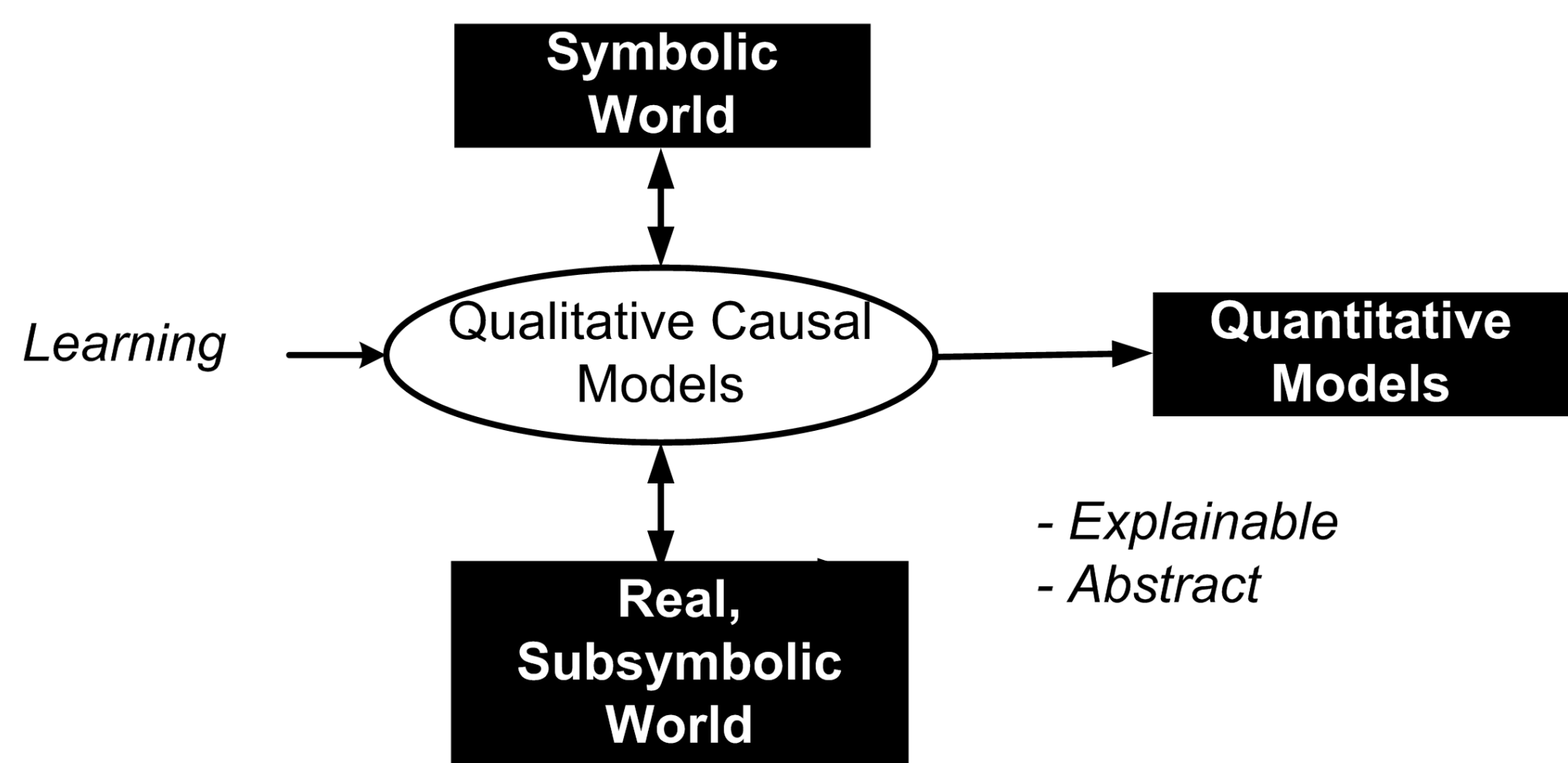


Qualitative Models – The Missing Link for Self-Learning Embodied Agents

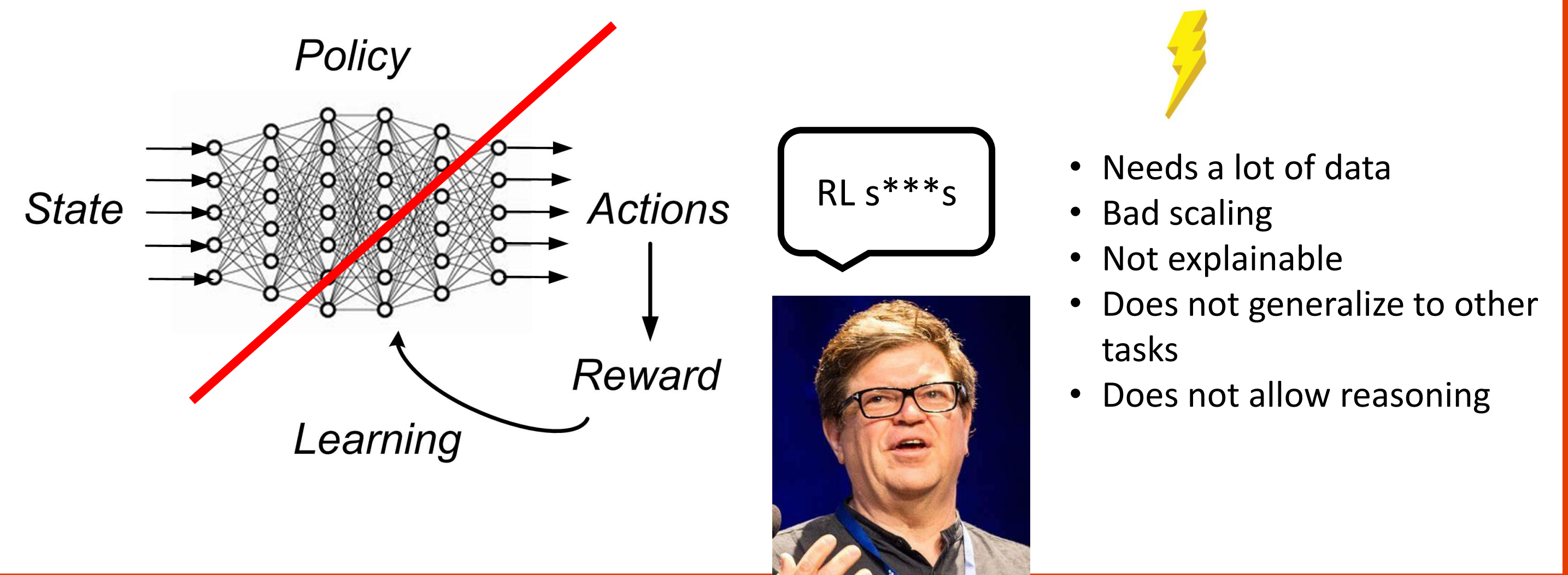
Jan Lemeire, Marco Van Cleemput and Ruben Spolmink - Vrije Universiteit Brussel, Belgium
 Jure Žabkar – University of Ljubljana, Slovenia; Domen Šoberl - University of Primorska, Slovenia

Contact: jan.lemeire@vub.be

The missing Link



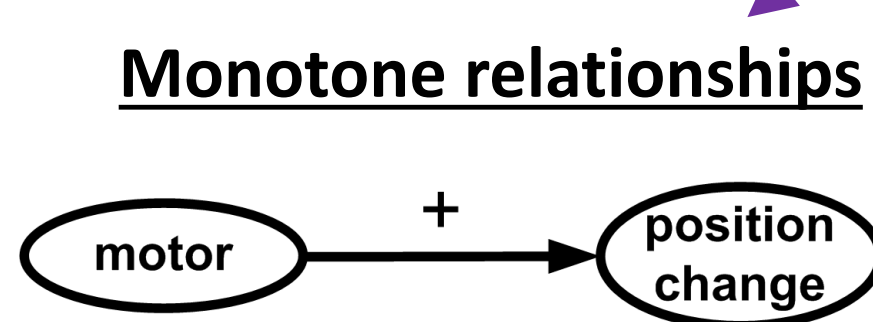
Reinforcement Learning & Neural Networks



Qualitative Causal Models

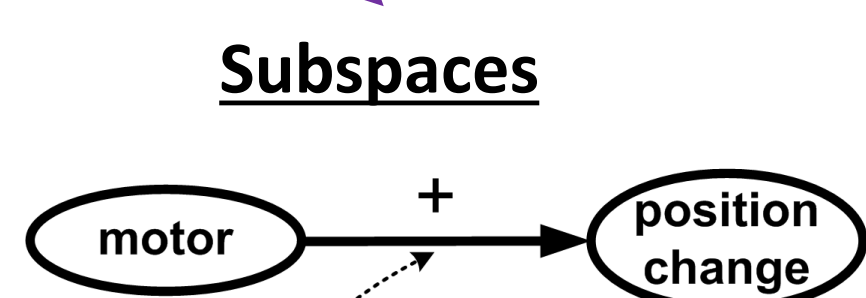
Qualitatively describing

$$s_{t+1} = f(s_t, a_t)$$



Also sign of derivatives:

$$\frac{\delta \text{position change}}{\delta \text{motor}} > 0$$



Context variable changes the causal behavior

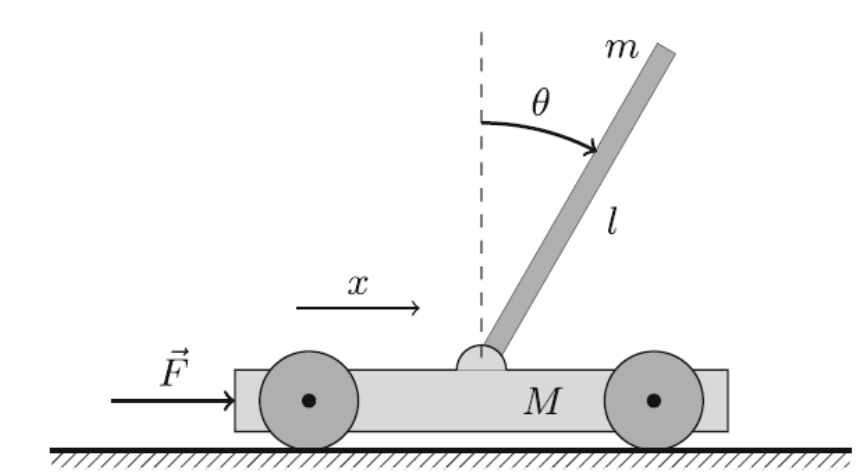
Assumptions:

- qualitative determinism
- known state

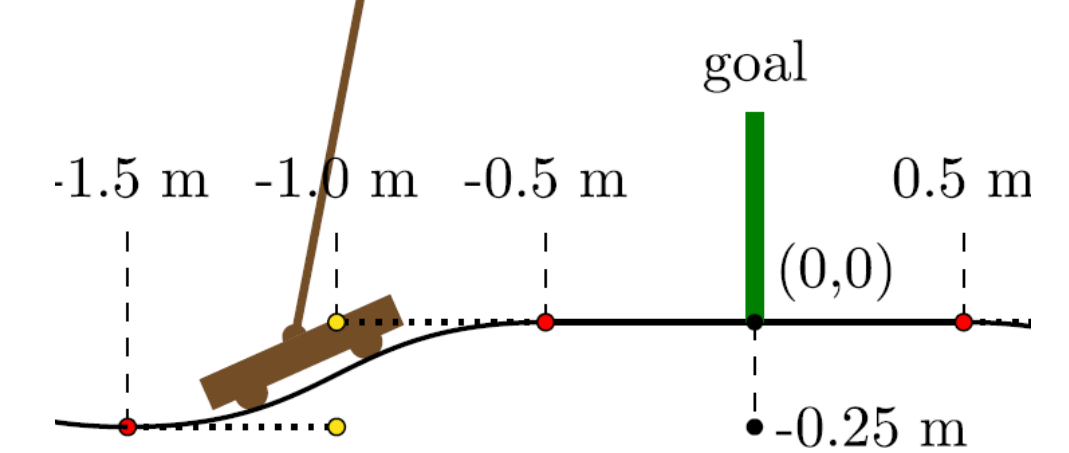
State space is partitioned into subspaces with monotone behavior

Strength 1: Generalization and Abstraction

Model learnt with



Also works in more complex environments:



Domen Šoberl, Ivan Bratko, *Qualitative control learning can be much faster than reinforcement learning*, Machine Learning, 2025

Driving a new car or bike:

- the quantitative parameters should be adapted
- but you know how to control it qualitatively

Strength 2: Ease of Learning and Adaptivity

Intrinsic motivation:

- Seeking to maximize influence over variables
- Probing regions that are unexplored
- that exhibit ambiguity on the causes

When a new actionable variable is discovered, actions are learned to control the variable in isolation - its effects can be observed and modelled

See poster of Ruben Spolmink: "Skill learning using qualitative models."

Incremental learning:

- newly discovered actionable variables and subspaces are added gradually
- if a qualitative relationship gives wrong predictions -> search for correlating context variable -> create new subspace

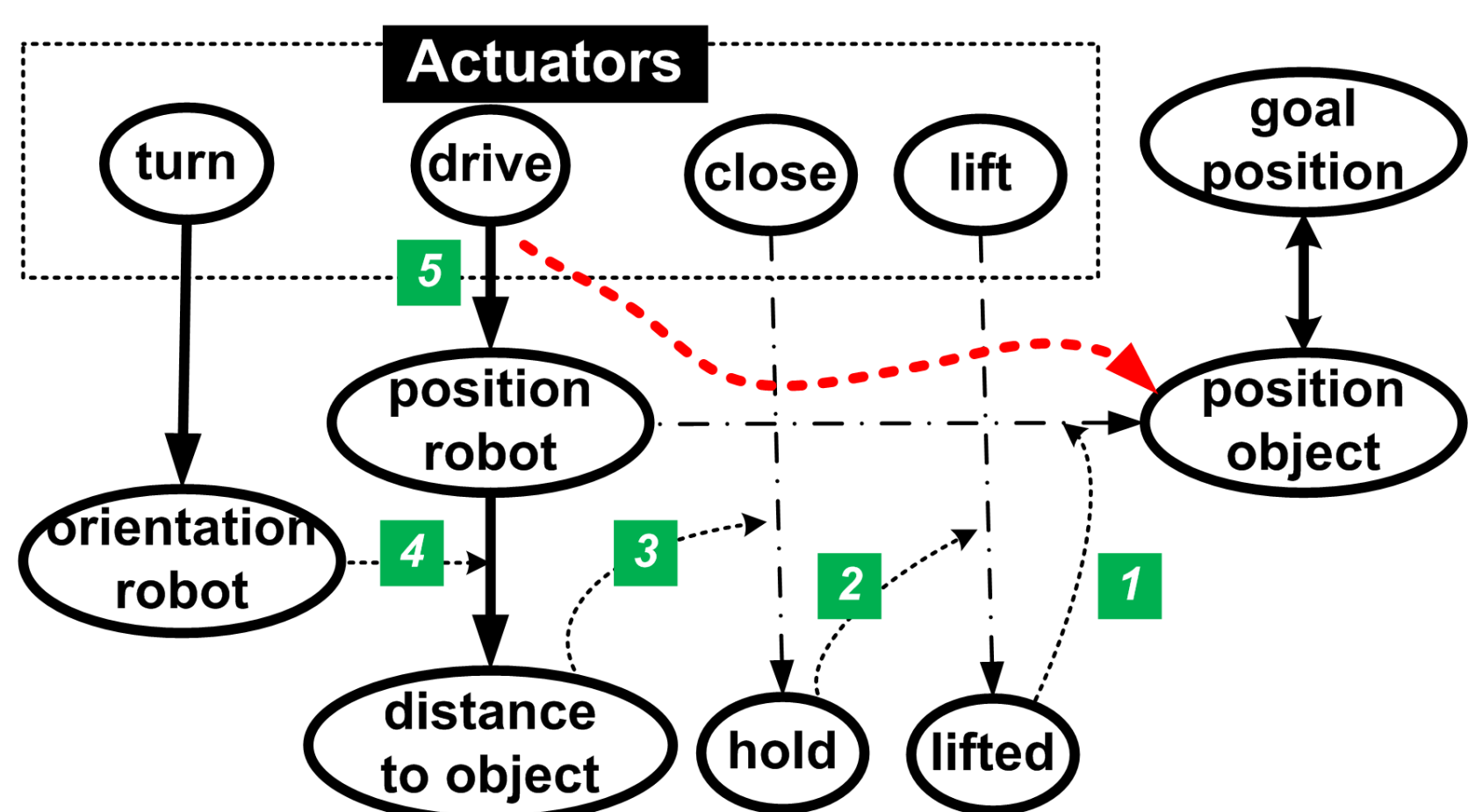
=> Identify deterministic qualitative functions to link causes with effects



Mimic the way human infants play, learn, and develop

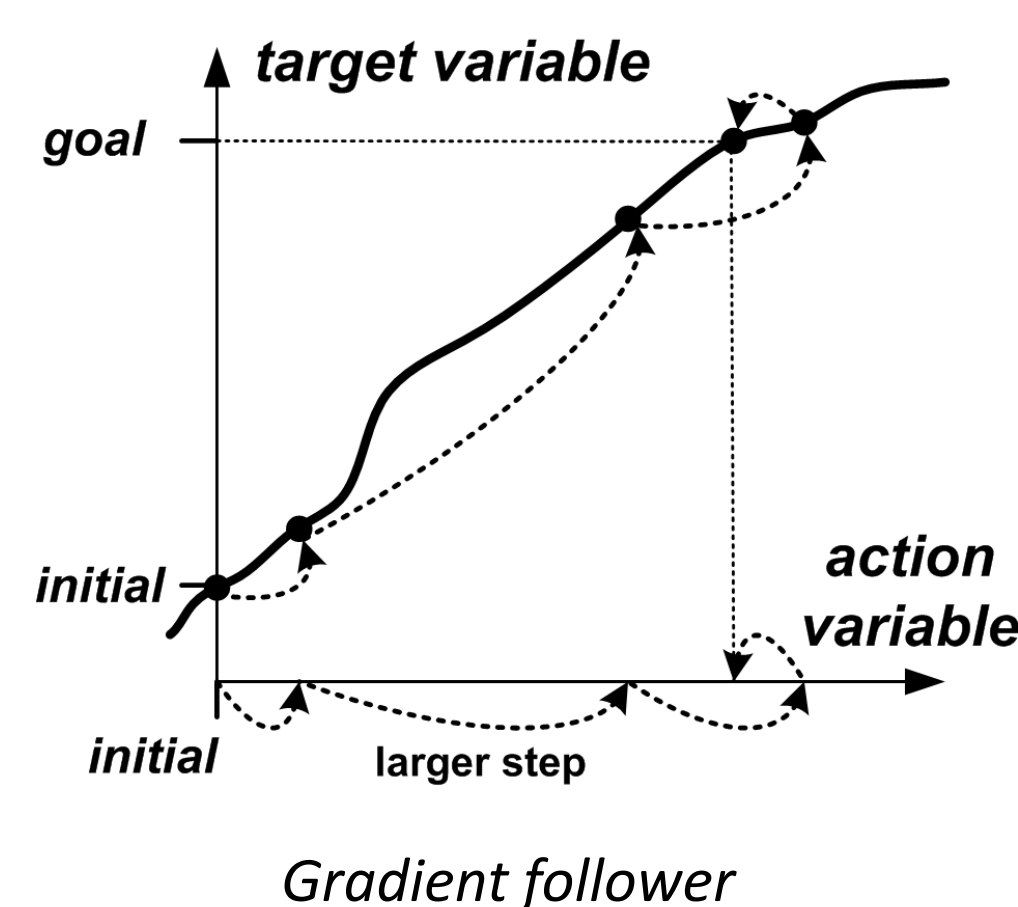
Strength 3: Planning and control

Planning: by backward reasoning



=> sequence of actions that results in a travel to new subspaces

Control: loop within a subspace



Gradient follower

Strength 4: The Link with the symbolic world

Language is about qualitative properties; symbols are attributed to qualitative properties.

```
PDDL:
(:action turn
 :parameters (?r - robot ?from - location ?to - location)
 :precondition (facing ?r ?from)
 :effect (and (not (facing ?r ?from)) (facing ?r ?to))
)
(:action drive-forward
 :parameters (?r - robot ?from - location ?to - location)
 :precondition (and (facing ?r ?from) (at ?r ?from))
 :effect (and (not (at ?r ?from)) (at ?r ?to))
)
(:action close
 :parameters (?r - robot ?o - object ?pos - location)
 :precondition (and (at ?r ?pos) (object-at ?o ?pos) (gripper-empty ?r))
 :effect (holding ?r ?o)
)
```

In terms of actions that allow going from one subspace to another

Can be learnt bottom-up from qualitative model, which provides an objective criterion => Symbols defined by (inter)action

as opposed to the shape or look of objects

Example: concept "door" – can be opened or closed, allows access to another place
 Also in abstract sense: "the door to success is..."

Strength 5: Learning quantitative models

See poster of Ruben Spolmink: "Skill learning using qualitative models."