Chapter 2
Fundamentals of Swarm Robotics – An Interdisciplinary Approach

Yet such is oft the course of deeds that move the wheels of the world: small hands do them because they must, while the eyes of the great are elsewhere.

J.R.R. Tolkien in “Lord of the Rings”

We give definitions of important terms and short introductions to related fields of research.

2.1 Definition of Fundamental Concepts

In the following we give definitions for concepts that are fundamental in swarm robotics. These concepts will be used throughout this work.

2.1.1 Agent

An agent is an autonomous entity which perceives through sensors and acts through actuators as defined by Russell and Norvig (1995). They group agents into five classes based on their degree of perceived intelligence and capability. Here, only the first two classes are relevant. The first class is the simple reflex agent which acts based on the current perception only and, thus, without any use of memory. The second class is the model-based reflex agent which manages an internal state as a model of the environment. The agents in this work are reflex agents. Most of them make use of memory. However, they have an internal state that can hardly be called a model of the environment. Typically, they just store their internal state comparable to a finite state automaton, sometimes combined with a floating point variable representing a “virtual feature of the environment” (e.g., value of a virtual potential
field). Thus, the considered agents are hybrids between the simple reflex agent and the model-based reflex agent. Not considered are tele-operated or semi-autonomous robots. In this work an agent will always be a real or simulated robot, thus, we use agent and robot as synonyms. In principal, animals, for example, bees or ants, can also be such an agent which is not excluded.

### 2.1.2 Agent–Agent Interaction

An agent–agent interaction is basically the encounter of two robots with mutual influence. In a simple example, such an interaction occurs when robots $A$ and $B$ recognize each other as obstacles and they rotate away from each other to avoid a collision. This is called collision avoidance behavior. If only robot $A$ perceives $B$ this encounter could also be an interaction but with influence to robot $A$ only. This is an inadequacy of the literal sense of “interaction” as $B$’s contribution is only passive by entering the sensor range of robot $A$. For simplicity, the mere encounter of two robots will be called collision in the following.

### 2.1.3 Macroscopic and Microscopic Level

The microscopic level (or micro-level) of a multi-agent system is the individual level. In a microscopic description of a multi-agent system the individual agent is addressed, that is, we can determine, for example, trajectories of agents and distances between agents.

The macroscopic level (or macro-level) of a multi-agent system is the group level. Individual agents are not addressed as we work only on group fractions or densities of agents, that is, trajectories of individual agents cannot be determined, only, for example, a mean trajectory of the swarm’s barycenter.

A level in between is also conceivably even though of less relevance. This intermediate level can be called mesoscopic. In a mesoscopic description neither individual robots are represented nor do we have a fully abstract model of agent densities. An example is the Boltzmann equation in physics, which models agent densities but also agent velocities and collisions.

### 2.1.4 Phenomenological Approach

In this work the adjective phenomenological will be used without a deeper philosophical meaning in the sense of phenomenology (Moran, 2000). In the natural sciences it is rather used to describe preliminary approaches that just describe phenomena instead of applying a profound theory or interpreting the observed features. For example, a phenomenological approach to swarm behavior is to develop a macroscopic model based on the observed swarm-level features that describes the swarm behavior. However, such a model will not have much explanatory power without any connection to the underlying microscopic rules. Say, we assume that the macro-behavior is defined