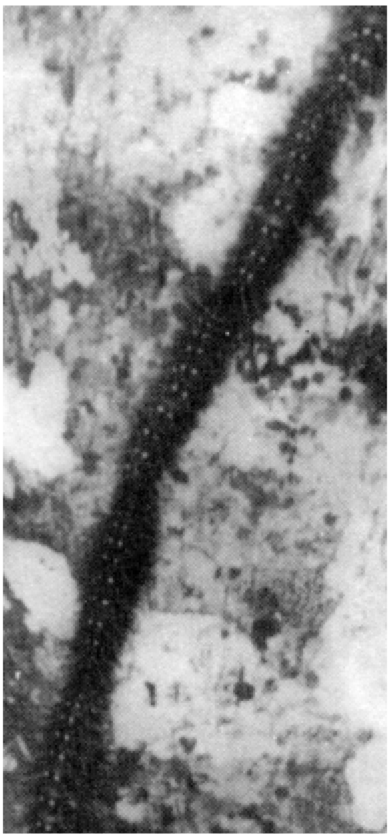
Introduction

We are pursuing a bottom-up exploration of the evolution of behaviours involving collective locomotion of numerous miniature autonomous mobile robots. Collective locomotion is a subset of collective robotics [Bonabeau & Theraulaz 94] which focuses on the specific tasks required to move a group of autonomous agents (e.g. mobile virtual or physical robots) from an origin to a destination. It deals with topics such as navigation, distributed path planning, inter-individual communication, co-operation, auto-organisation, robustness, etc.

Our work is influenced by concepts such as distributed autonomous robotic systems : each robot interacts only with neighbours (within a limited range) and operates on its own, without external supervision [Asama 94]. We reject centralised control systems, since they have multiple restrictions and drawbacks, considered unacceptable for real-world robotics : in such systems, a supervisor needs to communicate permanently with each individual; with a growing number of robots, the limited bandwidth and computational power no longer allows real-time reactions.



A taxonomy for collective locomotion

Animals exhibit many different collective locomotion patterns depending on the number of individuals in the group, on their size, speed, morphology or habits, on the environment and on the task to be accomplished.

We classify the behaviours involving the locomotion of a group of individuals in the following categories : herds (e.g. sheep, cows, etc.), flocks (birds), schools (fish), formations (migrating birds), fronts (grazing animals), processions (insect larvae), swarms (bees) and unstructured groups (young animals following their parent).

Research in collective locomotion

Most papers related to collective locomotion originate from scientists working on disciplines such as computer graphics [Reynolds 87] and artificial life [Hodgins *et al.* 94] [Terzopoulos *et al.* 95], which are both involved with the simulation of artificial creatures moving in virtual environments (mainly fish and birds).

The two main contributions to collective locomotion dealing with real robots originate from M. J. Mataric, who worked with groups of mobile robots exhibiting what she calls a *flocking behaviour* [Mataric 94] and from L. E. Parker who studied group locomotion while developing a general behaviour-based architecture, called ALLIANCE [Parker 96].

Requirements for the different behaviours

The collective locomotion behaviours impose different requirements on the sensors, on the actuators and on the available computational power. From an economical point of view, behaviours involving low sensor complexity, low actuator responsiveness and low computational power are most interesting, since the corresponding robots are less expensive to manufacture. Formations, fronts, processions and swarms match this criterion. These behaviours are mainly exhibited by insects, which are much more primitive than vertebrates, and have indeed less complex "sensors" and a lower "computational power".

A designer might want to chose the group's behaviour in advance and build robots with the appropriate sensors, actuators and computational power. Polyvalent robots might often be a better choice than specialised ones — even if their construction is more expensive — because they will be able to adapt to their environment and chose the behaviour best suited to their situation.

Robustness

Applications involving numerous robots may require high speed, efficient obstacle avoidance, maximal flexibility, minimal energy consumption, low cost, etc. but they all expect a high robustness of the overall system : the dysfunction of one or several individuals should not impair the group's ability to carry out the assigned mission; furthermore, the overall performance should only degrade slightly when a partial system failure occurs.

Robustness can be achieved through distributed decision making (partial failure will not immobilise the whole group) and by avoiding fixed hierarchical organisation (no robot should have to rely on orders issued by a single individual, unless it can be dynamically replaced by any other individual).

The simulator

We plan to set up collective locomotion experiments based on the Khepera, a miniature robot originally developed at the LAMI [Mondada *et al.* 93], see Figure 1. In order to test our algorithms and miscellaneous scenarios, we need a computer generic, highly flexible, realistic and portable simulation platform supporting multiple robots.

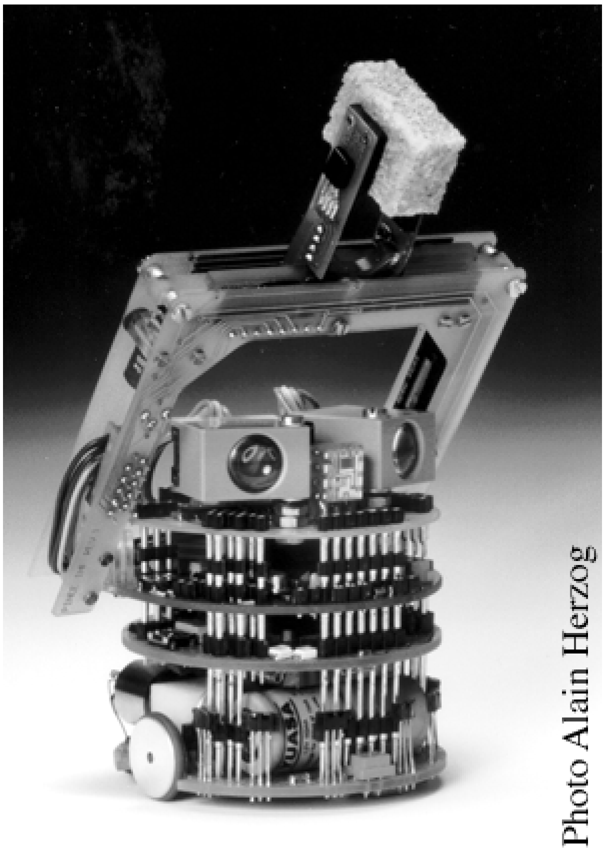


Figure 1. The Khepera robot.

Simulators supporting multiple robots exist, but are either aimed at high-end workstations — the generic computer simulation platform for distributed robotic system development and experiments presented by J. Wang is very similar to our simulator, but it runs on a network of SGI super computers [Wang 96] — or are too simple to support our needs.

The simulator we have developed is based on several components : robots, a position manager, three databases (which store measures from the sensors, robot / sensor / actuator parameters and positions / velocities of the objects moving around in the simulated arena), a system clock and a graphical front-end. This structure is presented in Figure 2.

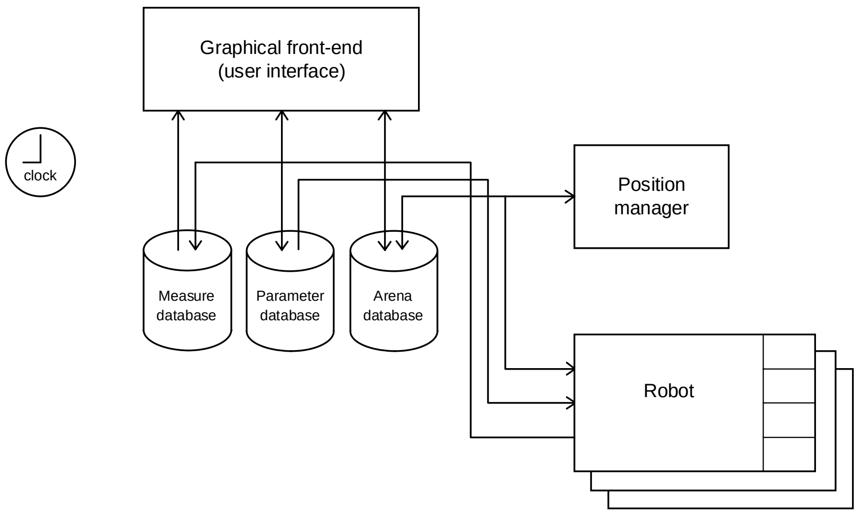


Figure 2. Components building up the simulator.

Figure 3 presents the software model of a simulated robot : information originating from the virtual world is sampled by the sensors. They relay their (possibly filtered or pre-processed) measures to the actors. They implement the algorithms needed to react to the robot's perceptions. The actors are responsible for the robot's low level (instinctive) intelligence. They output a general trend, characterised by a desired vector (usually the robot's velocity) and an associated priority; this can be viewed as a very low level behaviour. The trends are then combined by a special module : the trend manager, which is responsible for weighting them and driving the actuators with reasonable values.

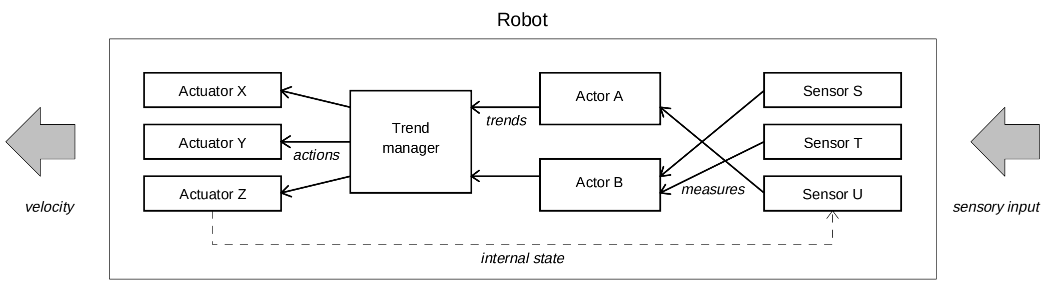


Figure 3. Simulated robot software model.

Our proposed trend architecture is somewhat similar to the subsumption architecture [Brooks 91] : a high priority actor inhibits the other ones. Whereas subsumption totally inhibits inappropriate behaviours, our trend architecture combines all the behaviours — even the less appropriate ones — and generates actions which probability is proportional to the trends' priorities. This can be viewed as some kind of *action fusion*.

Conclusion

We think that the study of collective locomotion, as exhibited by animals, will provide some interesting solutions to complex path planning problems involving numerous mobile robots. Fleets of robots might be used in factories with unstructured environment or in the open air. Specific solutions will be required in order to avoid excessive computation and face the environment's uncertainties.

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