By a hierarchic system, or hierarchy, I mean a system that is composed of interrelated subsystems, each of the latter being in turn hierarchic in structure until we reach some lowest level of elementary subsystem. In most systems of nature it is somewhat arbitrary as to where we leave off the partitioning and what subsystems we take as elementary. Physics makes much use of the concept of "elementary particle," although the particles have a disconcerting tendency not to remain elementary very long . . .

Empirically a large proportion of the complex systems we observe in nature exhibit hierarchic structure. On theoretical grounds we would expect complex systems to be hierarchies in a world in which complexity had to evolve from simplicity.

– *Herbert A. Simon, 1996*

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- The output of the perception depends on what you will do with it.

Hierarchical Control

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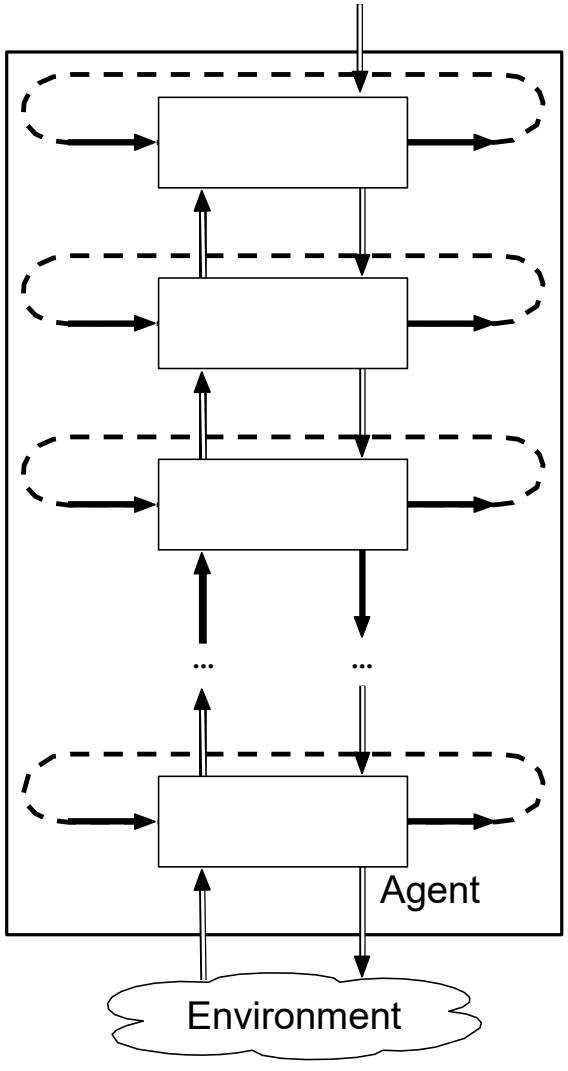
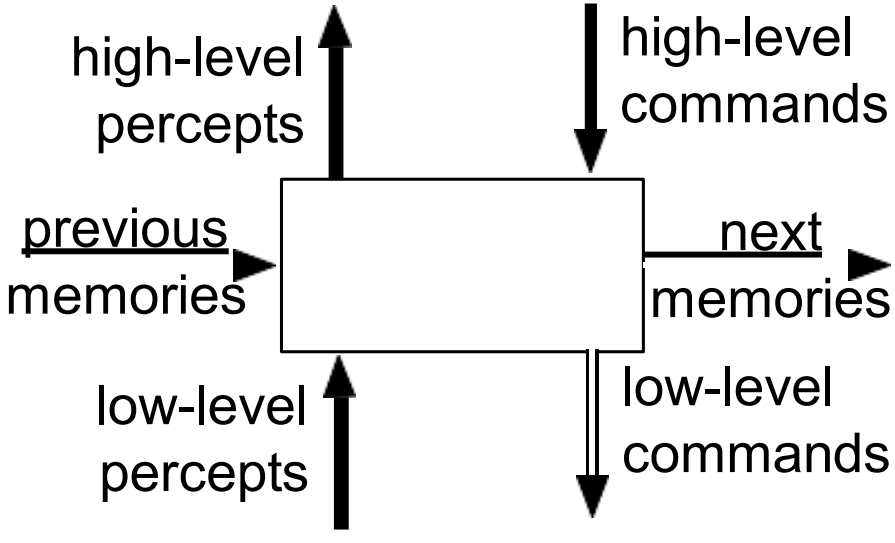
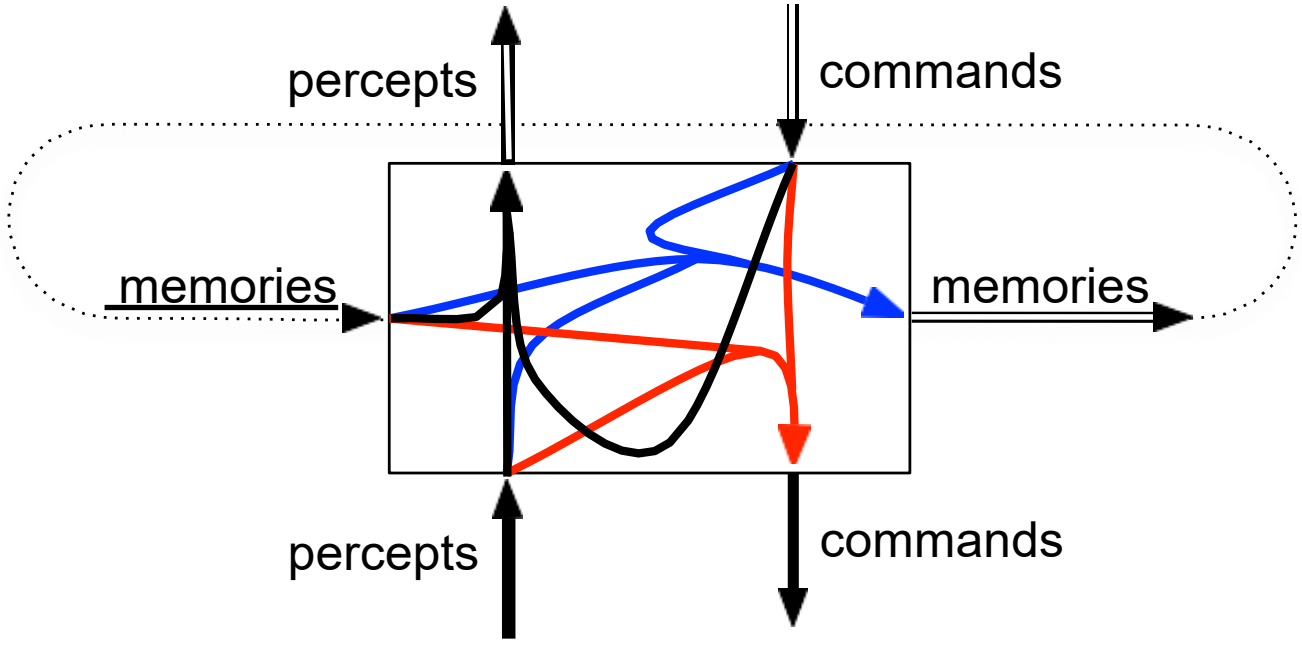
- Each controller sees the controllers below it as a virtual body from which it gets percepts and sends commands.
- The lower-level controllers can
  - run much faster, and react to the world more quickly
  - deliver a simpler view of the world to the higher-level controllers.

Hierarchical Robotic System Architecture





Functions implemented in a layer



- memory function *remember*(*memory*, *percept*, *command*)
- command function

  do(*memory*, *percept*, *command*)
- percept function

  higher_percept(*memory*, *percept*, *command*)

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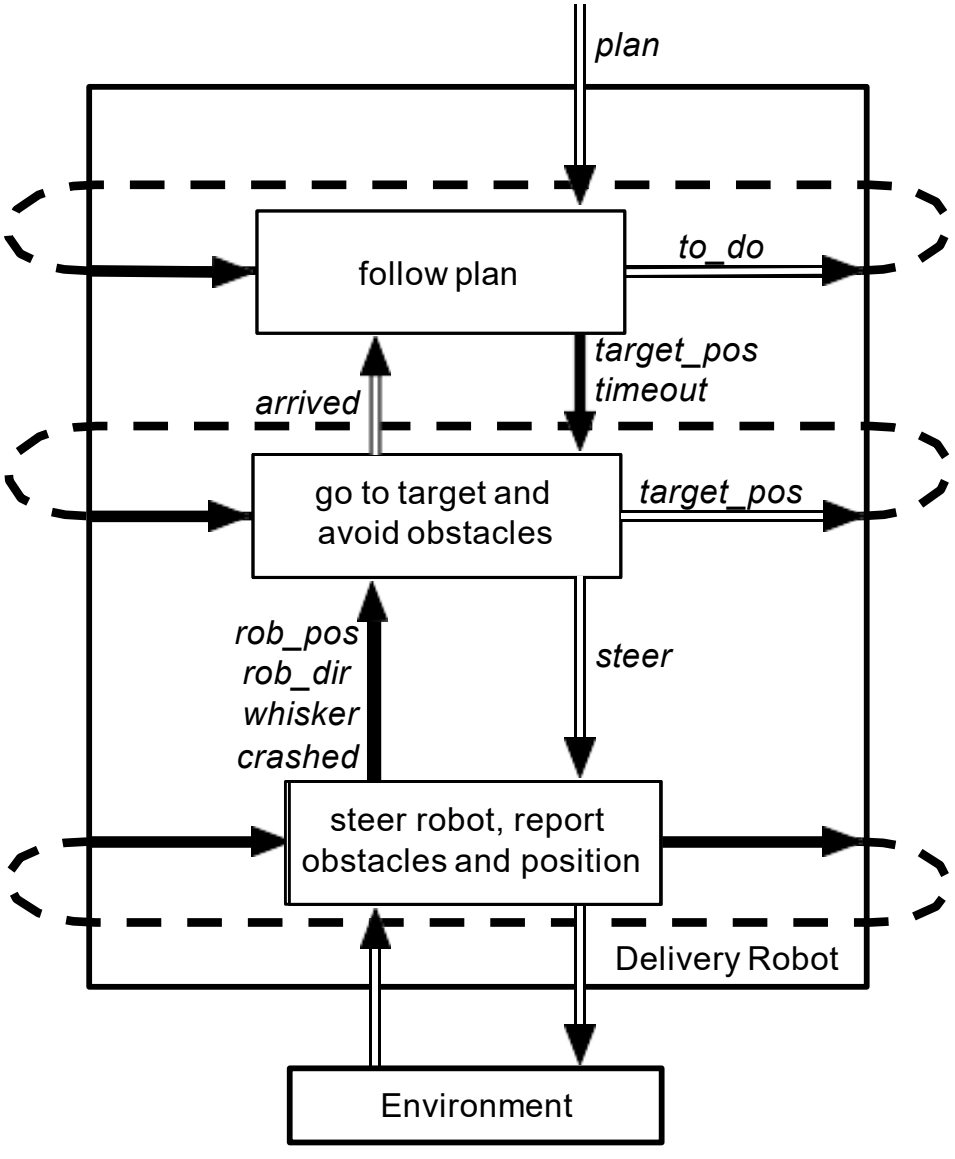
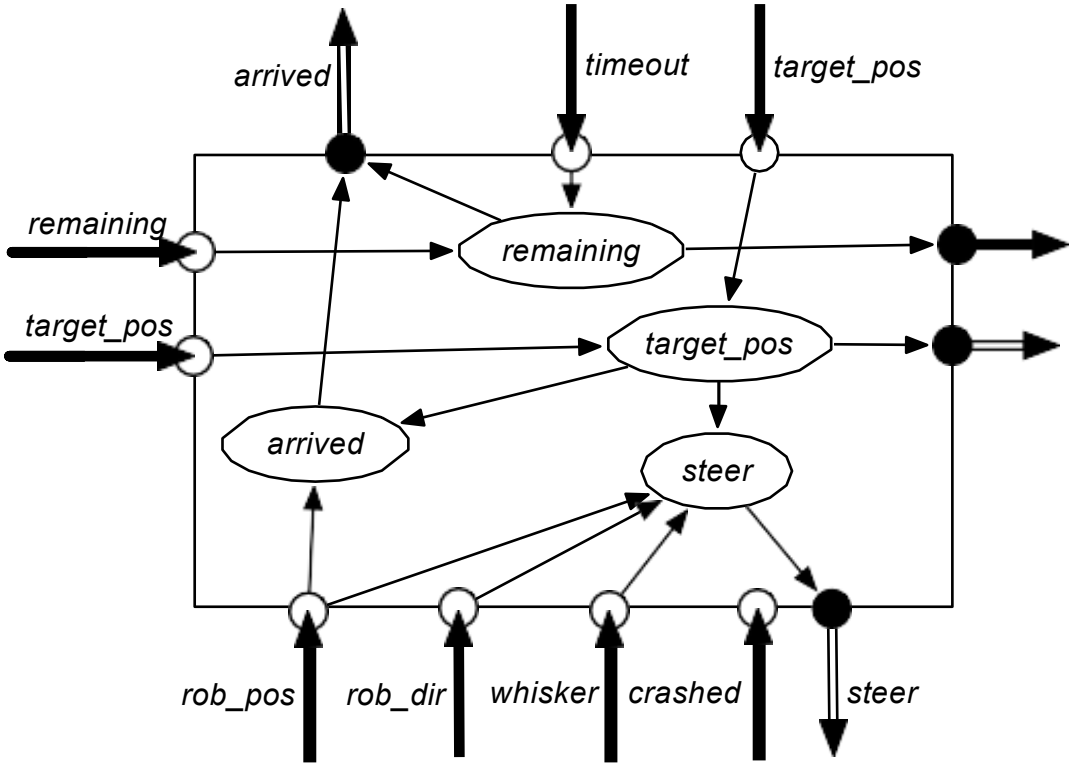
- It has a single whisker sensor pointing forward and to the right. The robot can detect if the whisker hits an object. The robot knows where it is.
- The obstacles and locations can be moved dynamically. Obstacles and new locations can be created dynamically.

A Decomposition of the Delivery Robot



Middle Layer



Middle Layer of the Delivery Robot

```
given timeout and target_pos:
    remaining := timeout
    while not arrived() and remaining /= 0
        if whisker_sensor = on
            then steer := left
        else if straight_ahead(rob_pos, robot_dir, target_pos)
            then steer := straight
        else if left_of(rob_pos, robot_dir, target_pos)
            then steer := left
        else steer := right
        do(steer)
        remaining := remaining − 1
    tell upper layer arrived()
```

Top Layer of the Delivery Robot

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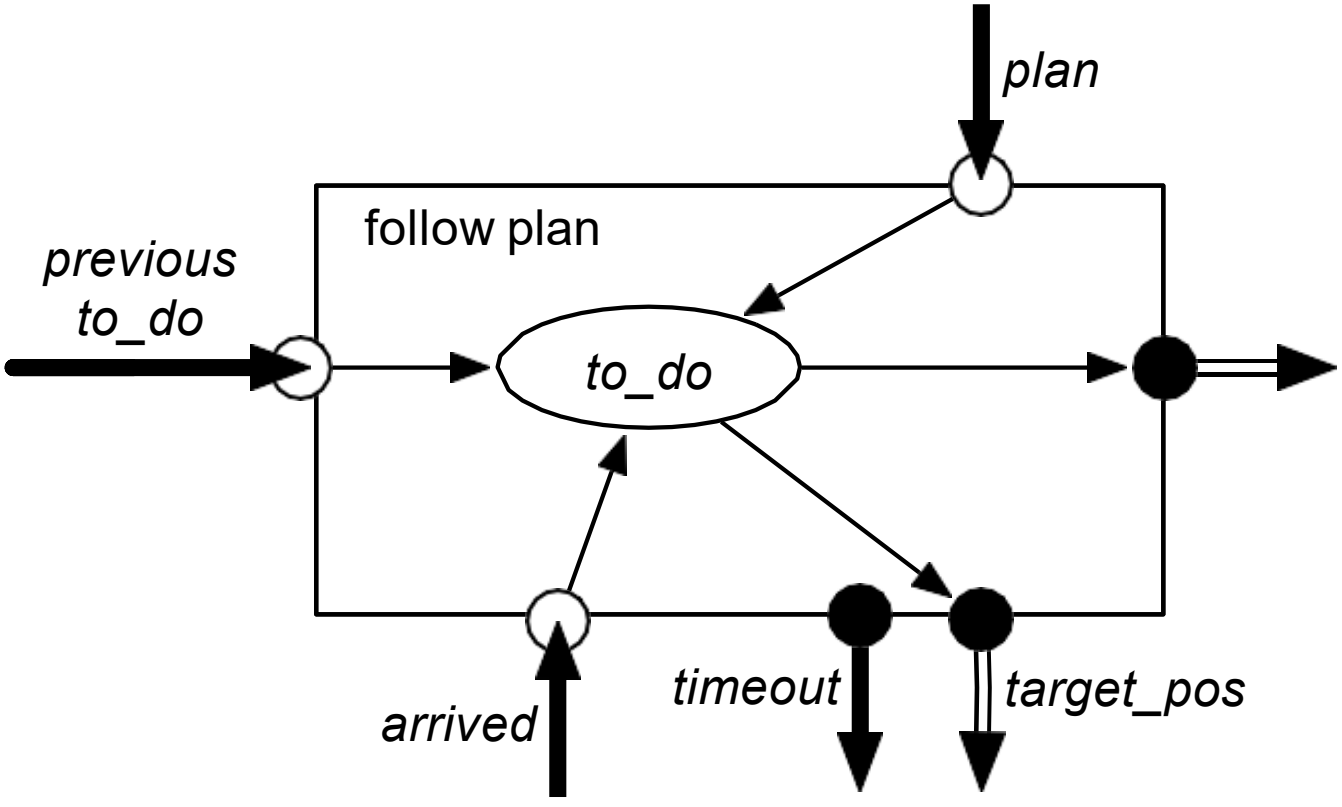
- The top layer tells the middle layer the goal position of the current location.
- It has to remember the current goal position and the locations still to visit.
- When the middle layer reports the robot has arrived, the top layer takes the next location from the list of positions to visit, and there is a new goal position.

Top Layer


plan
follow plan
previous
to_do
to_do
arrived
timeout
target_pos

Code for the top layer

given *plan*:

to_do := *plan*

timeout := 200

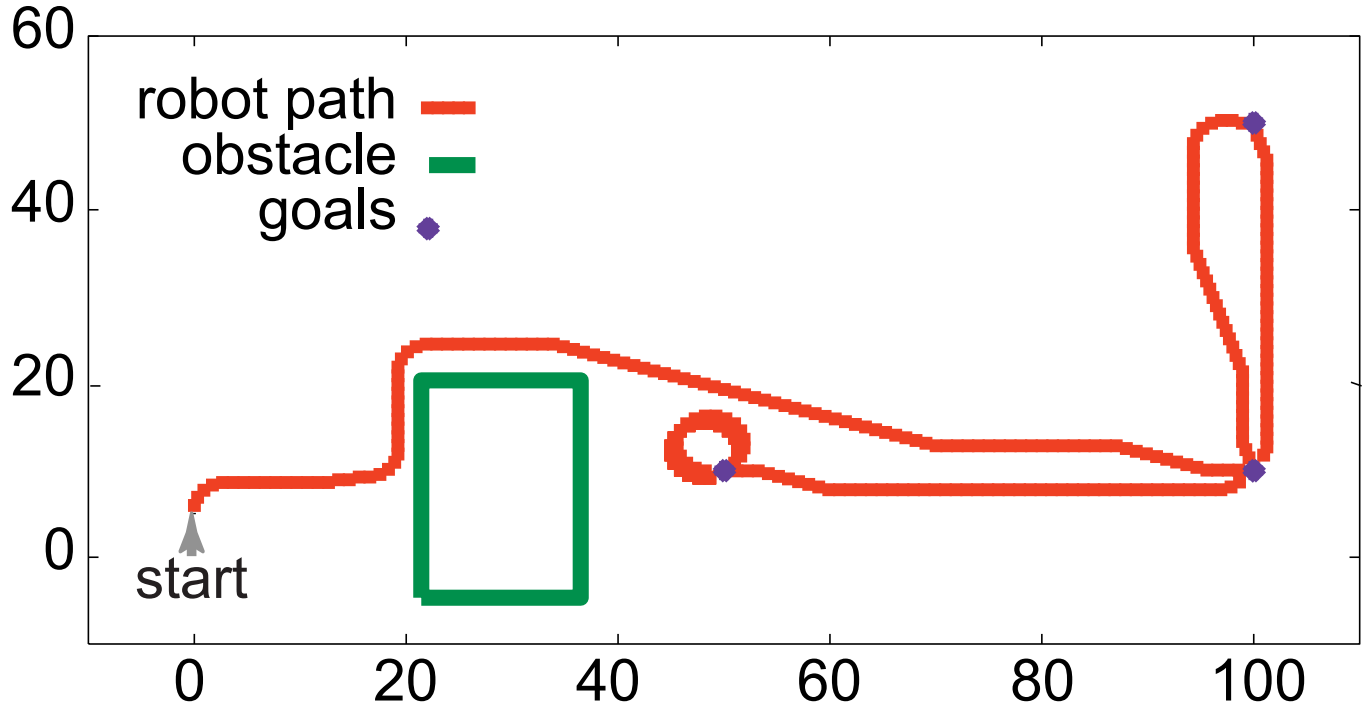
while not *empty*(*to_do*)

target_pos := *coordinates*(*first*(*to_do*))

do(*timeout*, *target_pos*)

to_do := *rest*(*to_do*)

Simulation of the Robot



to_do = [*goto*(*o*109), *goto*(*storage*), *goto*(*o*109),
goto(*o*103)]

arrived = *true*

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- A purely reactive agent doesn't have a belief state.
  A dead reckoning agent doesn't perceive the world.
  – neither work very well in complicated domains.
- It is often useful for the agent's belief state to be a model of the world (itself and the environment).