Spatial and Temporal Abstraction in QSIM and Cognitive Maps

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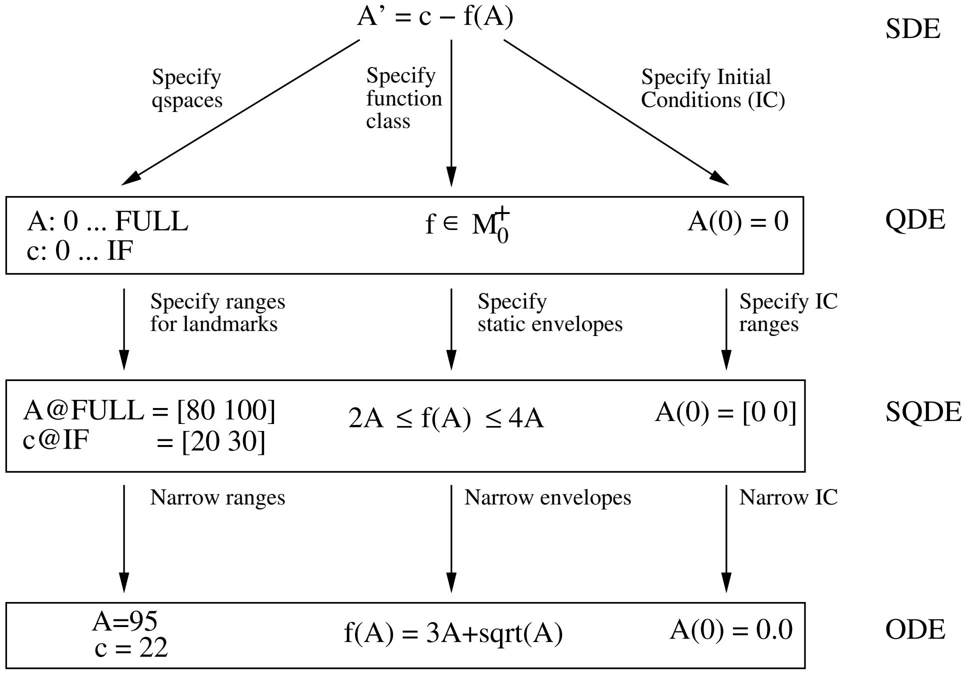
Abstraction from Continuous Behavior to Symbolic Description

Some experience using qualitative abstractions in foundational domains.

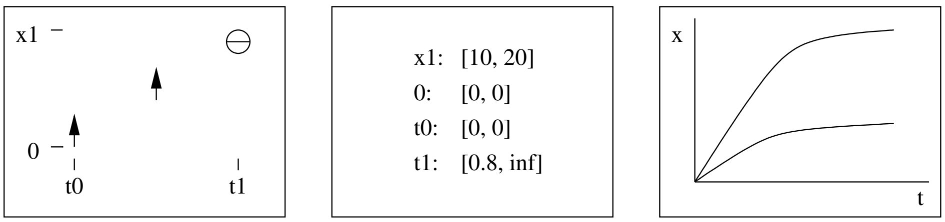
- Multiple representations provide flexibility and power.
- Carefully define relationships among representations.
- Qualitative differential equations (QSIM)
  - ordinal relations and monotonicity
  - numerical bounds and envelopes
  - continuous trajectories
- Cognitive map (SSH)
  - continuous behavior of control laws
  - causal action model
  - topological map
  - metrical map

QSIM and SQSIM

- Reason with abstractions of ordinary differential equations.



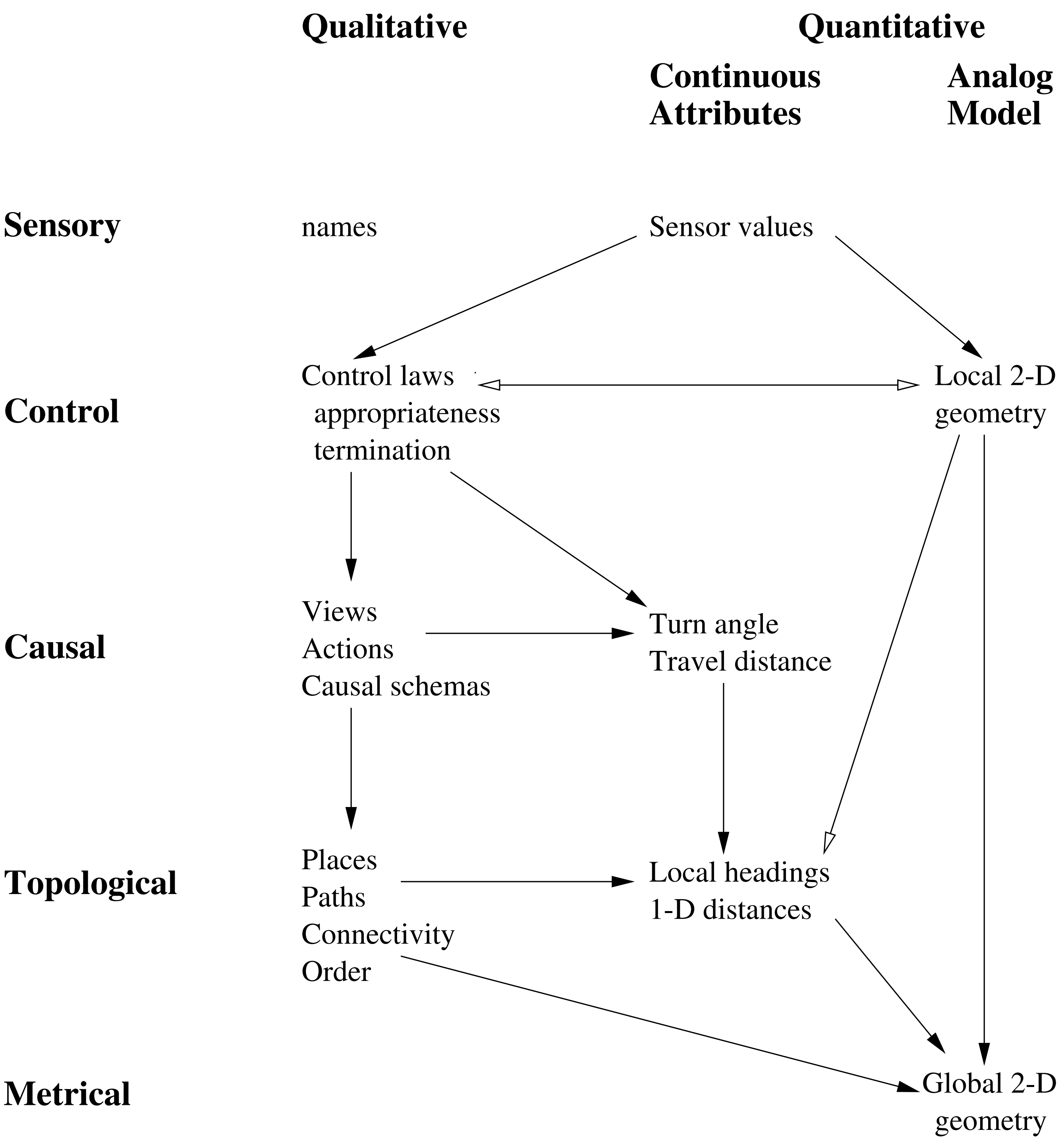
- Qualitative and semi-quantitative descriptions of continuous behavior.



qualitative description **event description** **dynamic envelope description**

[Kay, Rinner & Kuipers, *Artificial Intelligence Journal*, 2000.]

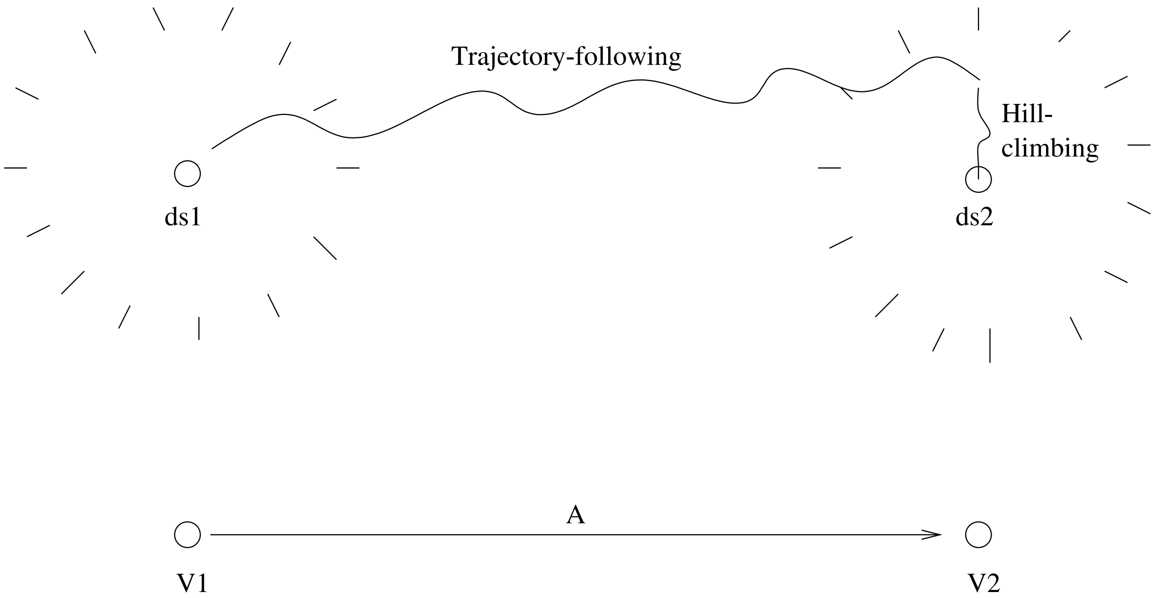
The Spatial Semantic Hierarchy



[Kuipers, *Artificial Intelligence Journal*, 2000.]

Locally Distinctive States

- A *locally distinctive state* is one associated with a control law (usually “hill-climbing”) that brings the system to that state from anywhere in its local neighborhood.
- “Trajectory-following” control laws carry the system from one distinctive state to the neighborhood of the next.



- Abstract this behavior pattern to a causal schema.

$$\langle S_0, A, S_1 \rangle \;\equiv\; S_1 = result(A, S_0)$$

- Some environments can be described by isolated, linked, distinctive states, hence a “cognitive map.”
  - Depends on environment, robot’s sensorimotor system, and robot’s knowledge of control laws.

Travel Between Distinctive States

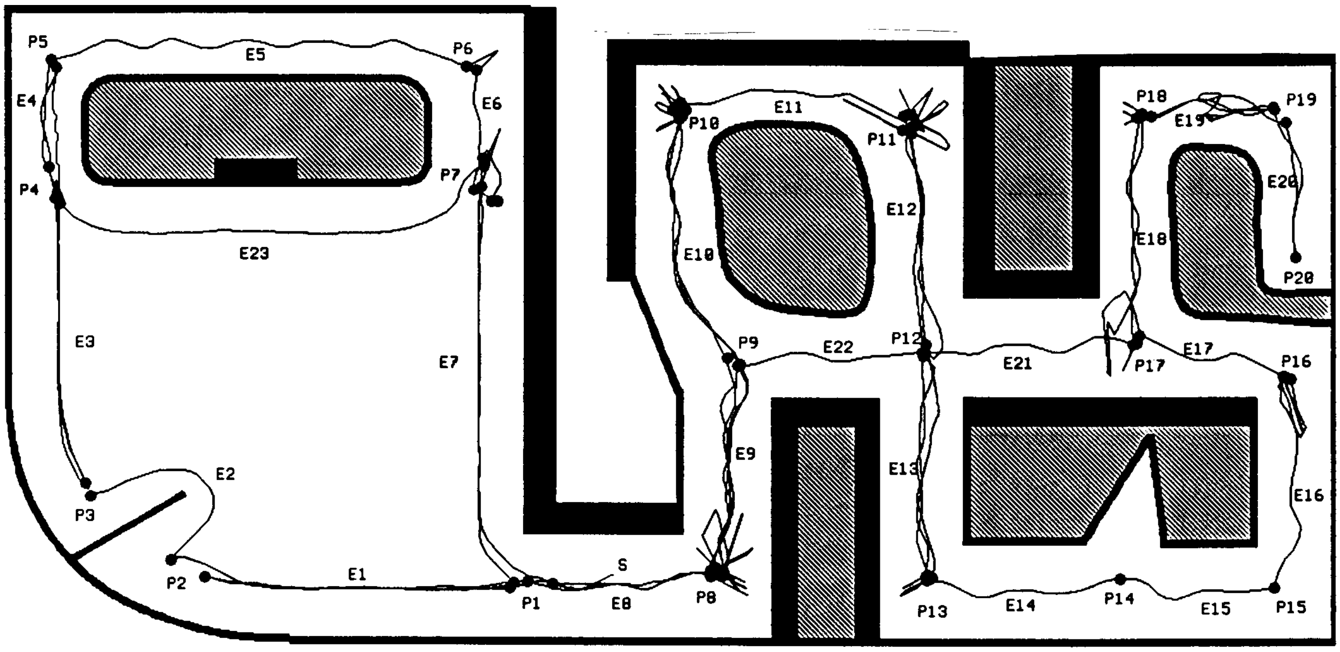
- From a distinctive state, select a *trajectory-following* control law.
- Follow it through a qualitatively uniform segment of the environment.
- Terminate when a qualitative change indicates a new local neighborhood.
- Select an appropriate *hill-climbing* control law to reach the next distinctive state.

Cumulative Position Error Is Eliminated.

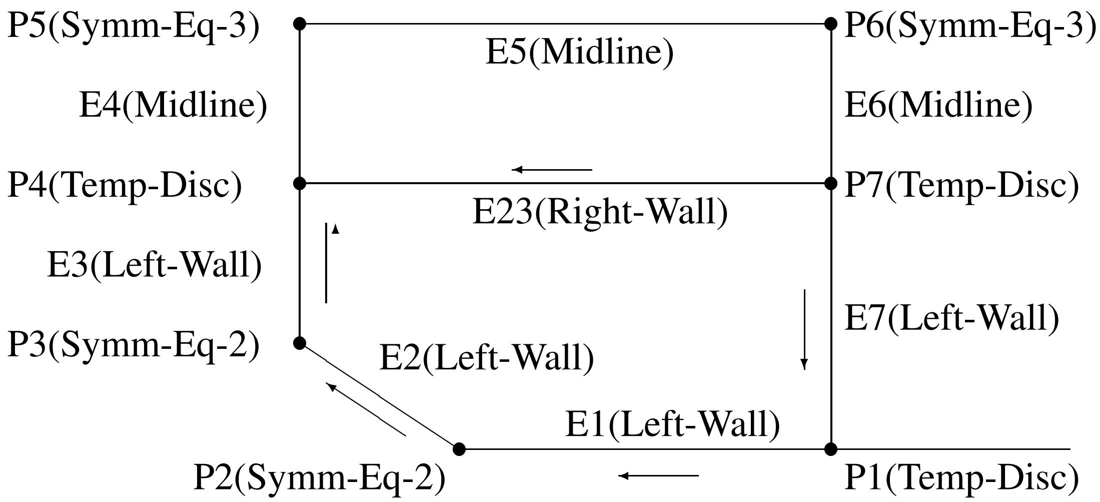
- Error on a path segment is reduced by hill-climbing.
- Error need not reduce to zero, as long as the *next* segment has small enough error to be captured by the next state neighborhood.
- No attempt to maintain a global frame of reference. Only linked local frames.

Exploring a Simulated Environment

The robot has a ring of 16 sonar-like range sensors, including limited range and specular reflection errors.

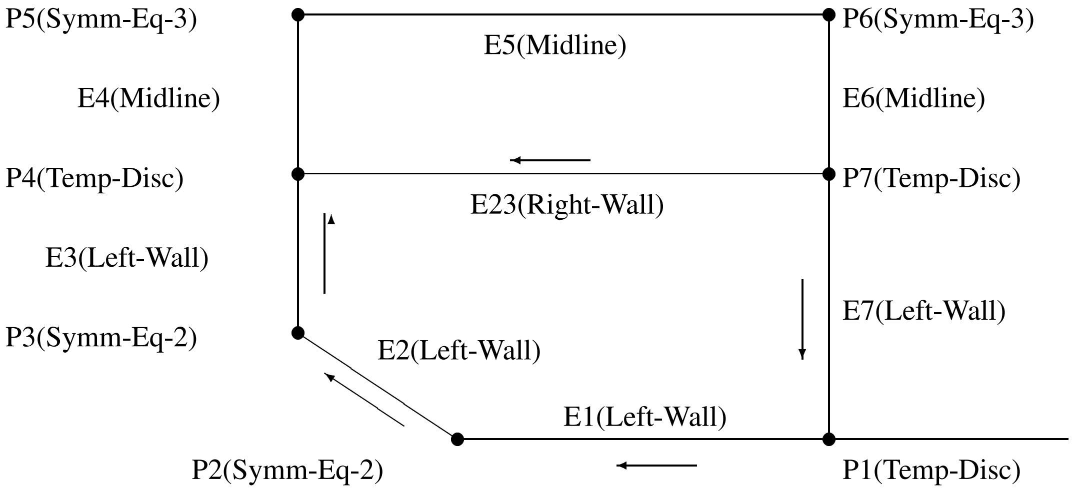


The topological model abstracts the behavior pattern.

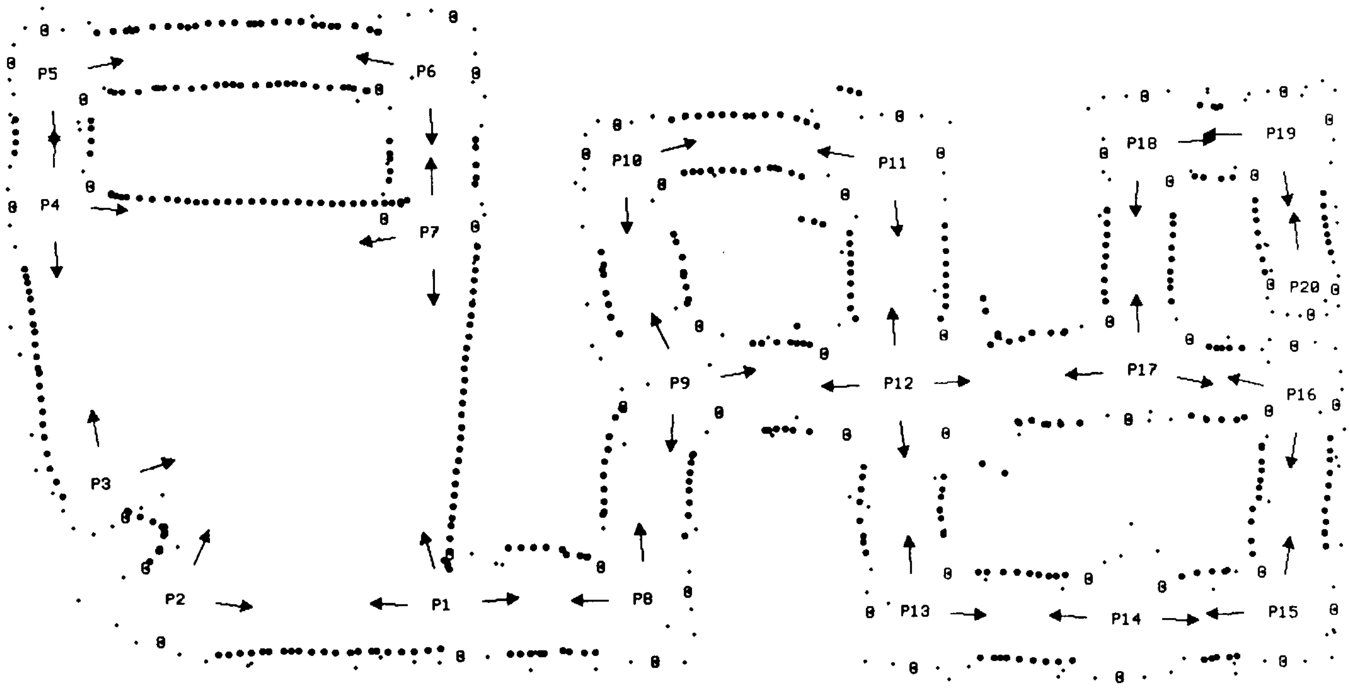


The Patchwork Metrical Map

The topological model can be annotated with local neighborhood maps and generalized cylinder models.



The local patchwork map can be relaxed into a global frame of reference.



Problems

- How does the agent learn features and control laws? [Pierce & Kuipers, AIJ, 1997].
- A control law applies to a "qualitatively uniform segment" of the environment. How do we trade off noise rejection with recognizing termination?
- How does the agent select a control law for the neighborhood or trajectory? Unique selection reduces false negative state matching.
- How do we disambiguate false positive state matching (perceptual aliasing)? Localization using probability distribution across states.

References

- Qualitative differential equations
  - B. J. Kuipers. *Qualitative Reasoning: Modeling and Simulation with Incomplete Knowledge*. Cambridge, MA: MIT Press, 1994.
  - H. Kay, B. Rinner and B. Kuipers. Semi-quantitative system identification. *Artificial Intelligence* **119**: 103–140, 2000.
- Cognitive maps
  - B. Kuipers. The Spatial Semantic Hierarchy. *Artificial Intelligence* **119**: 191–233, 2000.
  - D. M. Pierce and B. Kuipers. Map learning with uninterpreted sensors and effectors. *Artificial Intelligence* **92**: 169–227, 1997.