

Attractor dynamics approach to behavior generation: vehicle motion

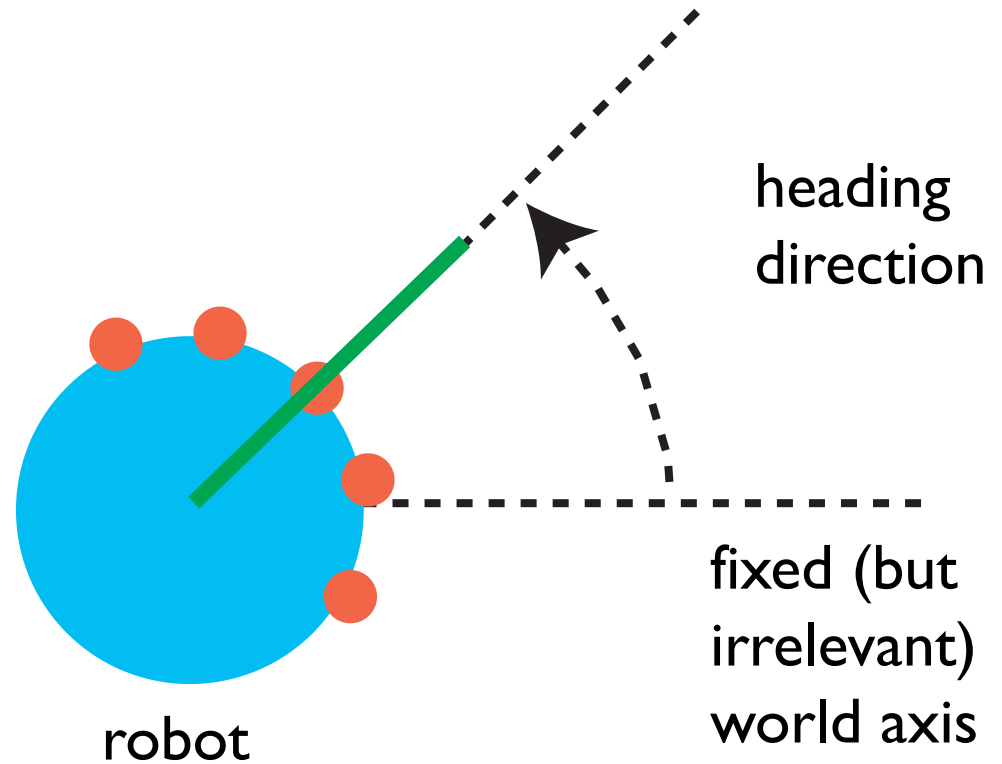
Gregor Schöner, INI, RUB

Basic ideas of attractor dynamics approach

- behavioral variables
- time courses from dynamical system:
attractors
- tracking attractors
- bifurcations for flexibility

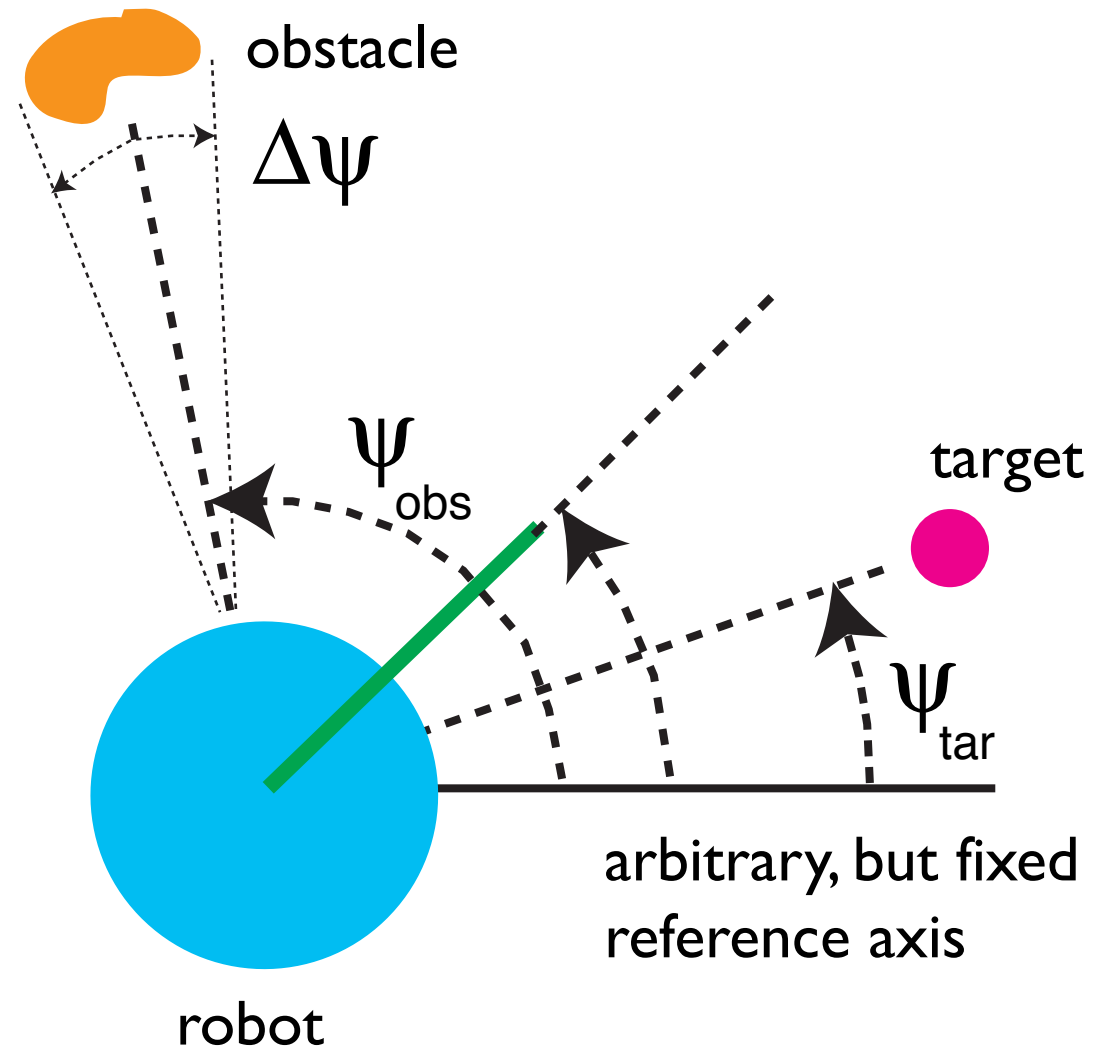
Behavioral variables: example

■ vehicle moving in
2D: heading
direction



Behavioral variables: example

- constraints:
obstacle avoidance
and target
acquisition



Behavioral variables

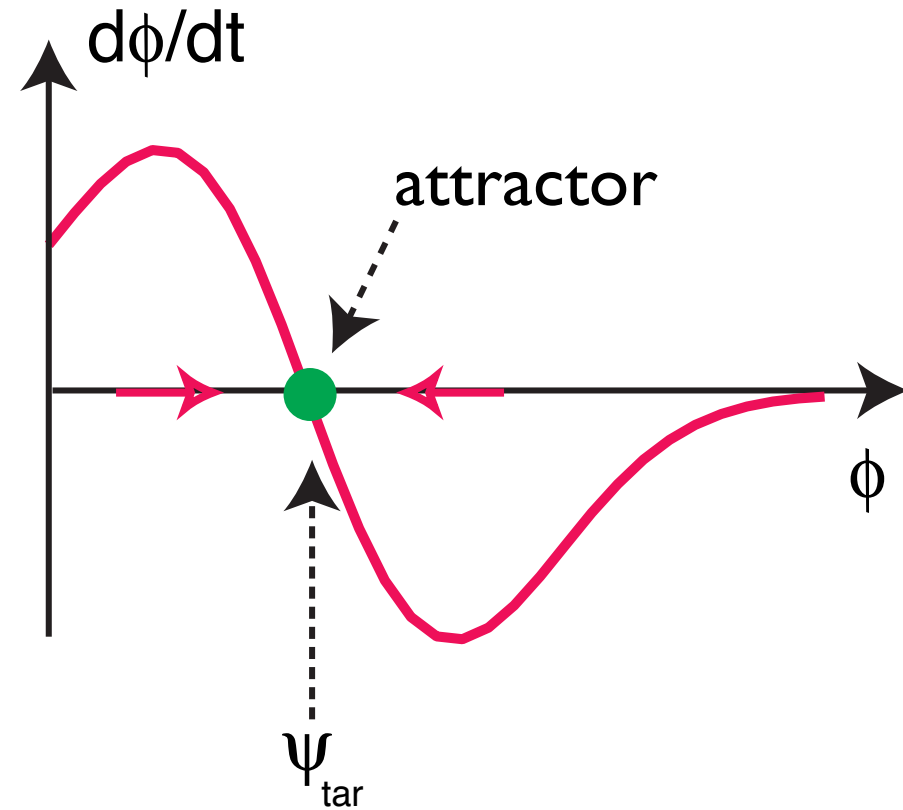
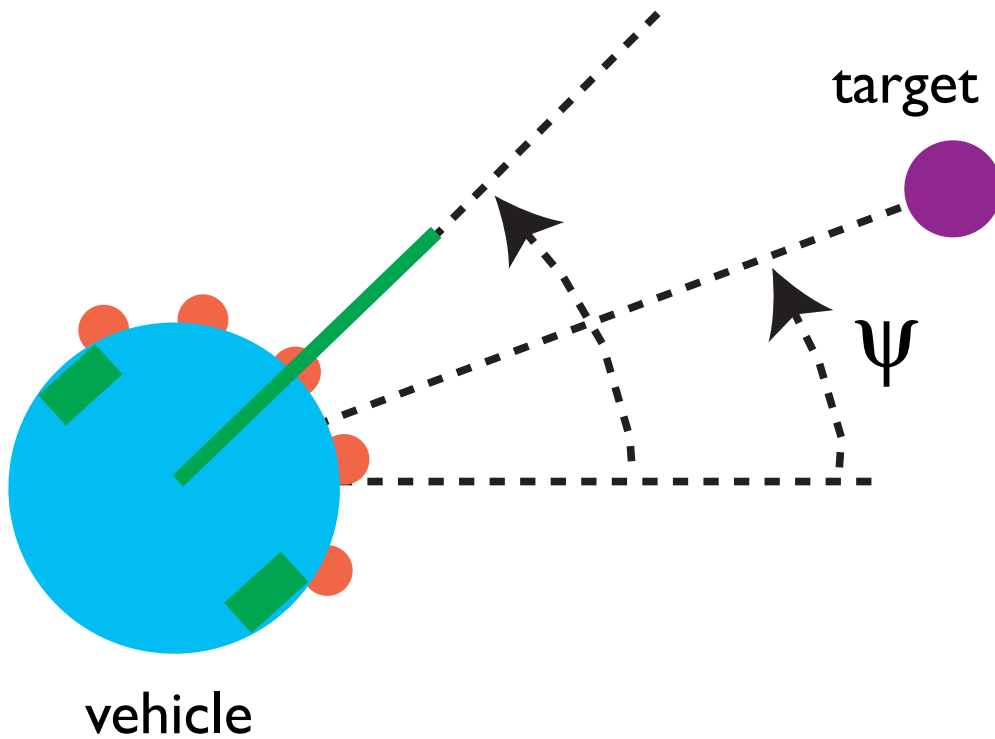
- describe desired motor behavior
- “enactable”
- express constraints as values/value ranges
- appropriate level of invariance

Behavioral dynamics

- generate behavior by generating time courses of behavioral variables
- generate time course of behavioral variables from attractor solutions of a (designed) dynamical system
- that dynamical system is constructed from contributions expressing behavioral constraints

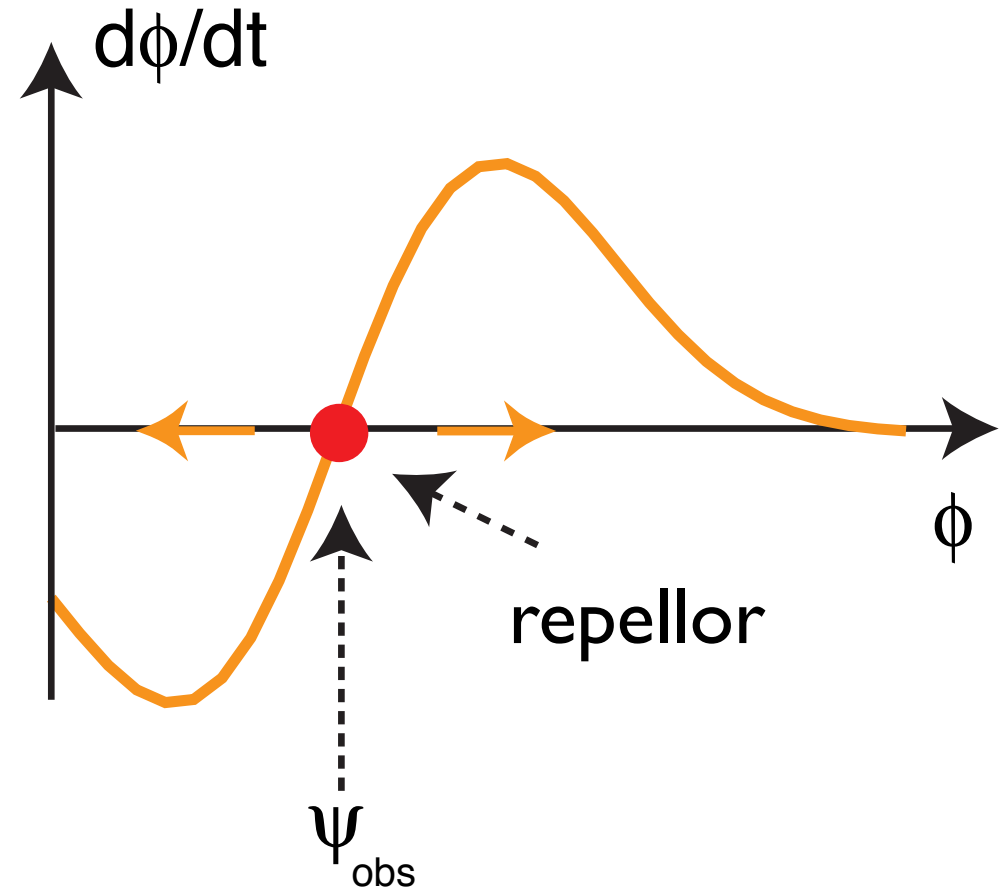
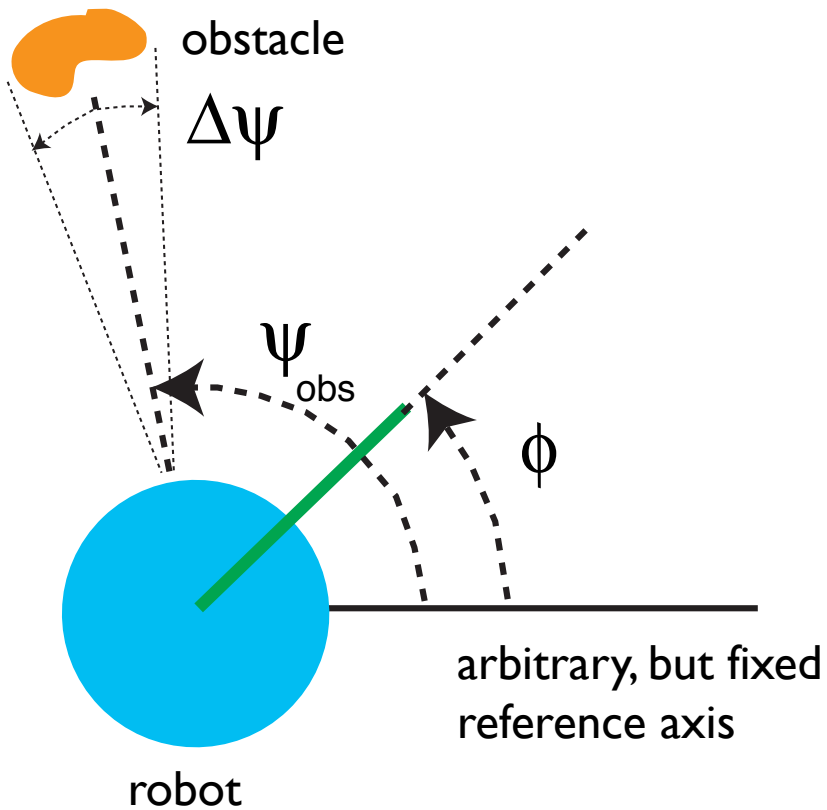
Behavioral dynamics: example

■ behavioral constraint: target acquisition



Behavioral dynamics: example

■ behavioral constraint: obstacle avoidance



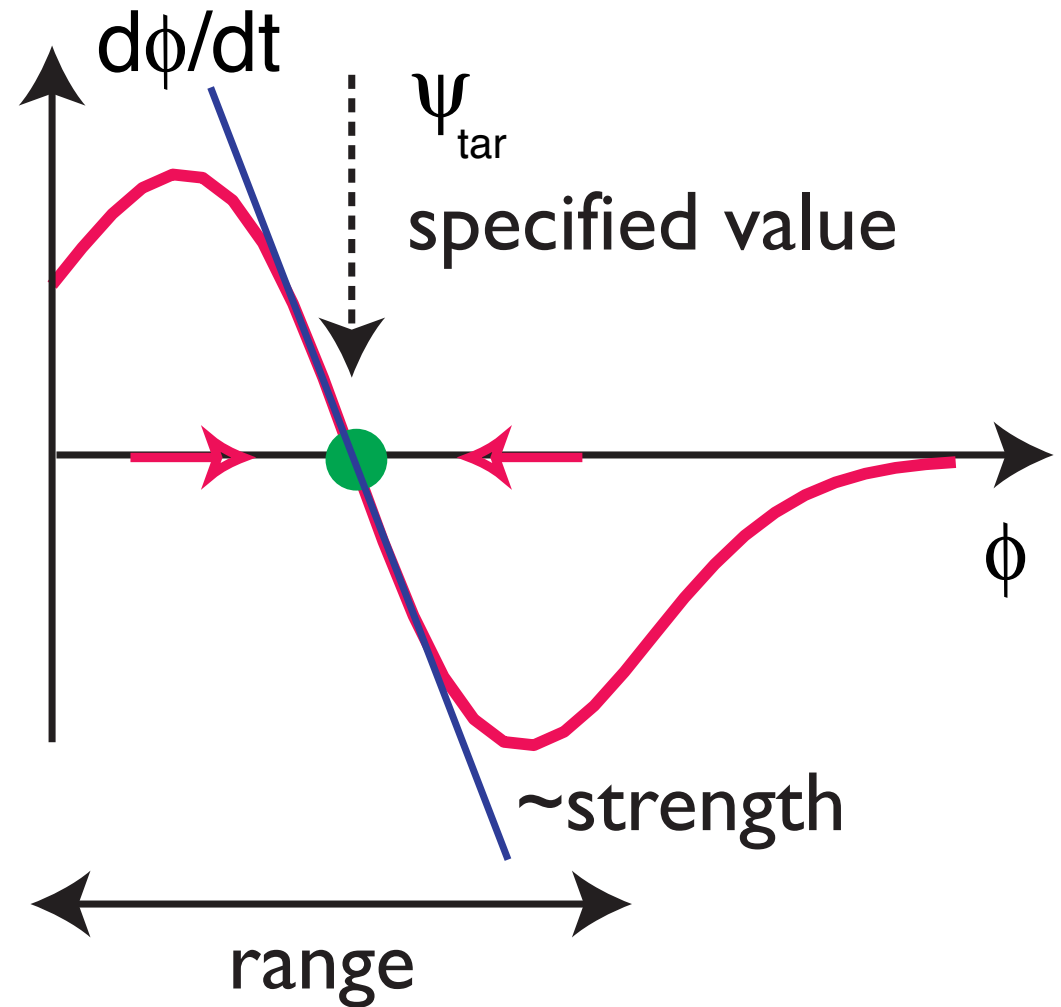
Behavioral dynamics

■ each contribution is a “force-let” with

■ specified value

■ strength

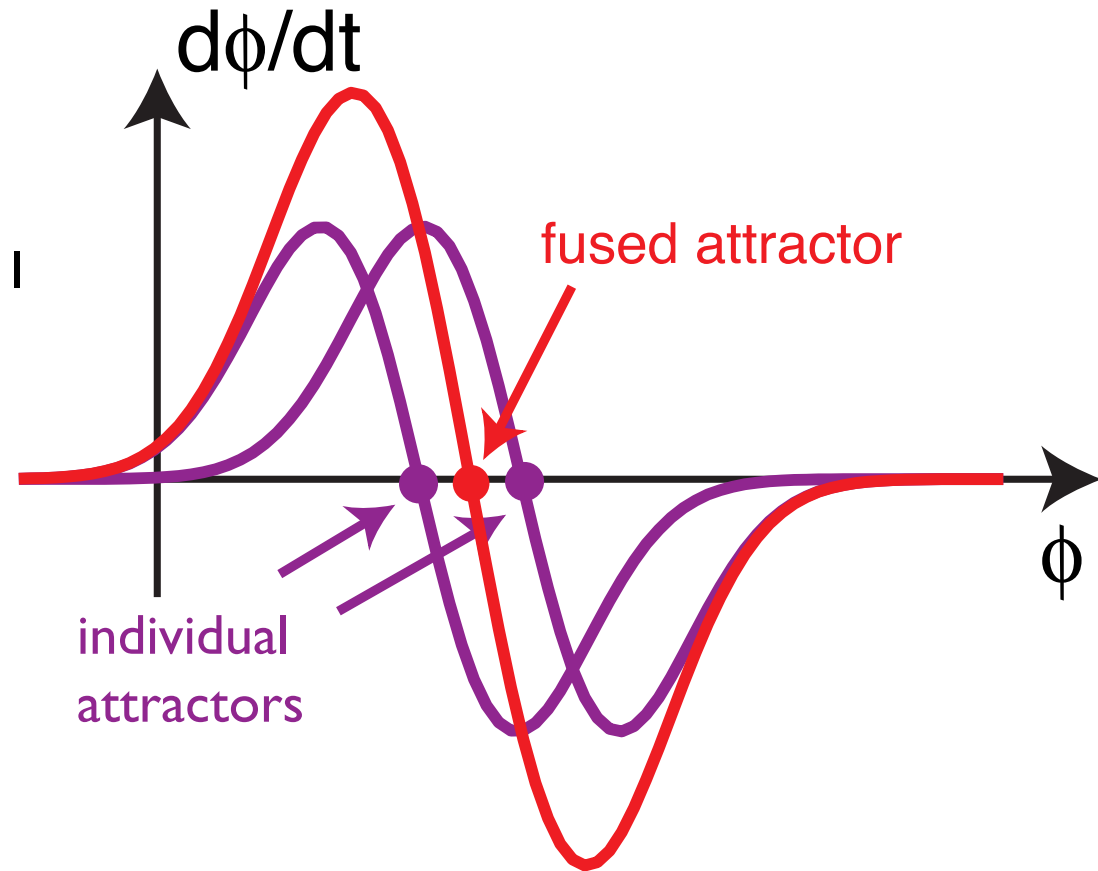
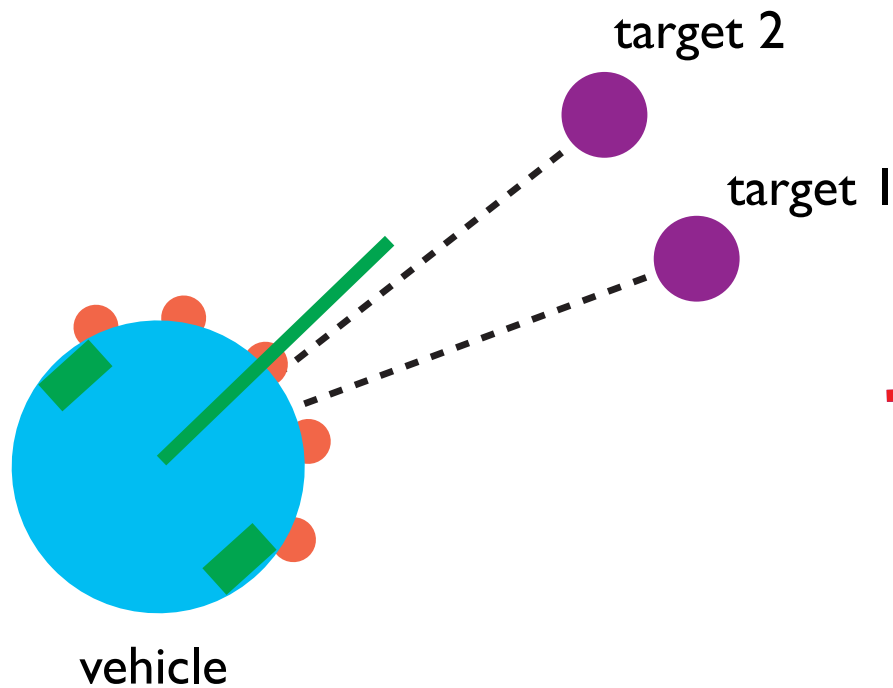
■ range



Behavioral dynamics

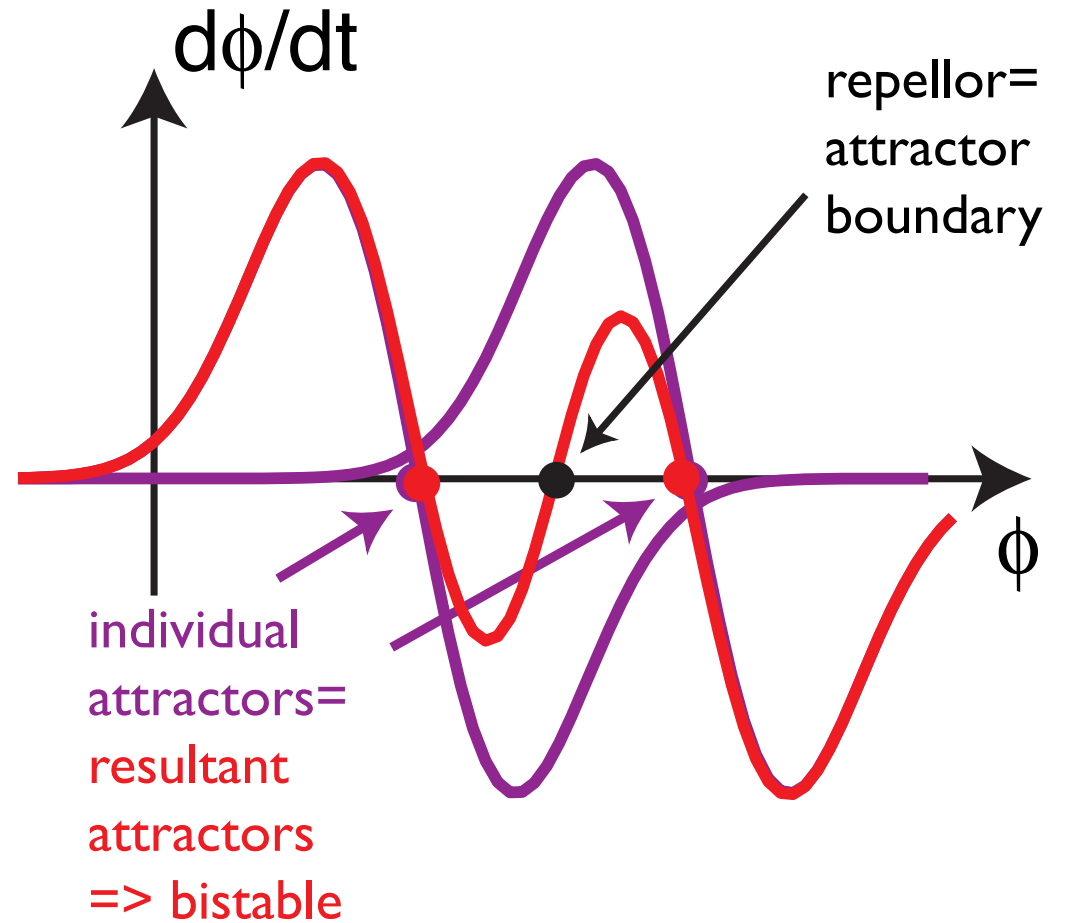
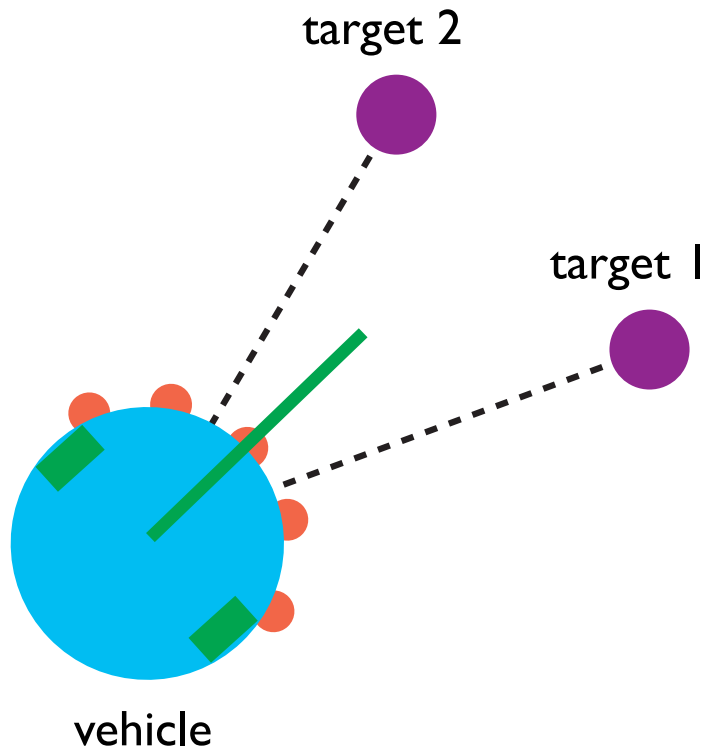
■ multiple constraints: superpose “force-lets”

■ fusion



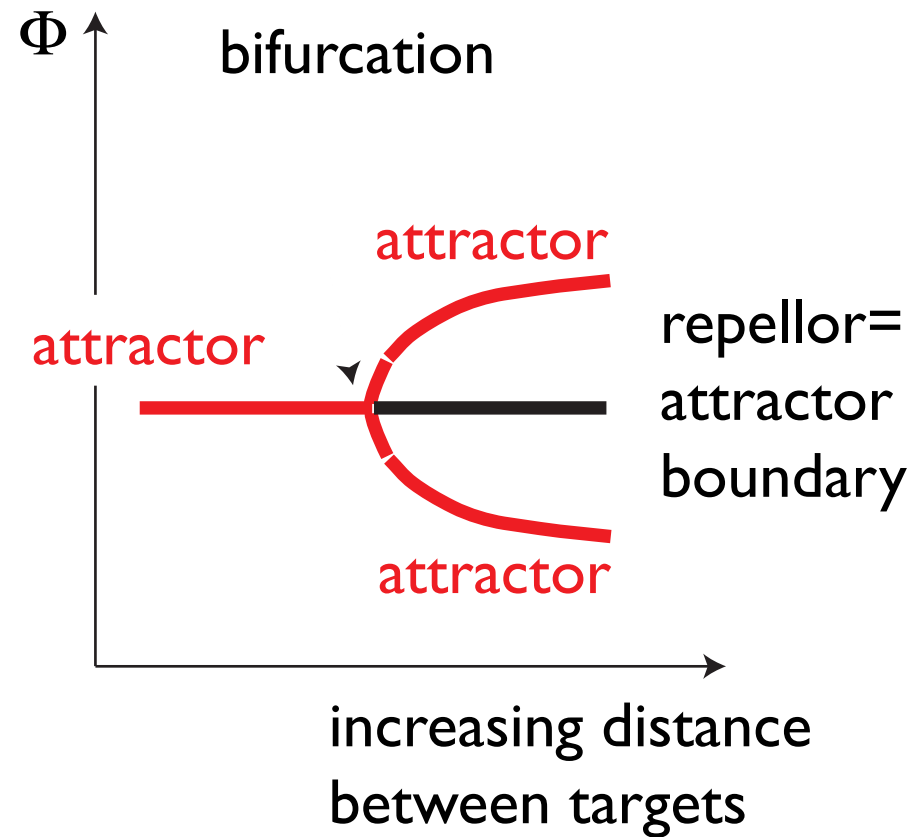
Behavioral dynamics

■ decision making



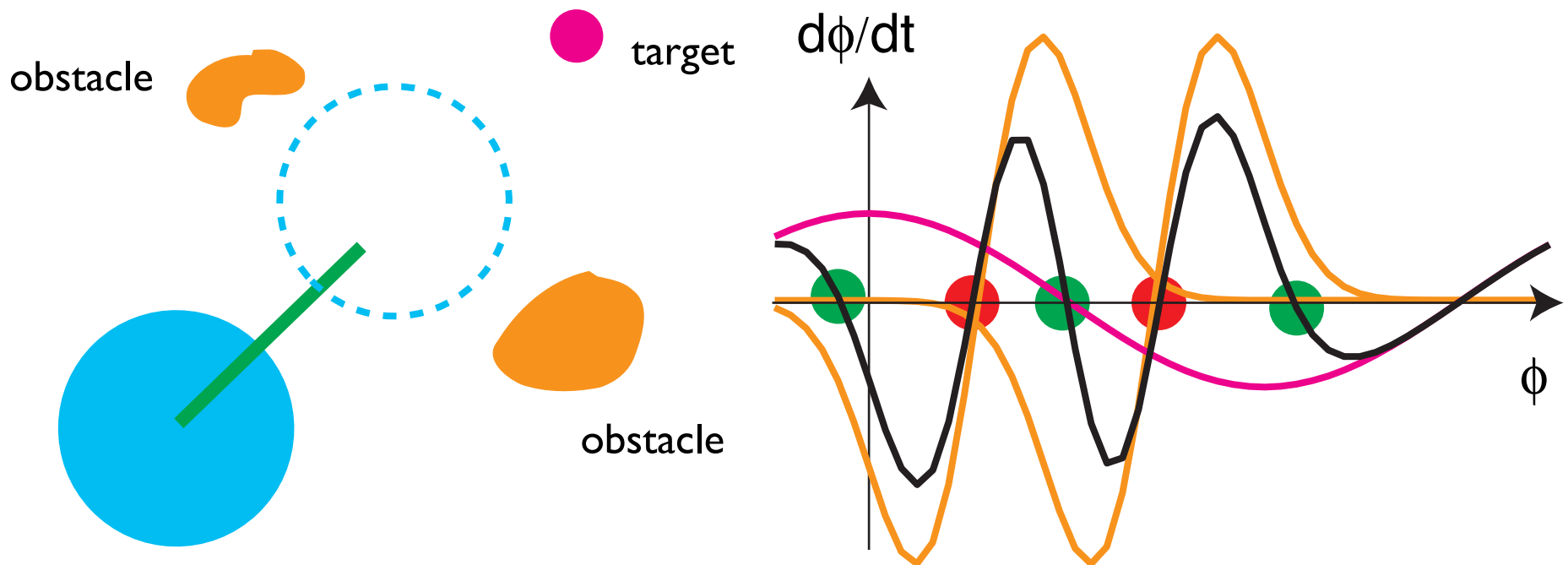
Behavioral dynamics

- Bifurcations switch between fusion and decision making



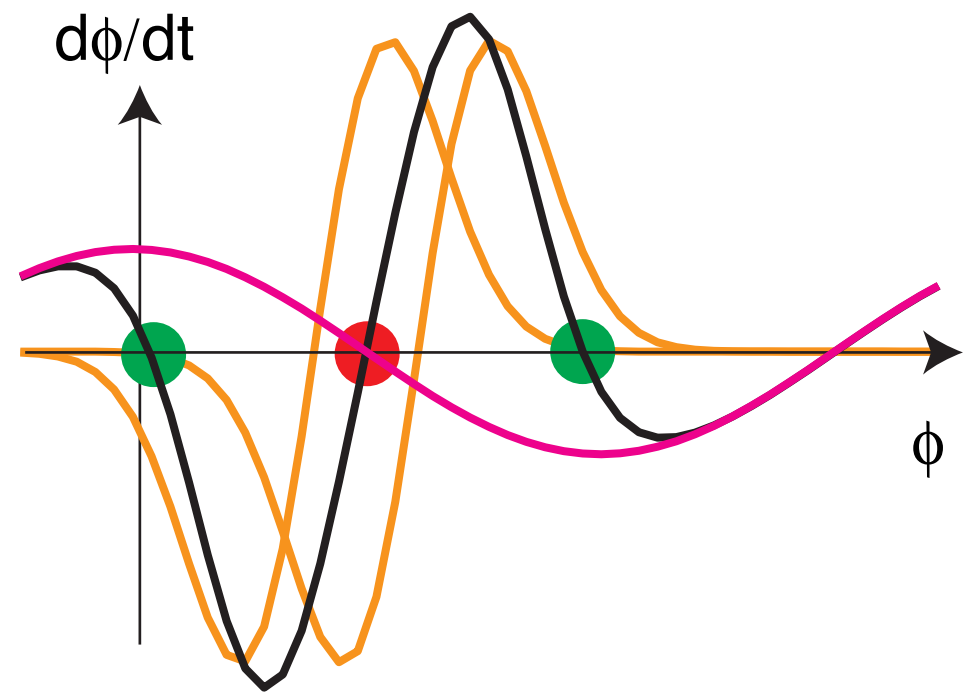
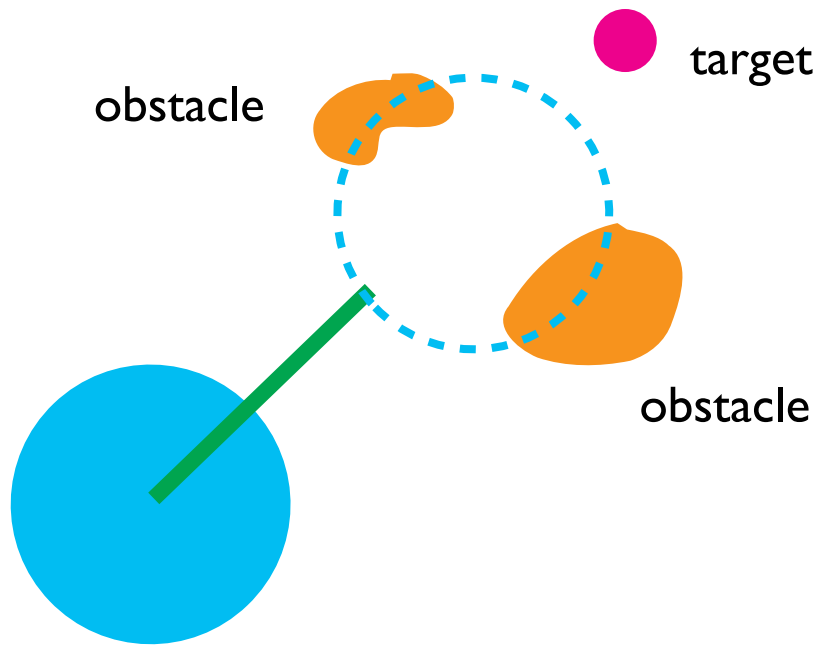
Behavioral dynamics

- an example closer to “real life”: bifurcations in obstacle avoidance and target acquisition
- constraints not in conflict



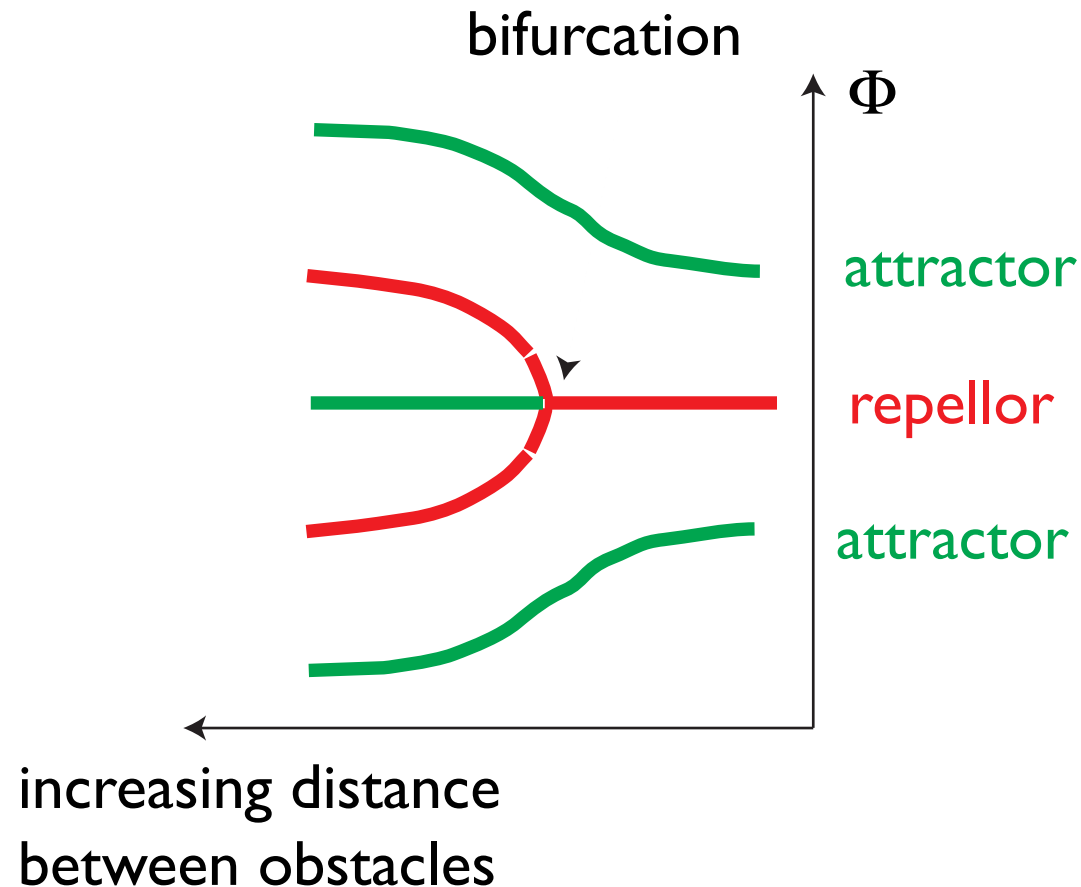
Behavioral dynamics

■ constraints in conflict



Behavioral dynamics

- transition from “constraints not in conflict” to “constraints in conflict” is a bifurcation

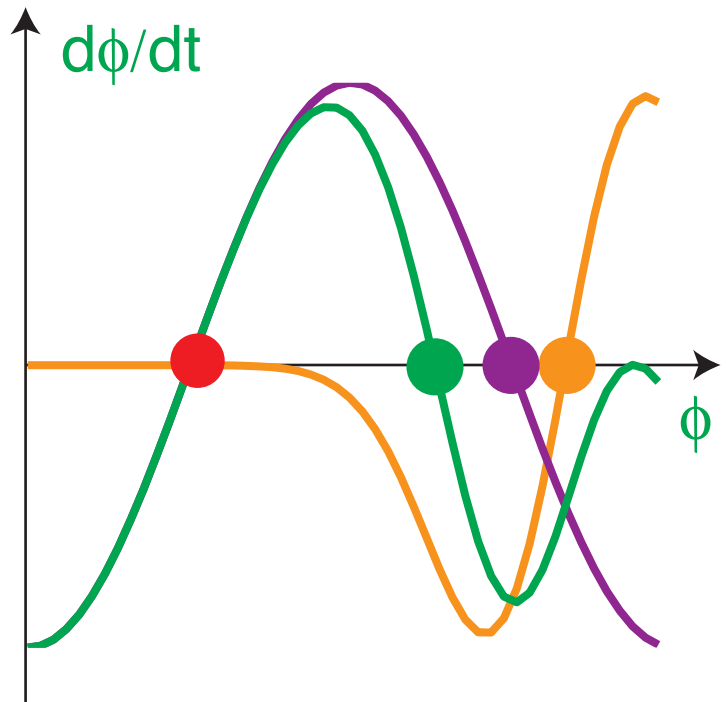
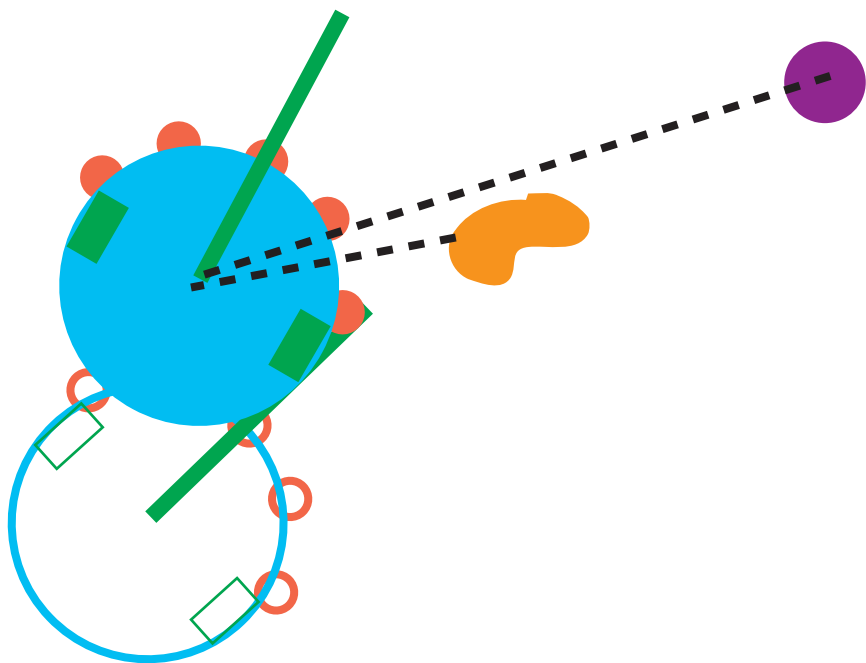
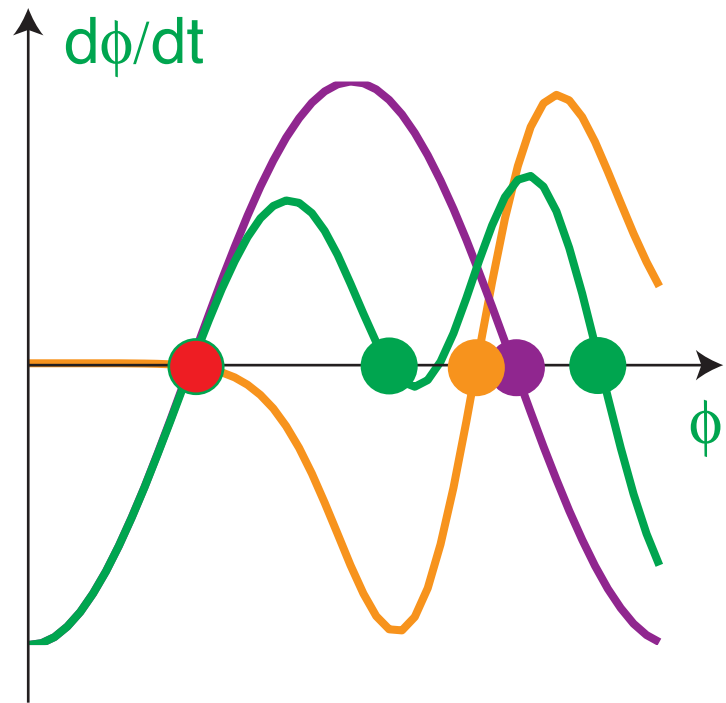
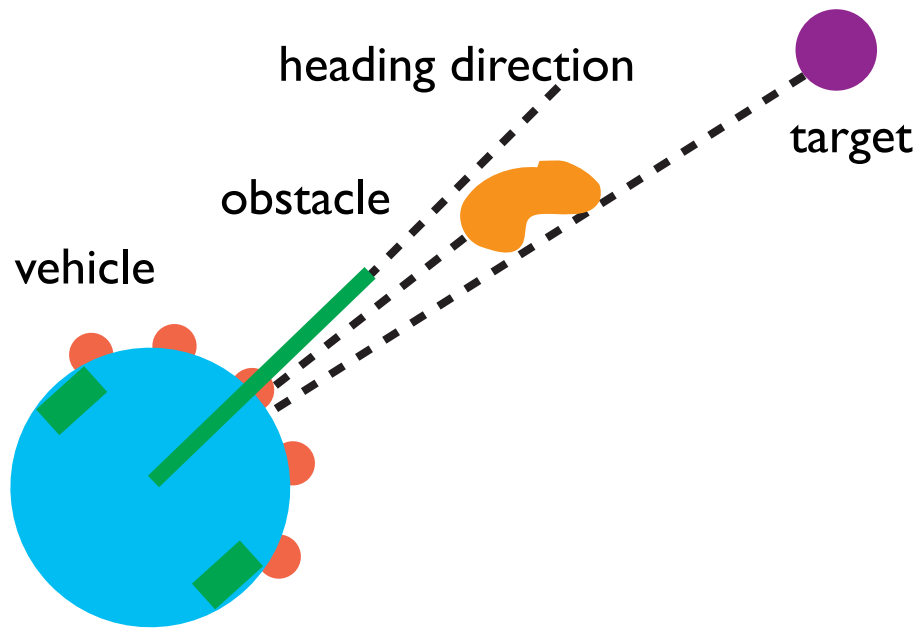


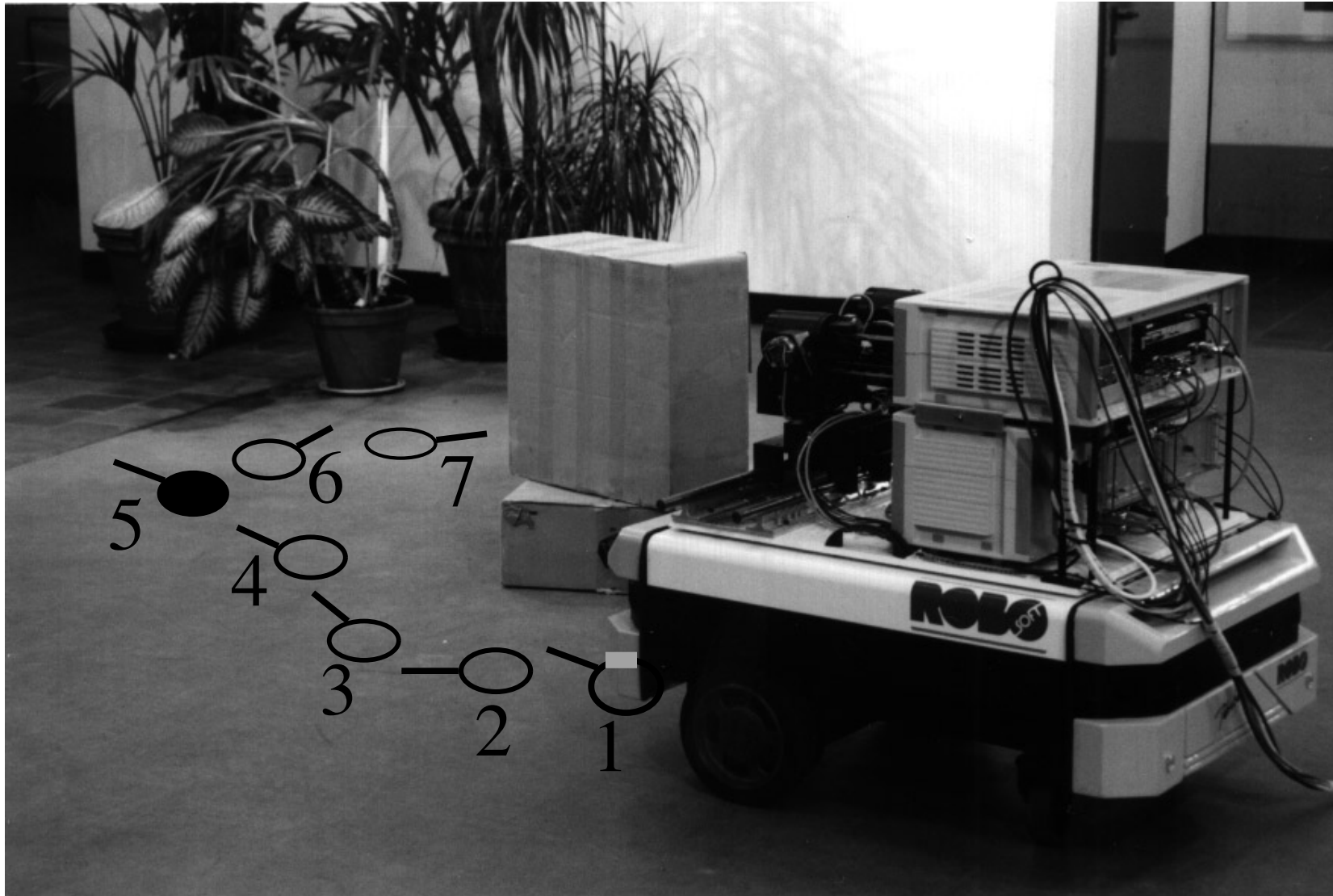
Behavioral dynamics

- Such design of decision making is only possible because system “sits” in attractor.
- This reduces the difficult design of the full flow (ensemble of all transient solutions) of non-linear dynamical systems to the easier design of attractors (bifurcation theory).

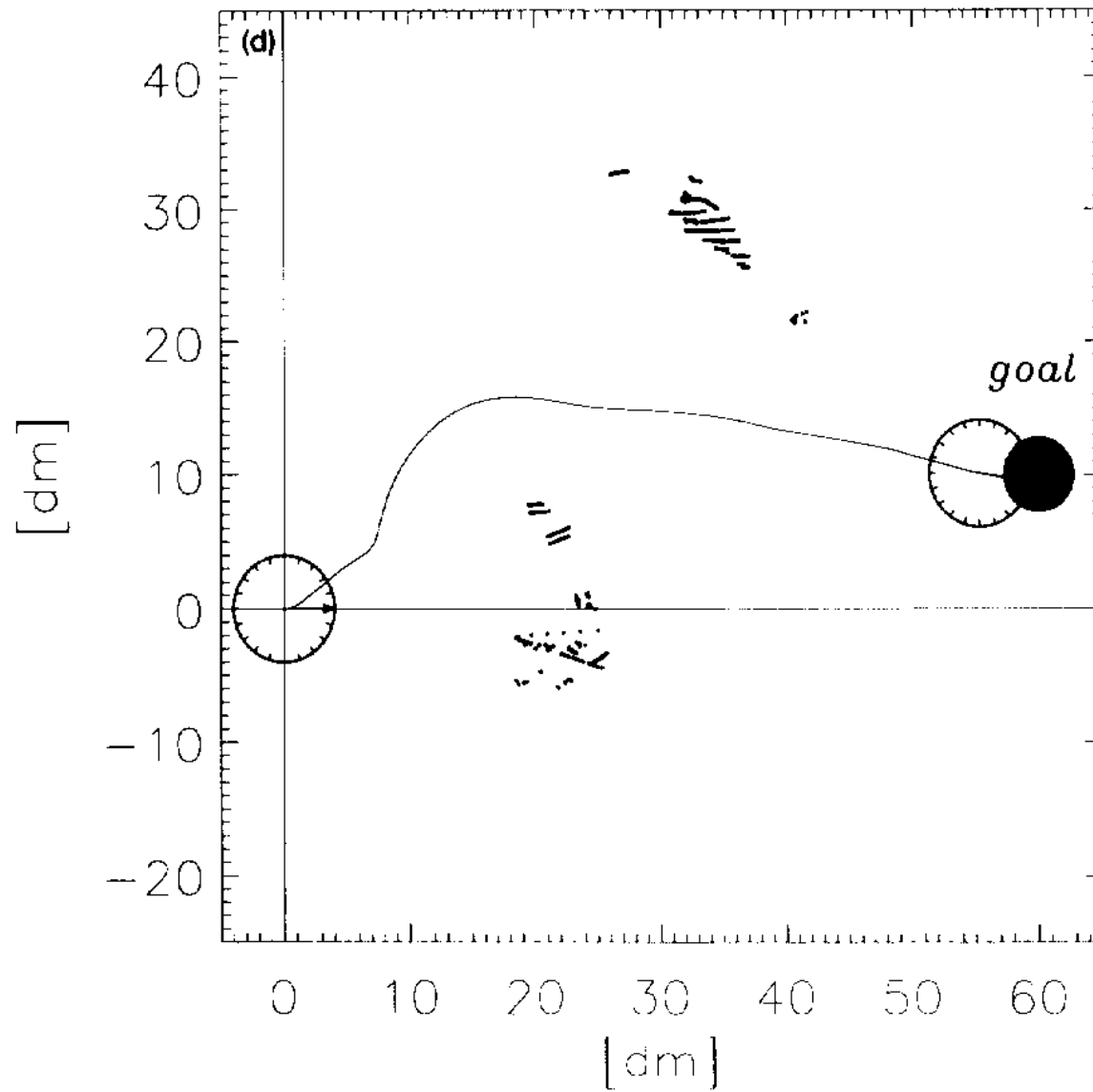
Behavioral dynamics

- But how may complex behavior be generated while “sitting” in an attractor?
- Answer: force-lets depend on sensory information and sensory information changes as the behavior unfolds





[Schöner, Dose, 1992]



[Schöner, Dose, Engels, 1995]

... this is a “symbolic” approach

- in the sense that we talk about “obstacles” and “targets” as objects, that have identity, preserved over time...
- making demands on perceptual systems...
- in the implementation we see that these demands can be relaxed...
- next week we’ll look at how a “sub-symbolic” attractor dynamics approach may work

Attractor dynamics model of human navigation

- Fajen et al, International Journal of Computer Vision 54(1/2/3), 13–34, 2003
2003

human locomotion

- Bill Warren and Bret Fajen have used the attractor dynamics approach to account for how humans locomote in virtual reality



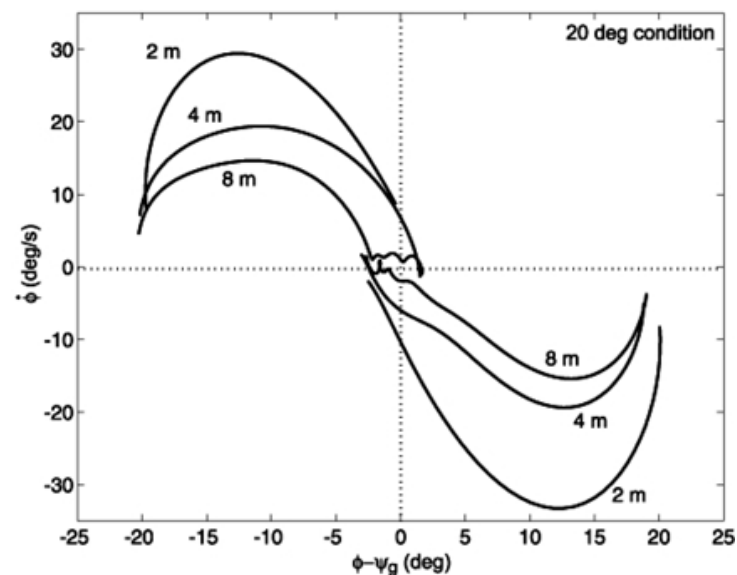
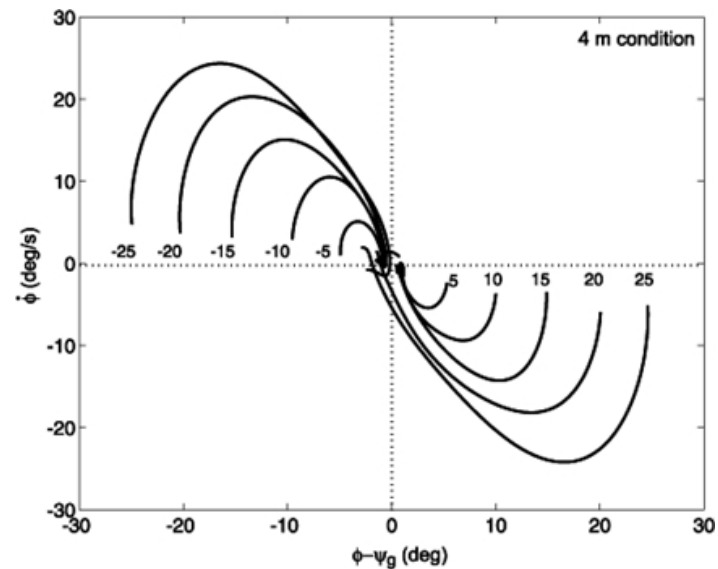
human locomotion to goal

- participants begins to walk
- after walking 1 m, a goal appears at 5, 10, 15, 20, or 25 deg from the straight heading at a distance of 2, 4, or 8 m from participant...
- participants are asked to walk toward the goal

human locomotion to goal

■ => turning rate increased with increasing goal angle

■ => turning rate decreased with increasing distance from goal



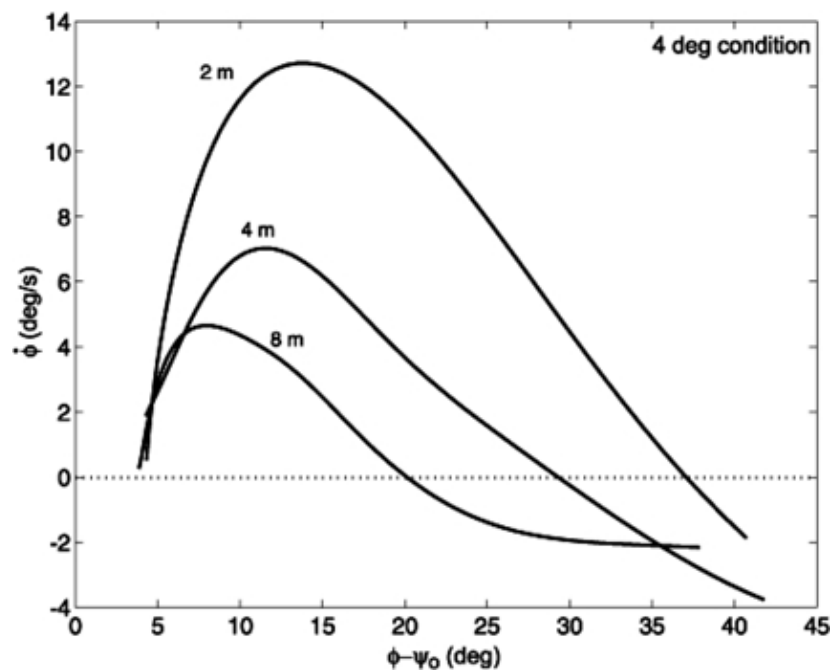
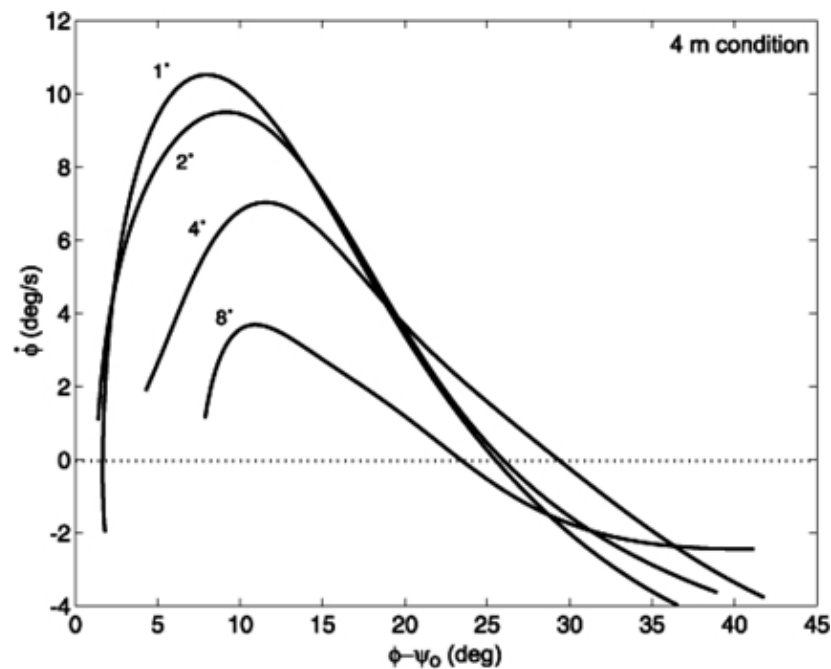
human locomotion: obstacle

- humans walk toward goal at 10 m distance
- after walking 1 m, an obstacle appears at 1, 2, 4, or 8 deg from heading and a distance of 3, 4, or 5 m

human locomotion: obstacle

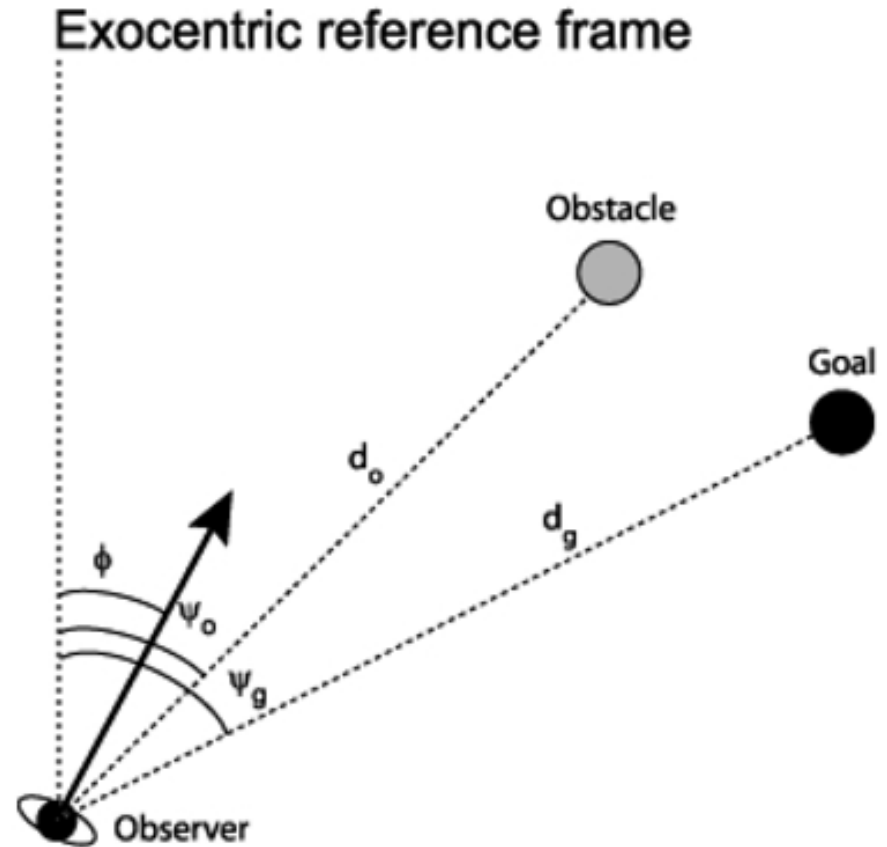
■ => turning rate away from obstacle decreased with obstacle angle

■ => and with obstacle distance



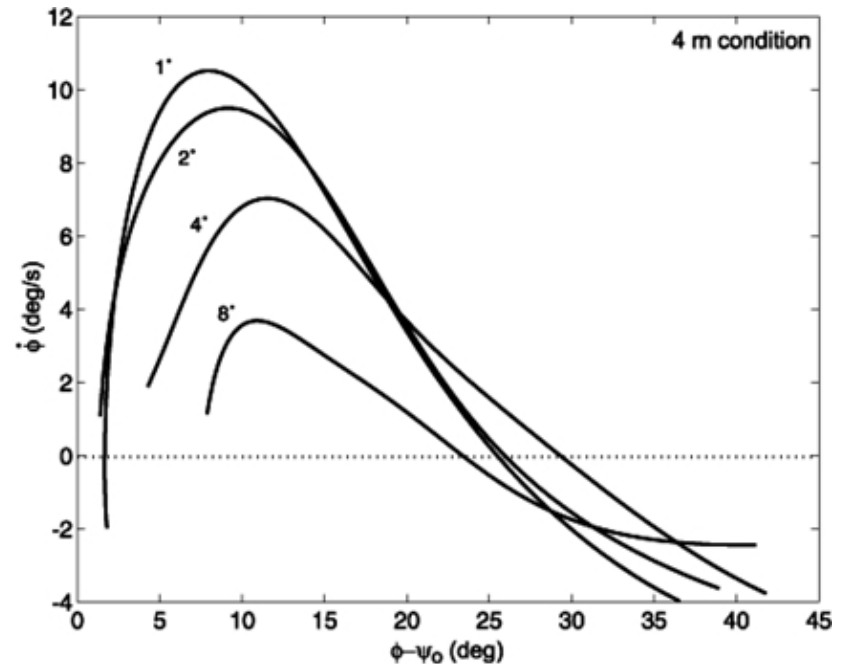
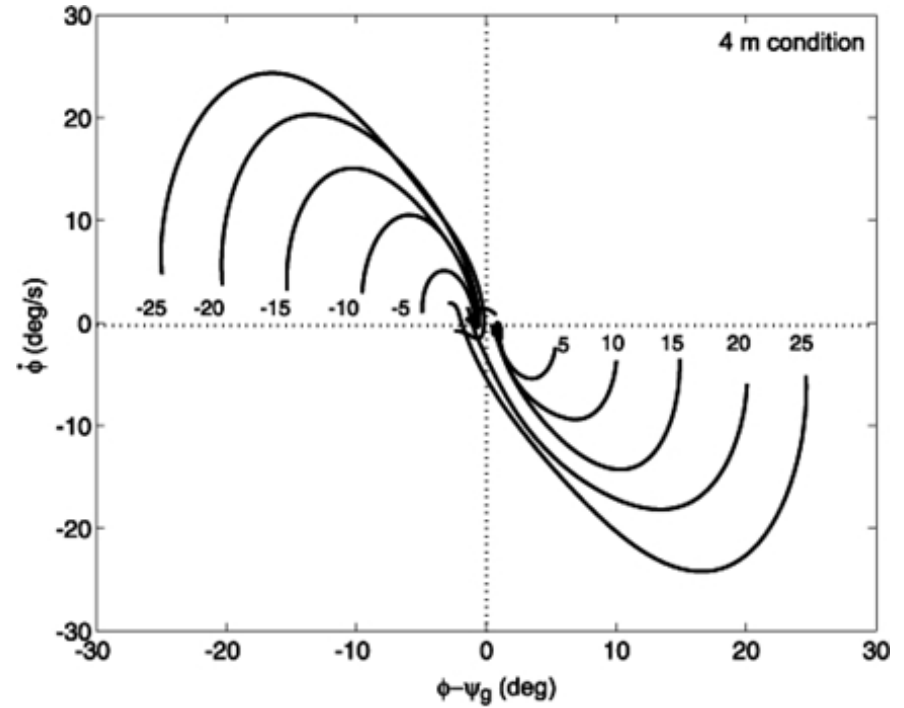
model

- heading direction as dynamical variable



model

- first order dynamics $\dot{\phi} = f(\phi)$ not quite consistent with dependence on initial heading...
- but overall shape of $\dot{\phi}$ vs ϕ and distance dependence consistent with attractor dynamics approach to heading direction



attractor dynamics model

- solution: 2nd order dynamics in heading

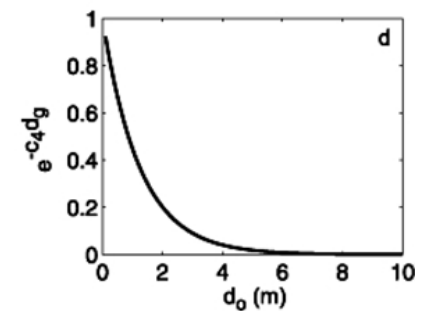
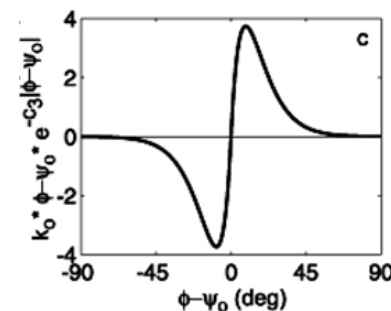
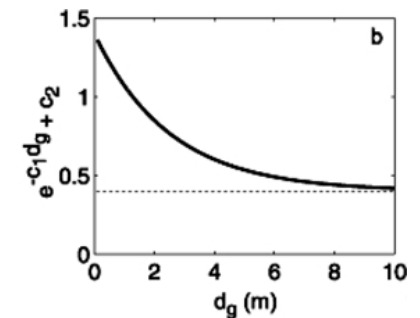
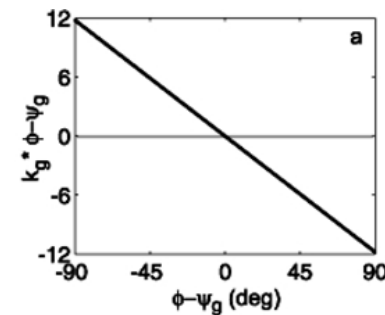
inertial term

damping term

attractor goal heading

$$\ddot{\phi} = -b\dot{\phi} - k_g(\phi - \psi_g)(e^{-c_1 d_g} + c_2) + k_o(\phi - \psi_o)(e^{-c_3|\phi - \psi_o|})(e^{-c_4 d_o})$$

repellor obstacle heading



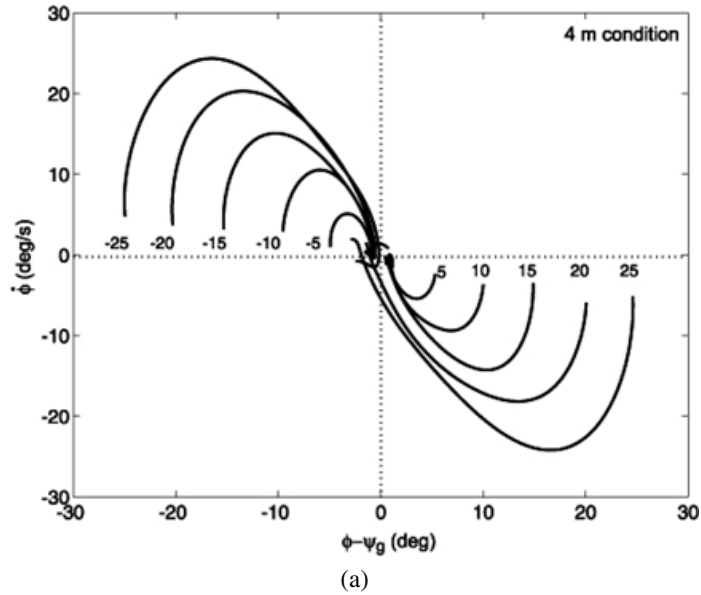
attractor dynamics model

- approximation: inertia to zero: find first order dynamics with time scale b
- compute fixed points and stability: fixed points of first order dynamics are fixed points too and have the matching stability

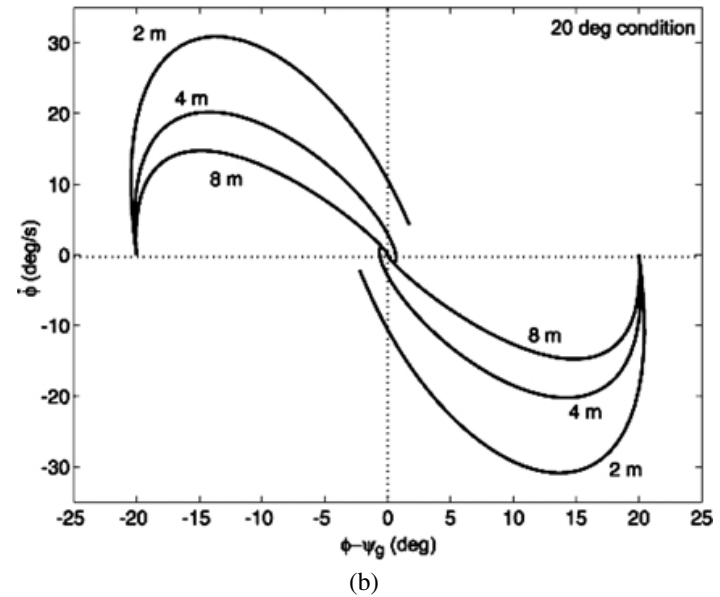
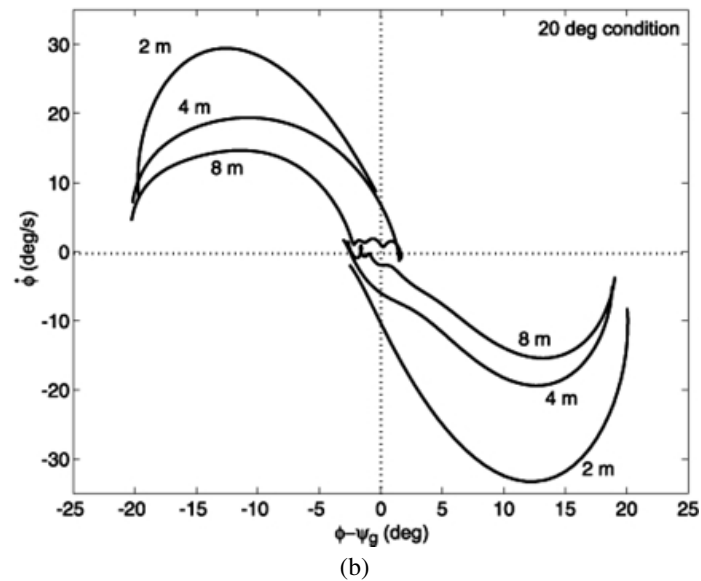
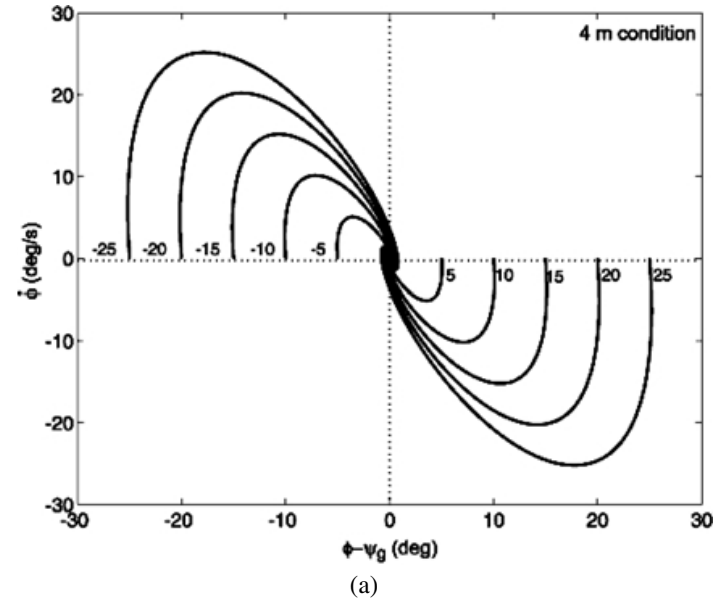
$$\ddot{\phi} = -b\dot{\phi} - k_g(\phi - \psi_g)(e^{-c_1 d_g} + c_2) \quad \text{attractor goal heading} \\ + k_o(\phi - \psi_o)(e^{-c_3|\phi - \psi_o|})(e^{-c_4 d_o}) \quad \text{repellor obstacle heading}$$

model-experiment match: goal

experiment

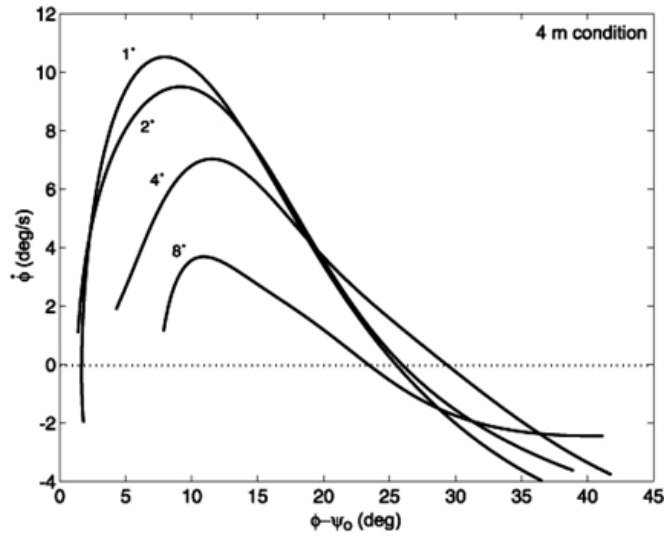


model



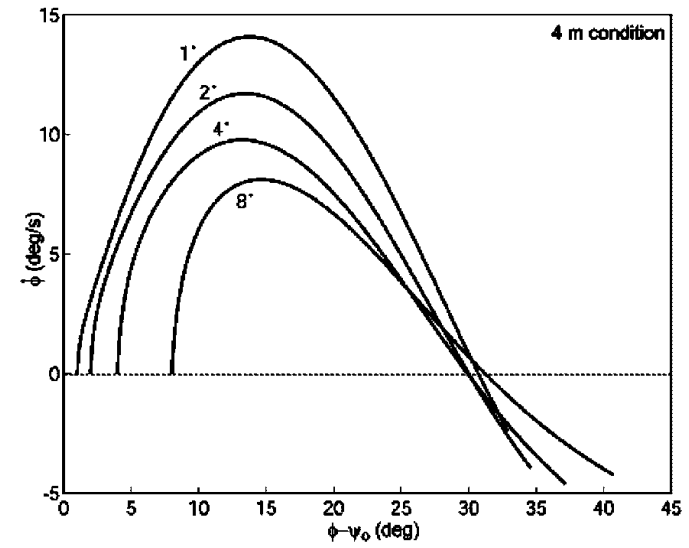
model-experiment match: obstacle

experiment

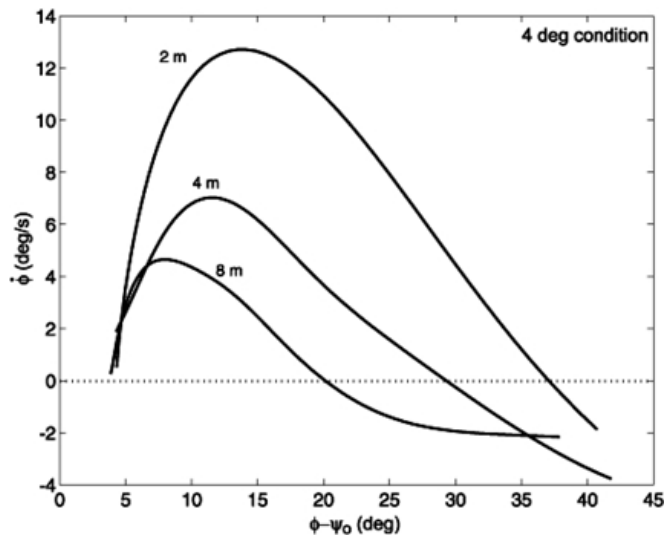


(a)

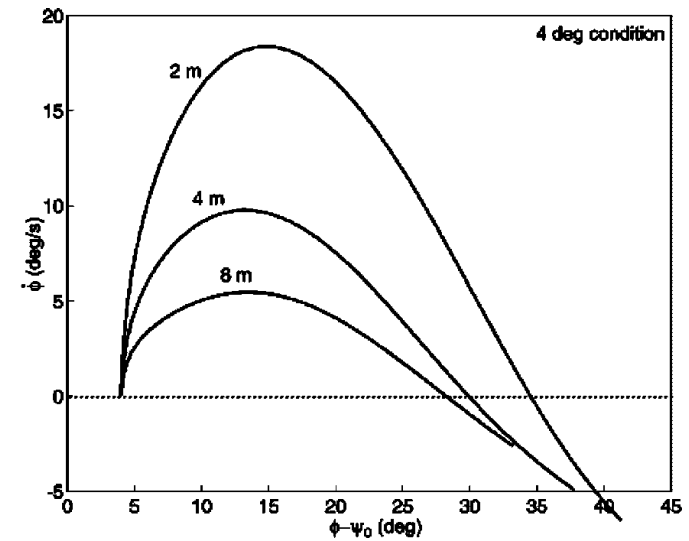
model



(a)

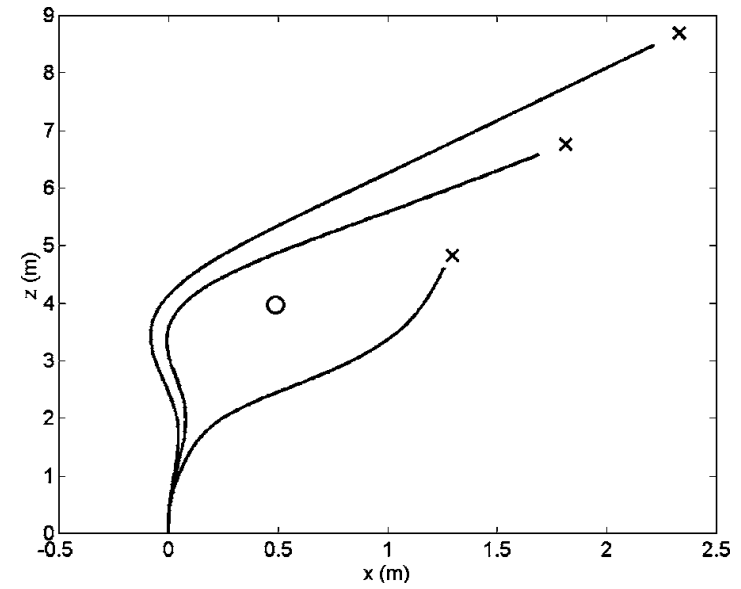
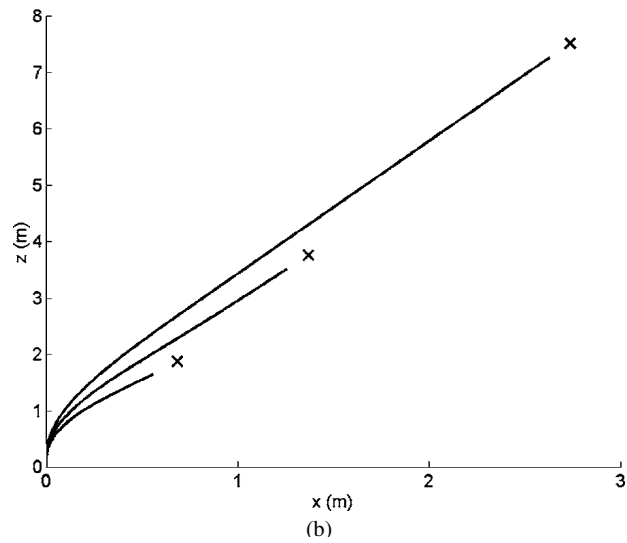
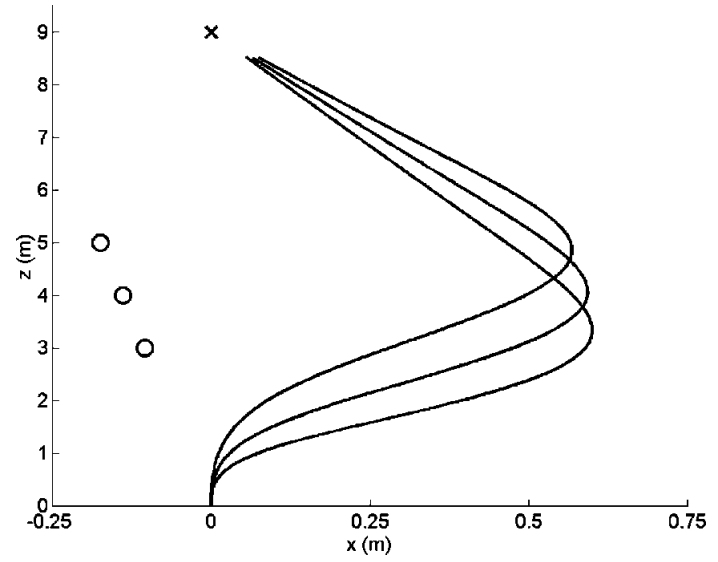
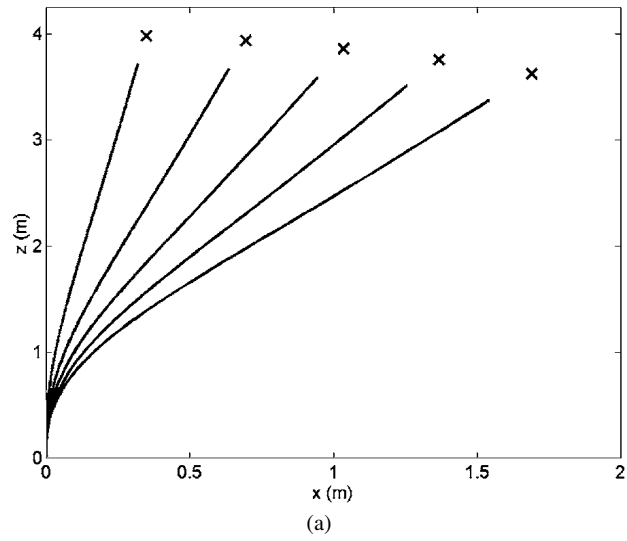


(b)



(b)

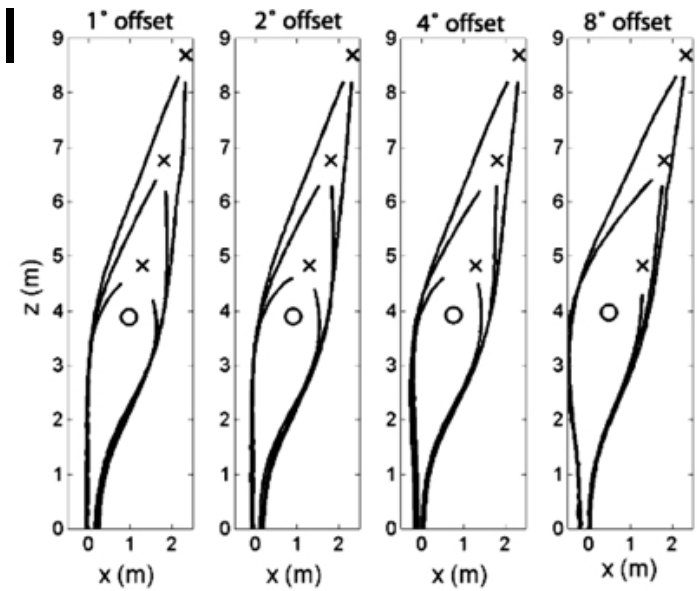
model: paths



model-exp: decision making

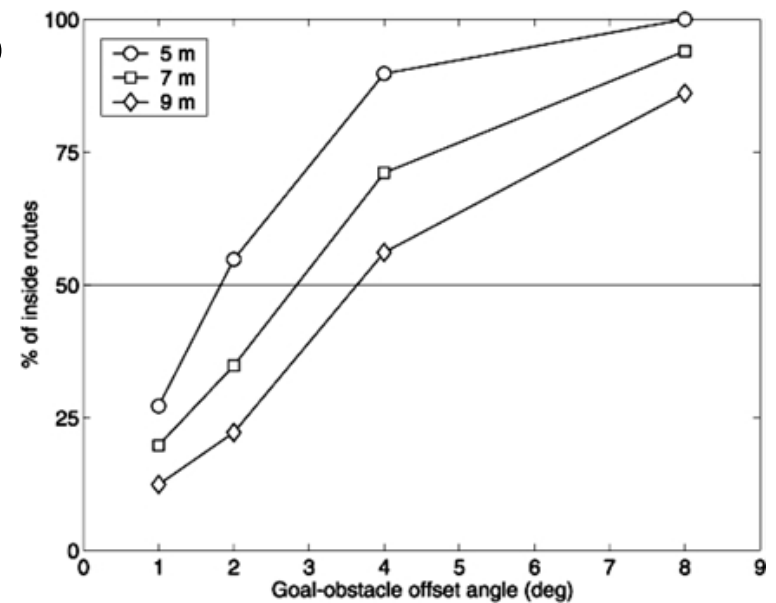
■ inside vs. outside path

model



(a)

exp



(b)

Conclusion

- the attractor dynamic model can account for human locomotory behavior in target acquisition and obstacle avoidance