Layered Control Paper Review

October 2, 2009

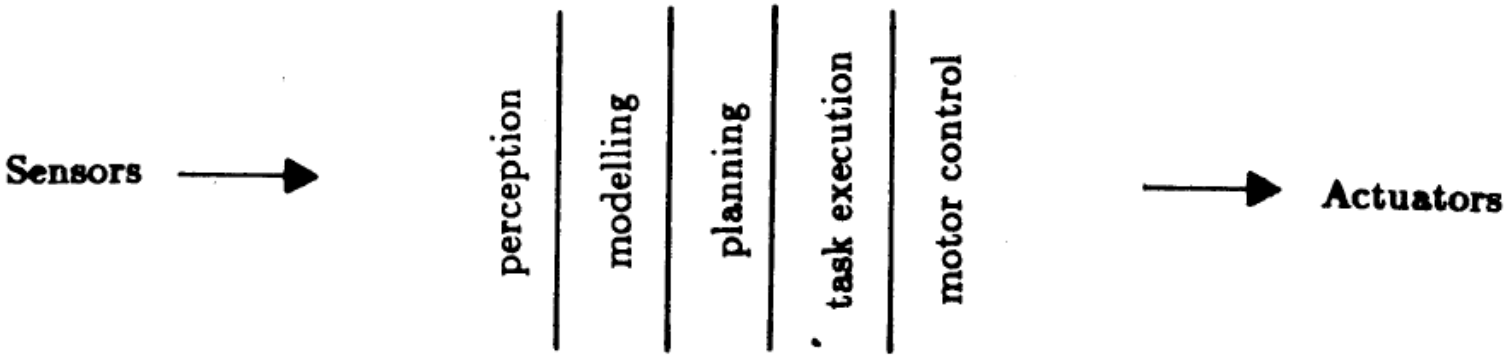
A Robust Layered Control System For A Mobile Robot, 1986

- *Rodney Brooks*
  - *At the time, Assistant MIT Professor*
  - *1997 – 2007, Director MIT AI Lab*
  - *Now, Well Known Roboticist*
    - *iRobot*
    - *Heartland Robotics*

Goal: Create a Robot with increasing levels of competence

0) Avoid contact with objects (whether the objects moving or are stationary)
1) Wander aimlessly without hitting things
2) "Explore" the world by seeing places in the distance that look reachable and heading for them
3) Build a map of the environment and plan routes form one place to another
4) Notice changes in the static environment
5) Reason about the world in terms of identifiable objects and perform tasks related to certain objects
6) Formulate and execute plans that involve changing the state of the world in some desired way
7) Reason about the behavior of objects in the world and modify plans accordingly

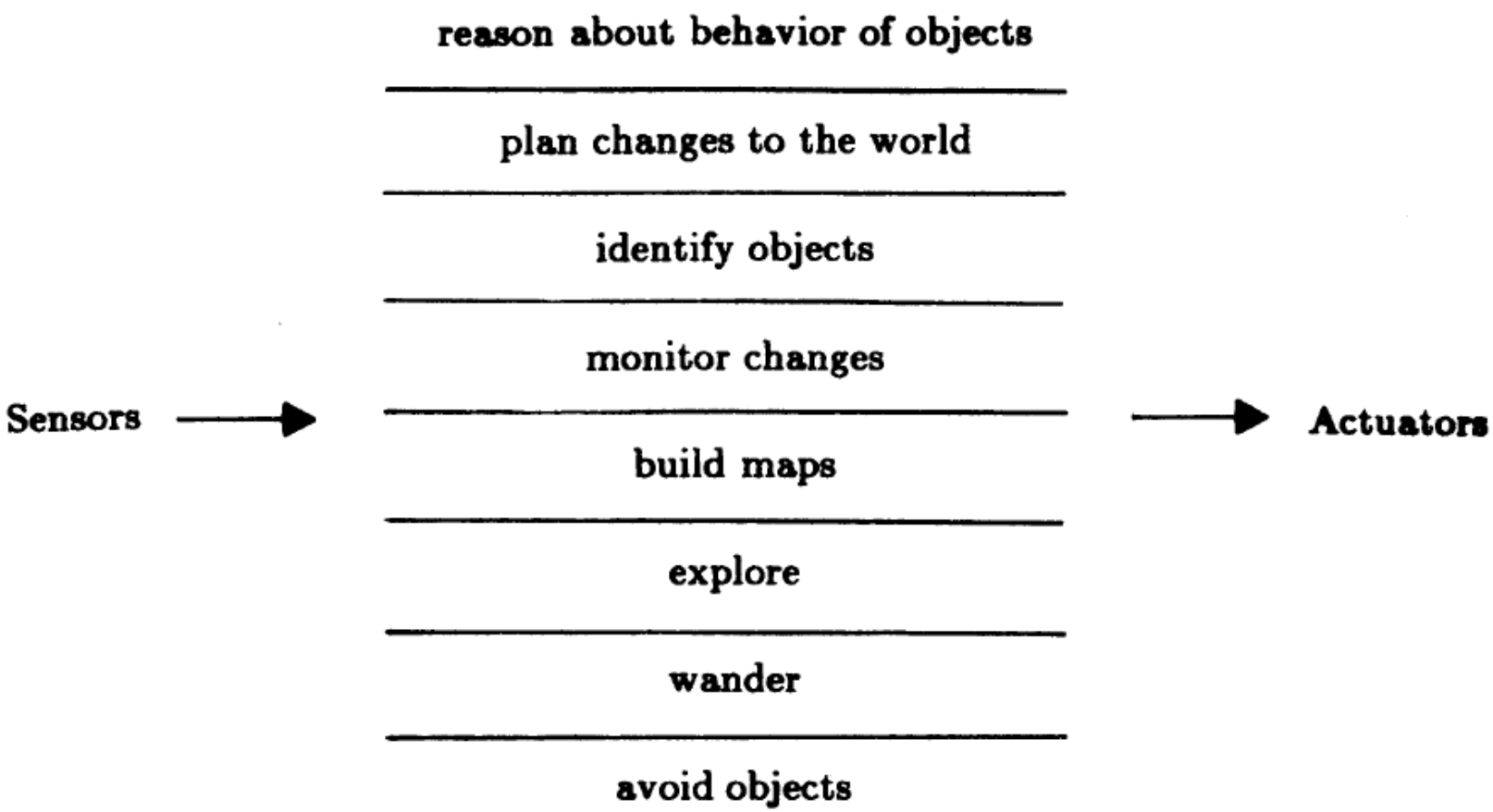
Prior model of robotic control systems



Cumbersome if robot has many goals

- Conflict resolution between goals
- Too much sensory data for some tasks
- Slow (dangerous)

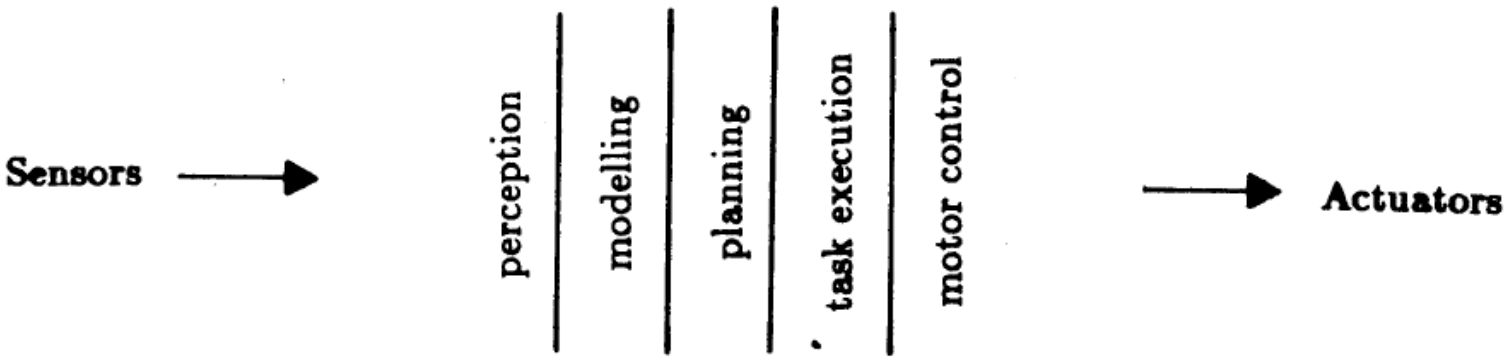
Layered Control



Layered Control

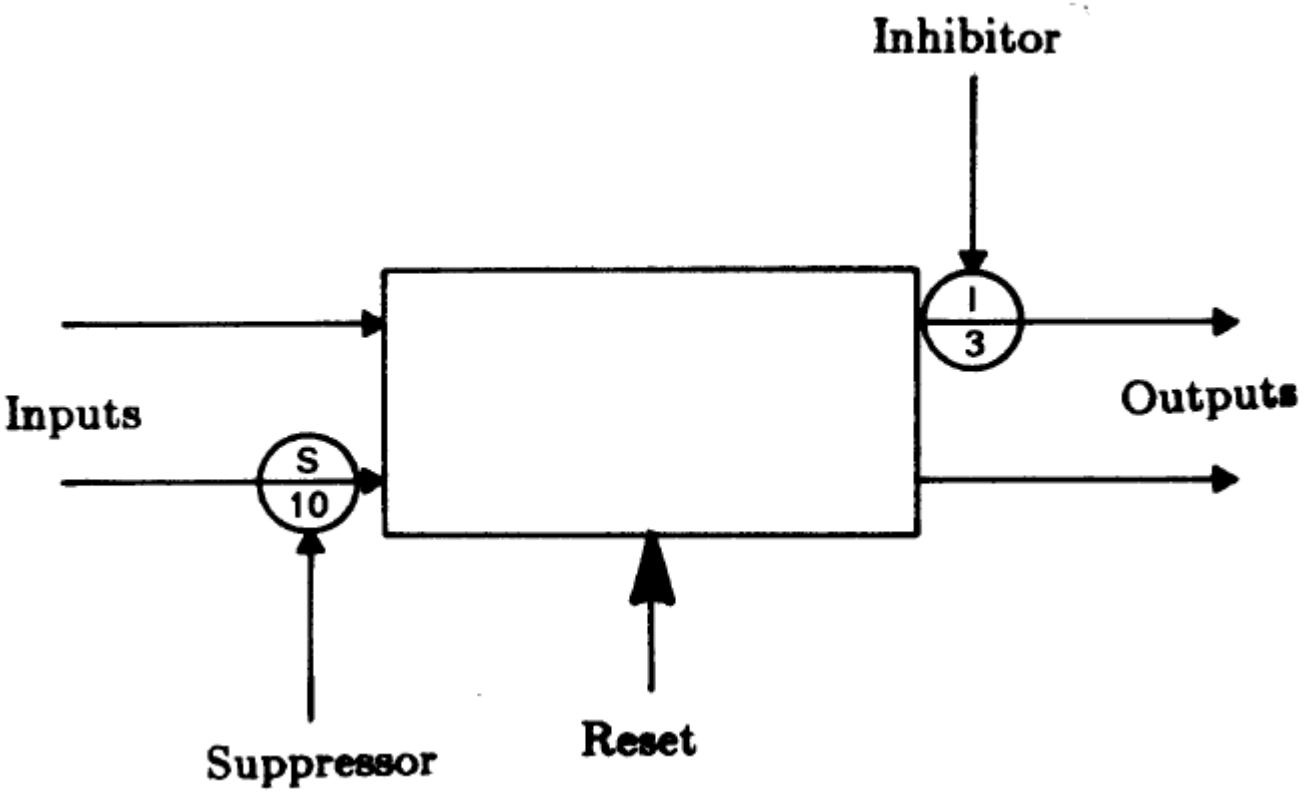
- Sensors need not feed into a central control. Instead, go directly to layer.
- Each layer can process and react on own clock
- Communication is performed by suppressing/modifying input or output

Layers follow old model (sort of)

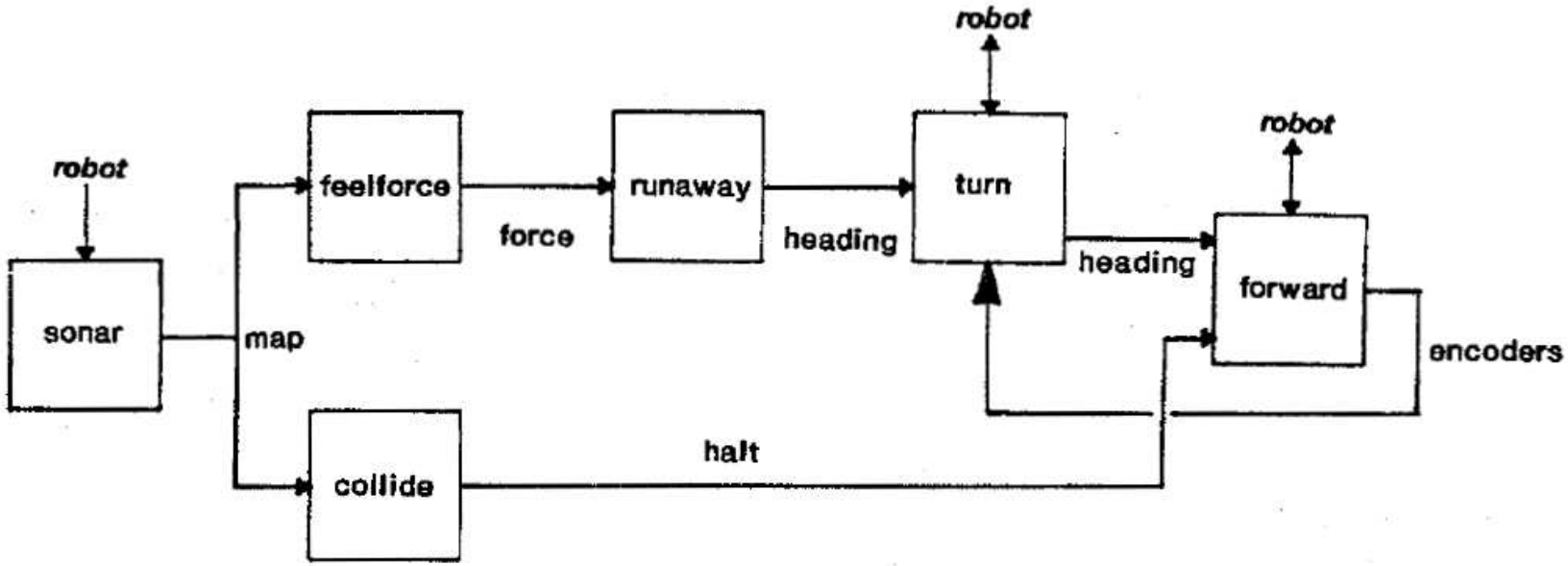


Each layers can actually be further broken down into “modules”

Modules

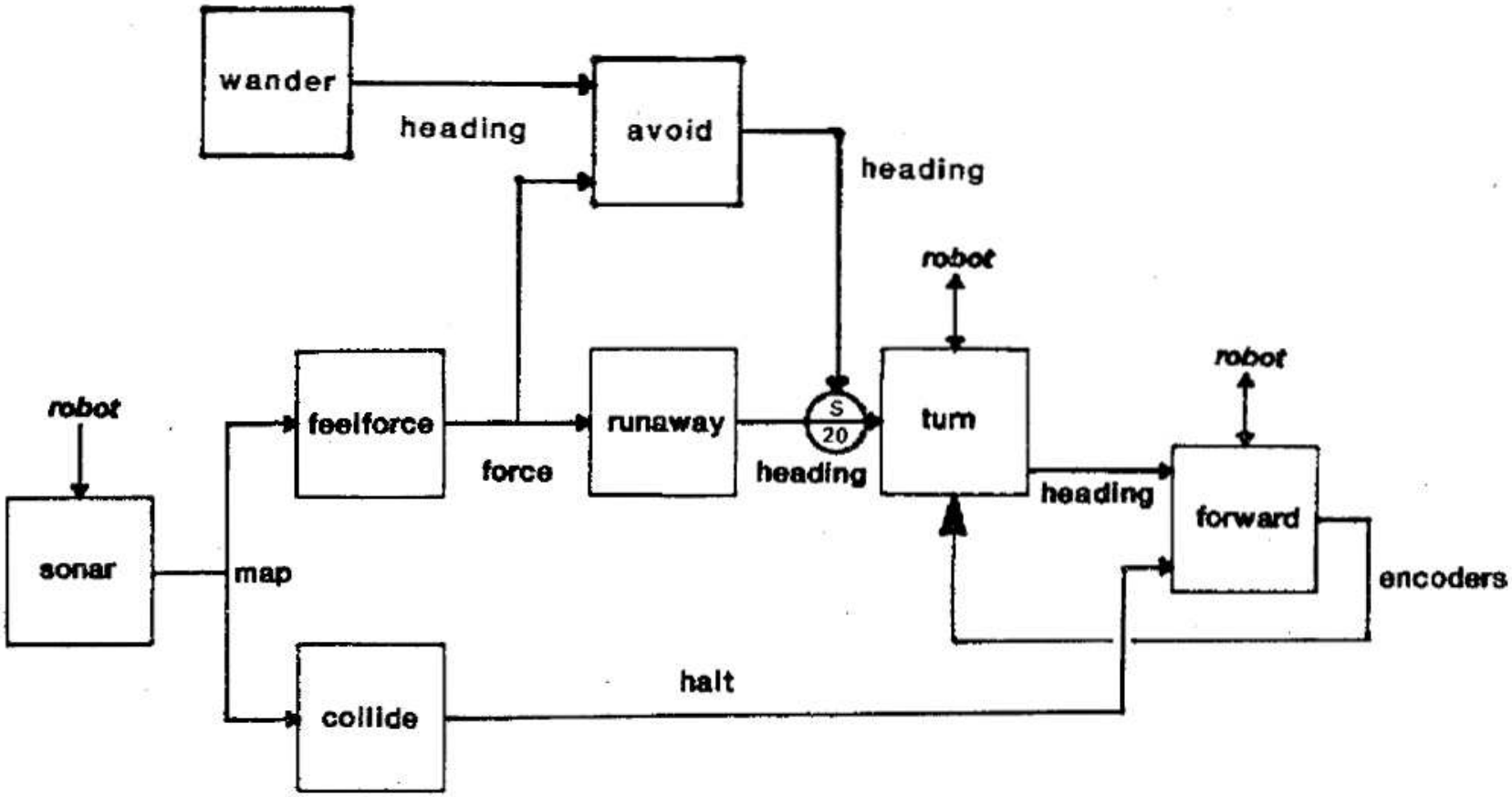


Level 0 Control System



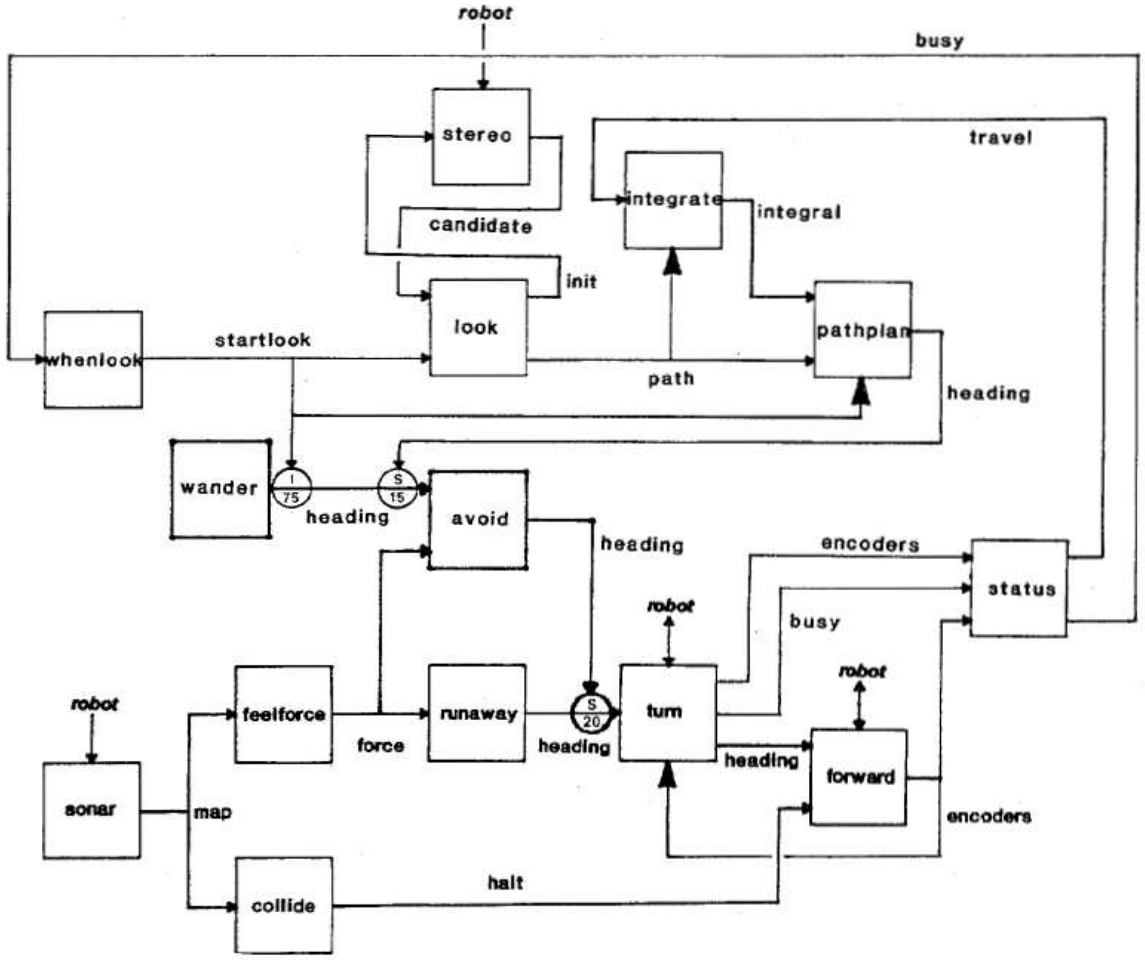
Avoid contact with objects (whether the objects moving or are stationary)

Level 0 Augmented with Level 1



Wander aimlessly without hitting things

Level 2 Added



"Explore" the world by seeing places in the distance that look reachable and heading for them

Simulation Results

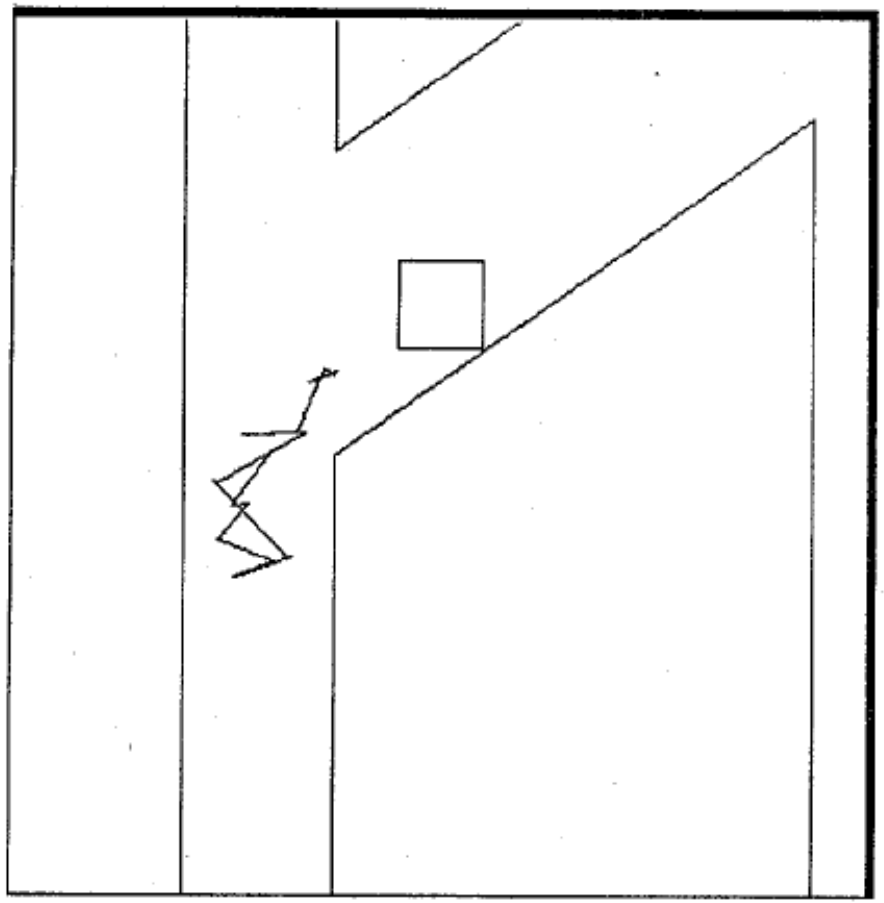
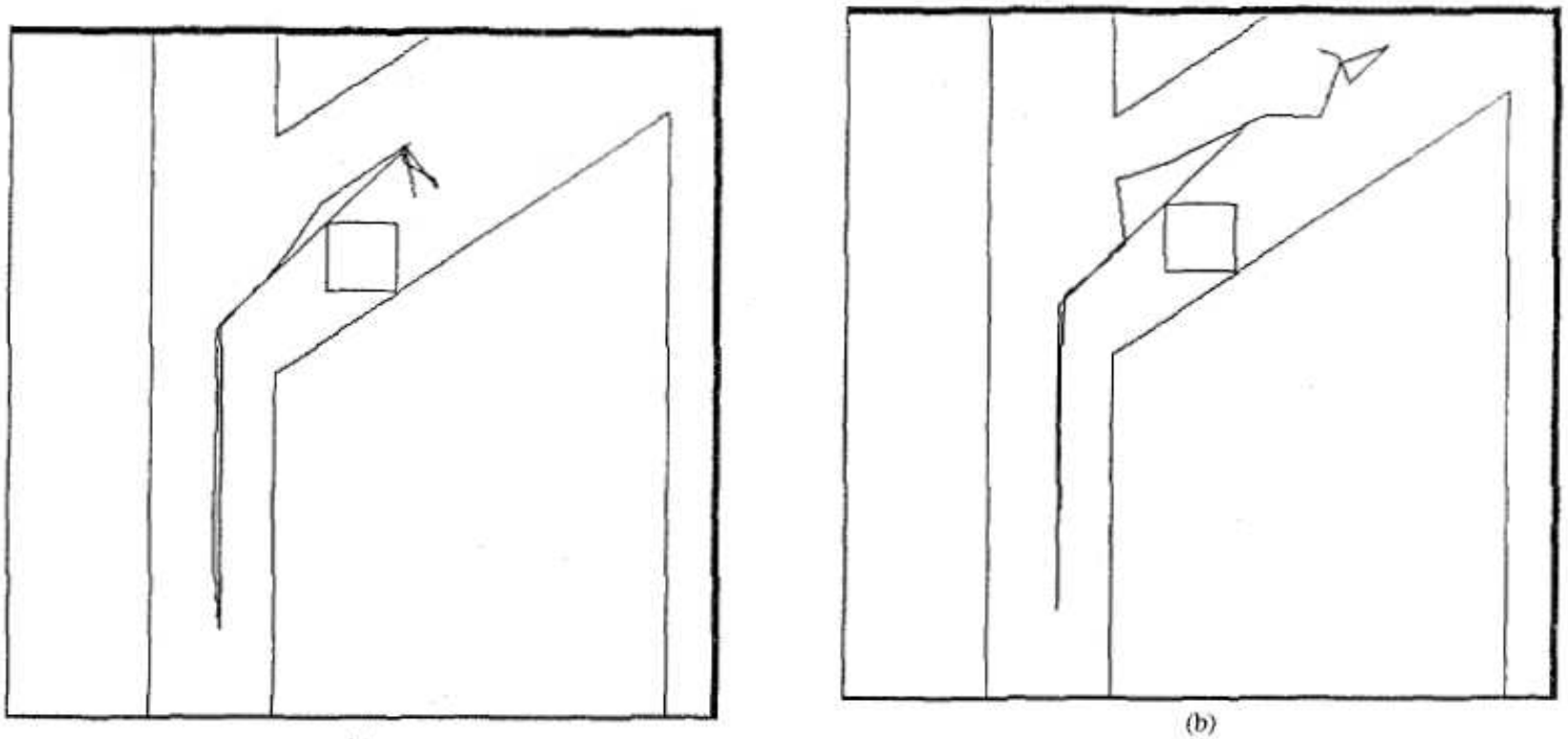


Fig. 9. Under levels 0 and 1 control the robot wanders around aimlessly. It does not hit obstacles.

Simulation Results (Cont)



(a) (b)

Fig. 10. (a) With level 2 control the robot tries to achieve commanded goals. The nominal goals are the two straight lines. (b) After reaching the second goal, since there are no new goals forthcoming, the robot reverts to aimless level 1 behavior.

Physical Implementation

- Level 0
  - Found Center of Room (Farthest from object)
  - Stayed out of people's ways
- Level 1
  - Moved around without hitting objects
- Level 2
  - Picked a goal and headed towards it
  - If goal overshot, did not run into objects b/c Level 1

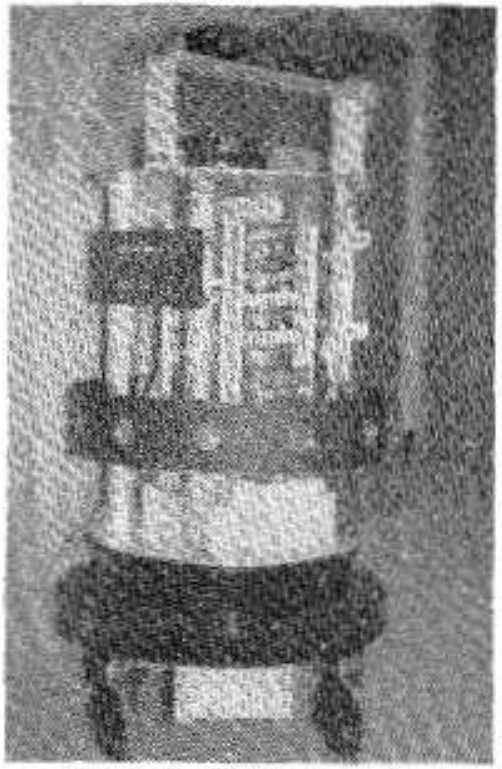


Fig. 11. The M.I.T. AI Lab mobile robot.

Layered Control Benefits

- Multiple Goals
- Multiple Sensors
- Robust
  - Low, Critical layers can be thoroughly debugged independent of upper layers
- Extensible
  - Layers (and even modules) can run independently on their own processors with loose coupling and little bandwidth

Layered Control Benefits

- Robot problems defined by behaviors, not functional modules
- Easy to incrementally build and test
- Processing can be performed asynchronously and in parallel
- No need for central control

State Configured Layered Control, 1990

- Sea Grant Program, MIT

James G. Bellingham

Thomas R. Consi
(Rutgers Alum!)

Goal: Software Architecture for AUVs to Complete Complex Missions

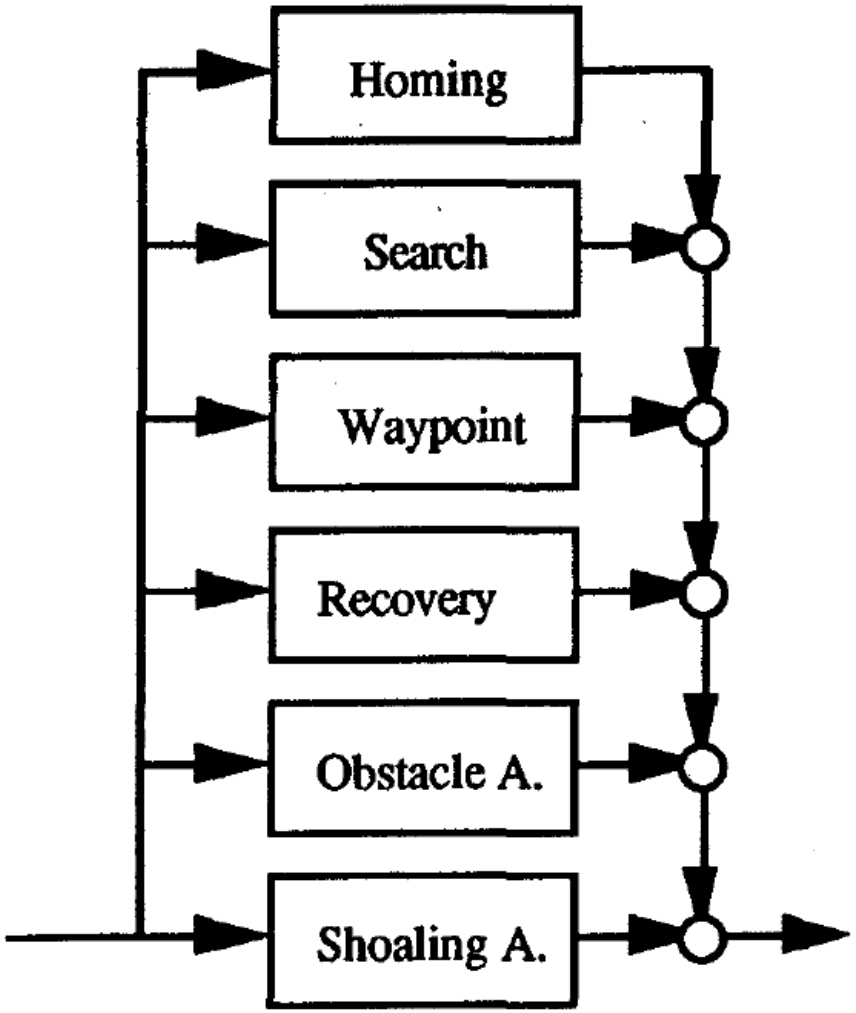
Sea Squirt

Complex Mission

1. Begin in a location
2. Transit to a waypoint
3. Search for a target
4. Travel home for recovery

- During all phases, avoid shallow water and obstacles

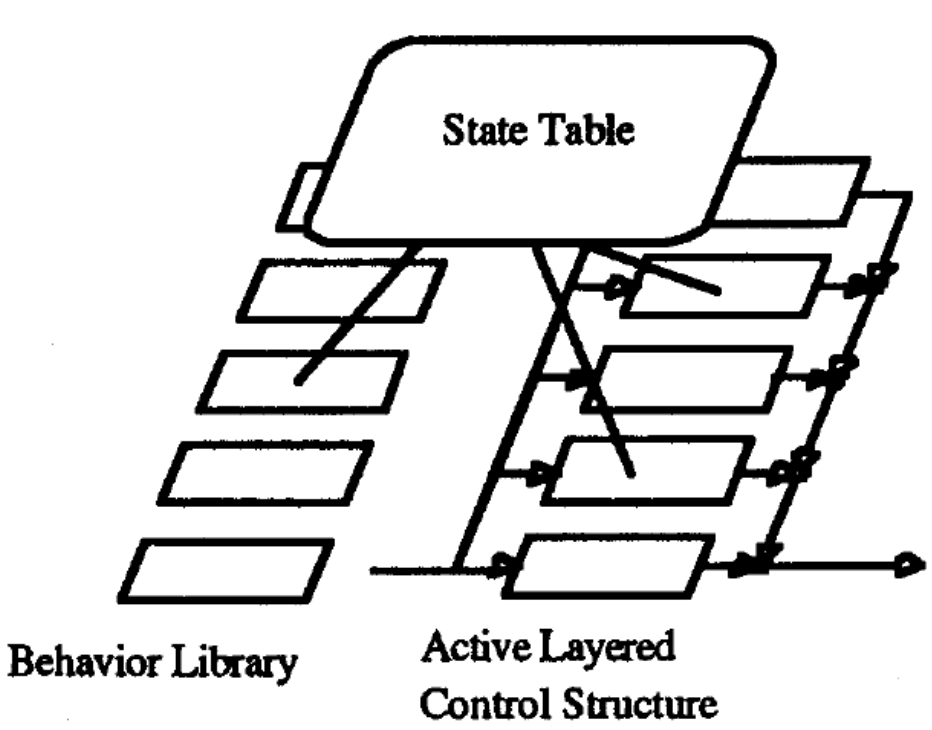
Layered Control



Simplifies problems into layers

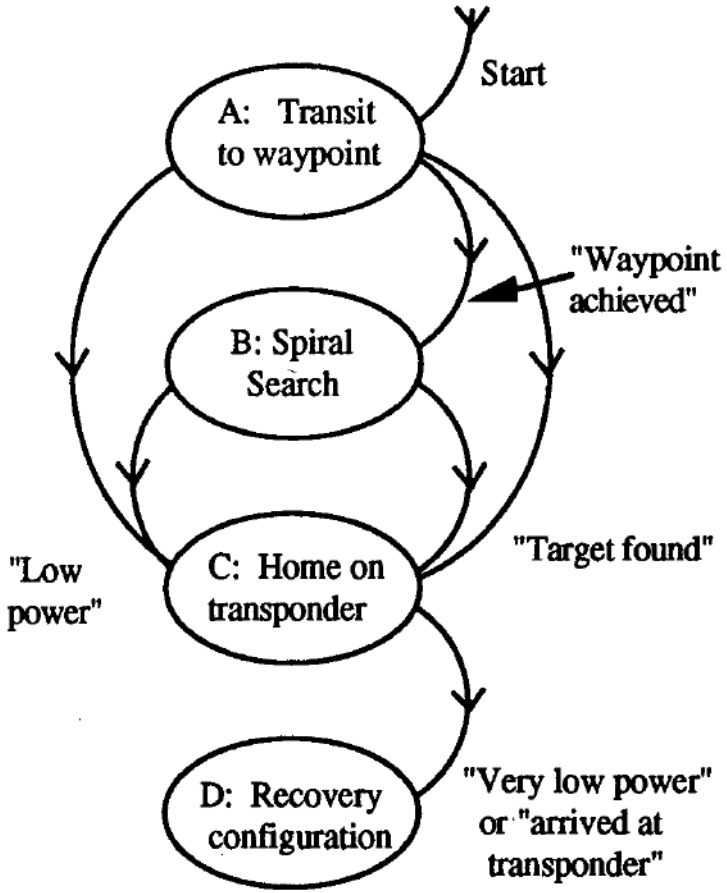
Yet, not all layers are needed during all mission phases

State Configured Layered Control

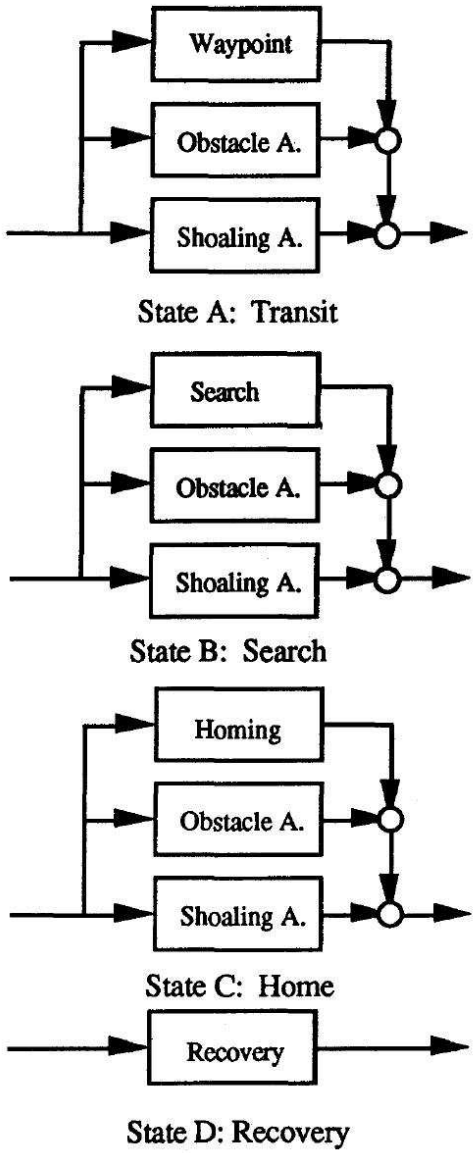


Break control into two levels:

- On the bottom, layered control
- On the top, a state table that activates other layers (behaviors) based on the state (i.e. mission phase)



State Diagram

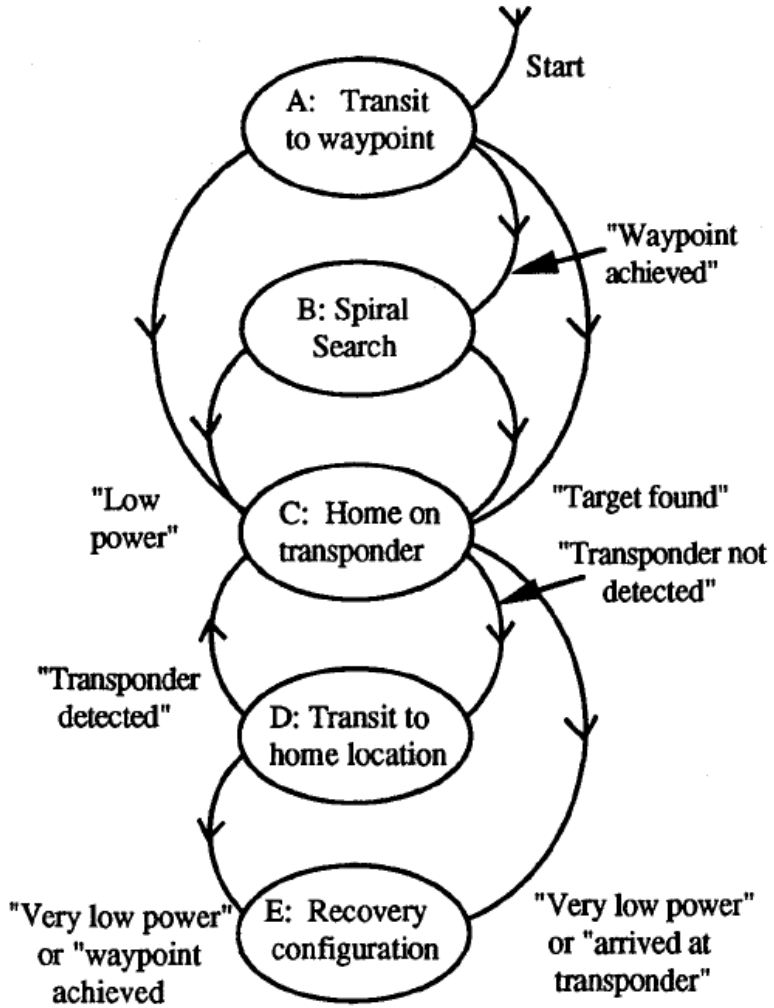


Layered Control Configurations

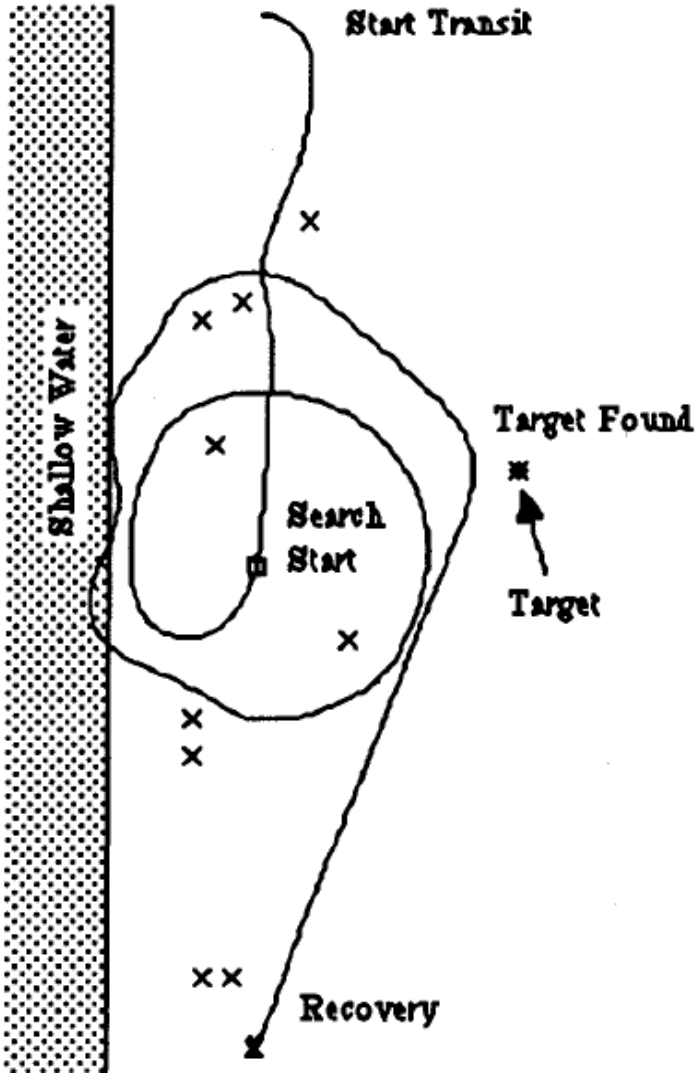
State Configured Layered Control

- Simplifies the layered control structure based on state
- Layered Control (lower) can still operate while State Control (upper) determines state configuration
- All benefits of layered control preserved
  - Multiple goals, Multiple Sensors, Robustness, Extensibility

Additional States Can Be Added To Handle Failure Scenarios



Simulation


Start Transit
Shallow Water
Target Found
Search
Start
Target
Recovery

Papers

- Brooks, R., “A Robust Layered Control System for a Mobile Robot,” IEEE Journal of Robotics and Automation, Vol.2, 1986
- J.G. Bellingham and T.R. Consi, “State Configured Layered Control” in Proc. 1st Workshop on Mobile Robots for Subsea Environments, Monterey, CA, Oct. 1990, pp. 75-80