

## Modeling though Machine Learning in Robotics

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Artificial systems are becoming more and more complex, almost as complex in some cases as natural systems. Up to now, the typical engineering question was “*how do I design my system to behave according to some specifications*”. However, the incremental design process is leading to so complex artifacts that engineers are more and more addressing a quite different issue of “*how do I model the observed behavior of my system*”. Engineers are faced with the same problem as scientists studying natural phenomena. It may sound strange for an engineer to engage in observing and modeling what a system is doing, since this should be inferable from the models used in the system's design stage. However, a modular design of a complex artifact develops only local models that are combined on the basis of some composition principle of these models; it seldom provides global behavior models.

These general remarks hold in computer sciences throughout several examples of complex systems, ranging from multi-core processors to internet networks. This talk will illustrate the global approach of observation and modeling on the problem of understanding and predicting the behavior of a mobile robot. Robots are becoming very complex, with a large number of sensory-motor functions combining dozens of actuators and sensors, offering the capabilities of many navigation and manipulation skills, and allowing the execution of sophisticated tasks. The design of these robots usually relies on some reasonable assumptions about the environment and does not model explicitly changing, open-ended environments with human interaction. Hence, a precise observation model of a given robot behavior in a varying and open environment can be essential for understanding how the robot operates within that environment, for predicting its behavior and for improving it.

Machine learning techniques are developed for acquiring the behavior models we are seeking. Three different approaches will be illustrated. In the first approach we learn from experience very robust ways of performing a high-level task such as “*navigate to*”. The designer specifies a collection of *skills* represented as *hierarchical tasks networks*, whose primitives are sensory-motor functions. The skills provide different ways of combining these sensory-motor functions to achieve the desired task. The specified skills are assumed to be complementary and to cover different situations. The relationship between control states, defined through a set of task-dependent features, and the appropriate skills for pursuing the task is learned as a finite observable Markov decision process. This MDP provides a general policy for the task; it is independent of the environment and characterizes the abilities of the robot for the task.

In the second and third approaches, we learn from observations and we model as stochastic automata the behavior of the robot in performing a given task. We use two different techniques:

- Hidden Markov models, where part of the learning problems are how to acquire the finite observation space and the finite state space;
- Dynamic Bayes networks, that can be less readable from a user's point of view, but that are used to improve online the robot behavior.



The talk will explain the main ideas, the tradeoffs, advantages and complexity of each approach, how the robotics experiments have been carried out, and the obtained results. The details of this joint research with several colleagues and PhD students can be found out in particular in the following publications.

- M.FOX, M.GHALLAB, G.INFANTES, D.LONG. Robot introspection through learned hidden Markov models. *Artificial Intelligence*, 170(2): 59-113, Feb. 2006
- B.MORISSET, M.GHALLAB, Learning how to Combine Sensory-Motor Functions into a Robust Behavior. *Artificial Intelligence*, 172(4-5): 392-412, March 2008
- G. INFANTES, F. INGRAND, M. GHALLAB, Learning Behaviors Models for Robot Execution Control. Proc. 17th European Conference on Artificial Intelligence ECAI 2006, Aug. 2006
- G.INFANTES , F.INGRAND , M.GHALLAB. Learning behavior models for robot execution control. 16th International Conference on Automated Planning and Scheduling (ICAPS), Anableside (GB), 6-10 June 2006, pp.394-397

