Attractor dynamics approach to behavior generation: vehicle motion

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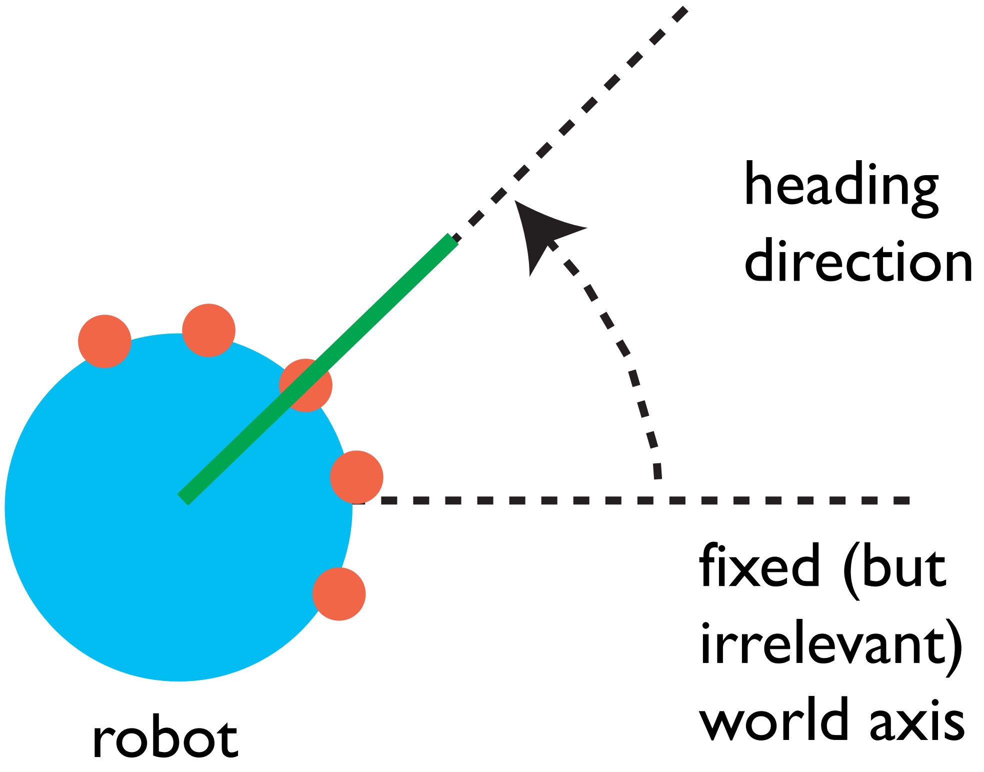
Basic ideas of attractor dynamics approach

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

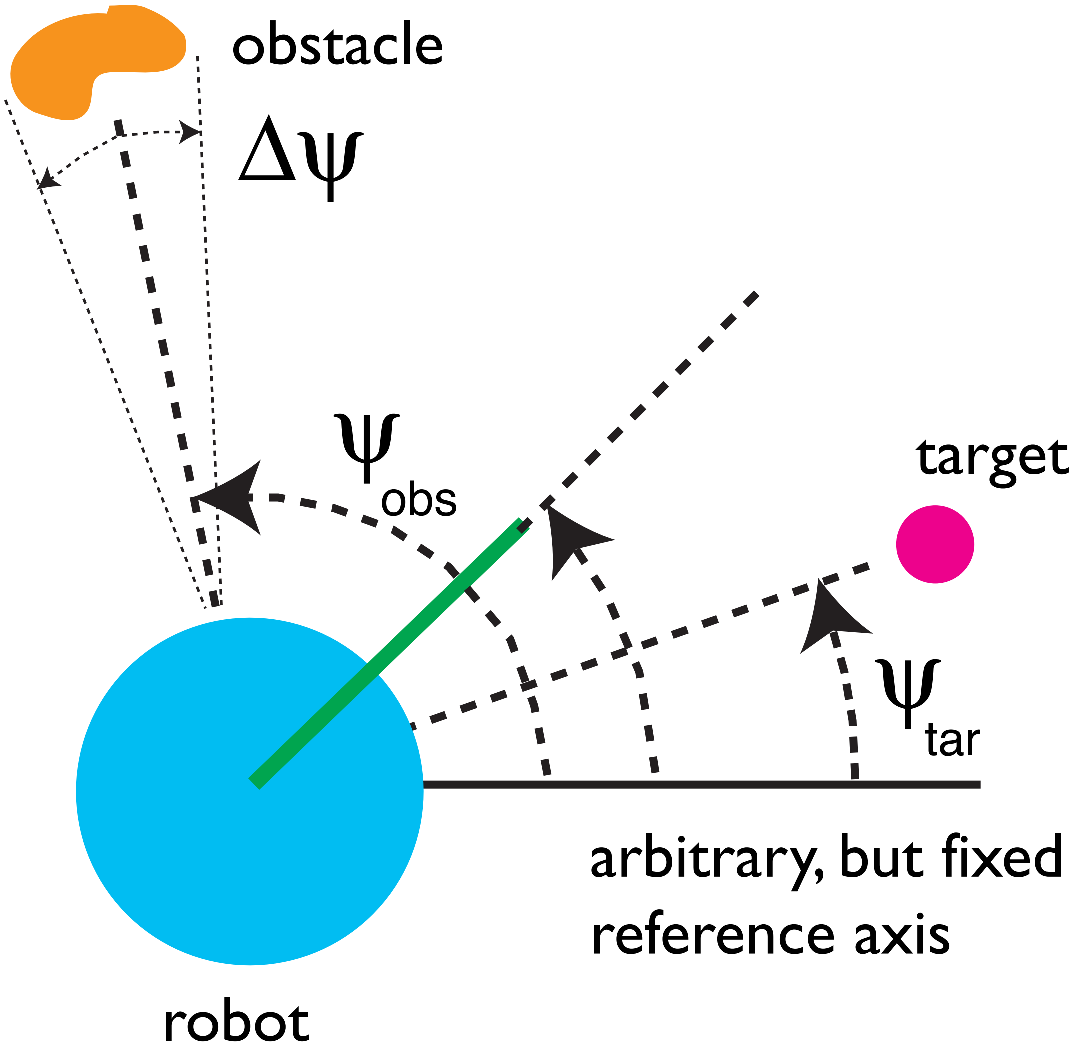
Behavioral variables: example

- vehicle moving in 2D: heading direction



Behavioral variables: example

- constraints: obstacle avoidance and target acquisition



Behavioral variables

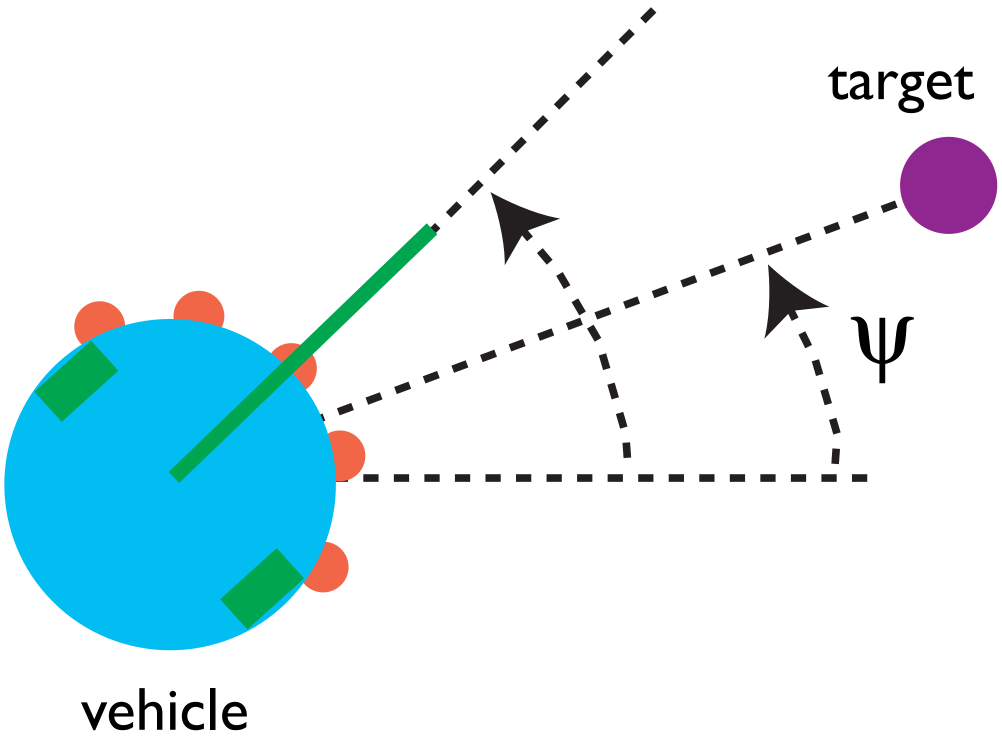
- describe desired motor behavior
- “enactable”
- express constraints as values/value ranges
- appropriate level of invariance

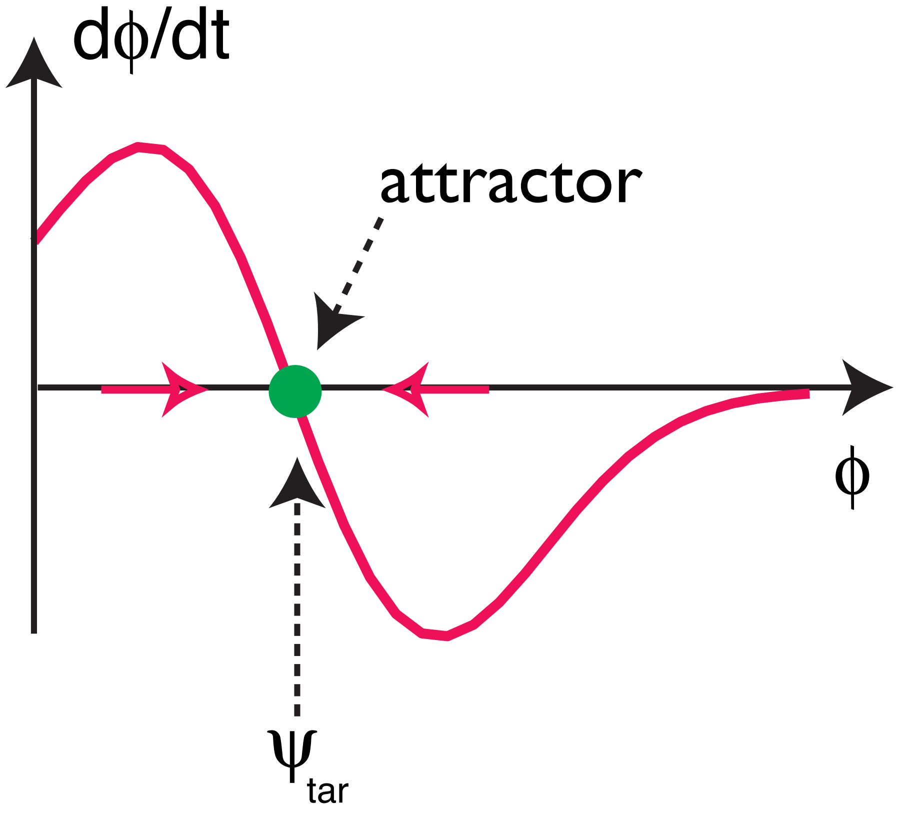
Behavioral dynamics

- 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

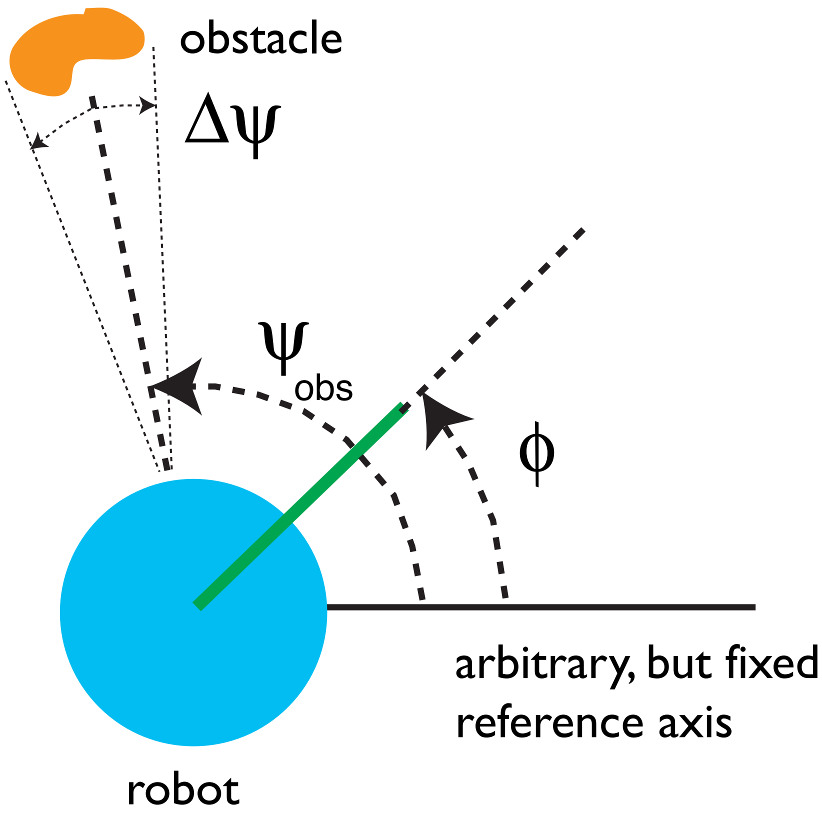
- behavioral constraint: target acquisition

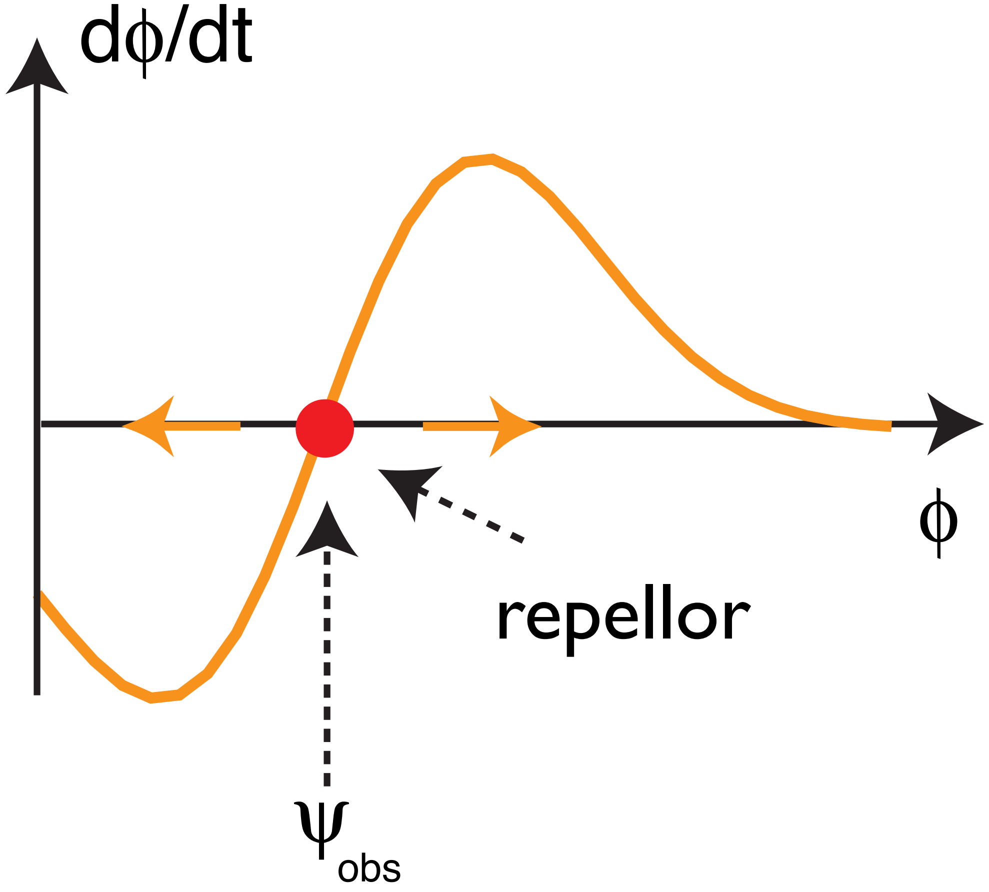




Behavioral dynamics: example

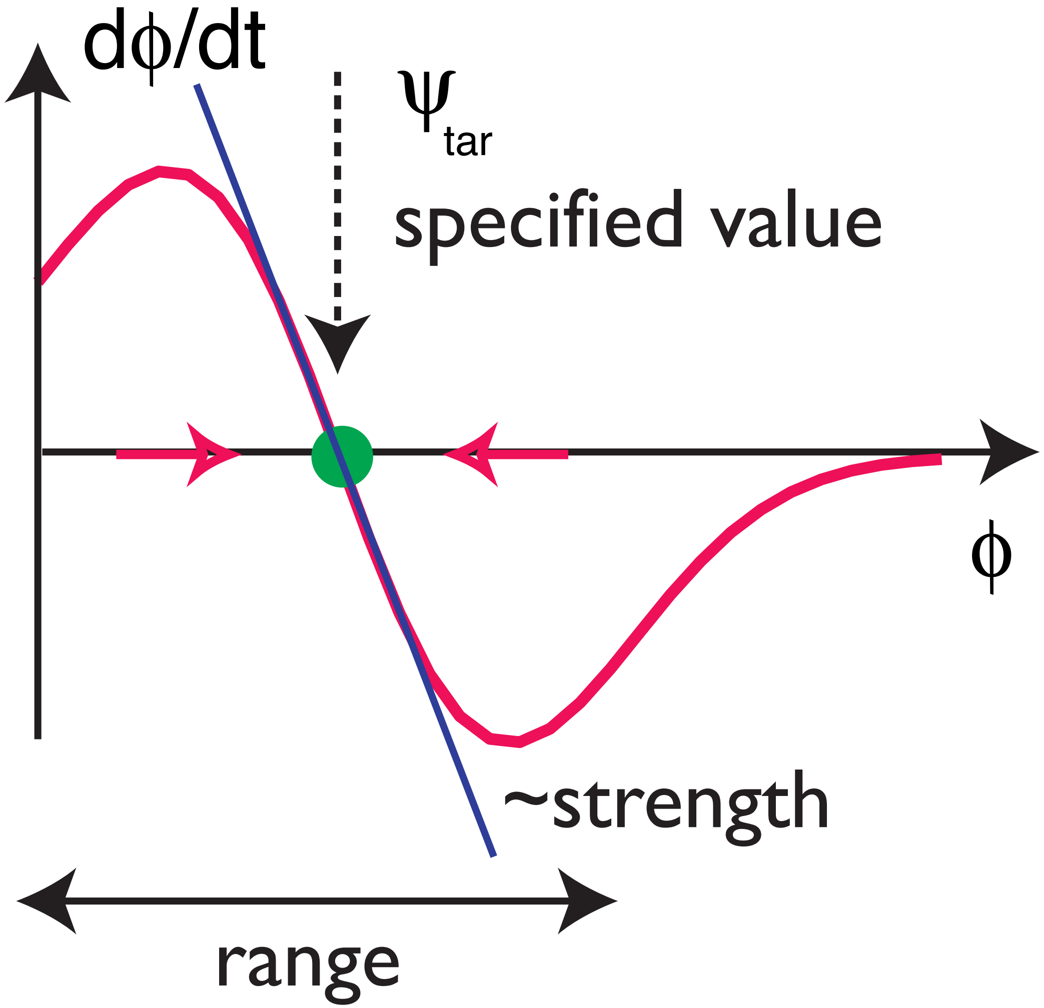
- behavioral constraint: obstacle avoidance





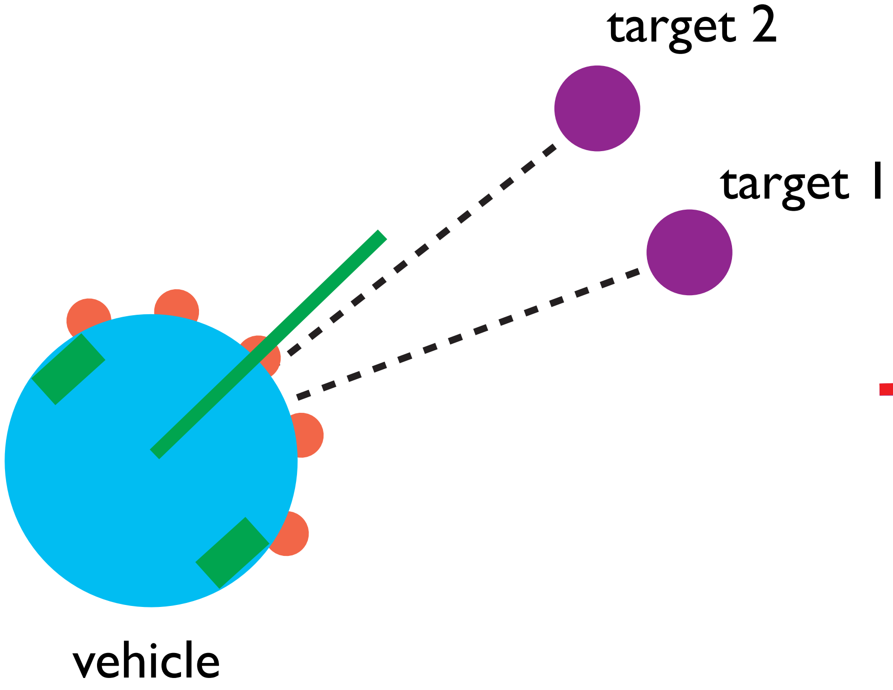
Behavioral dynamics

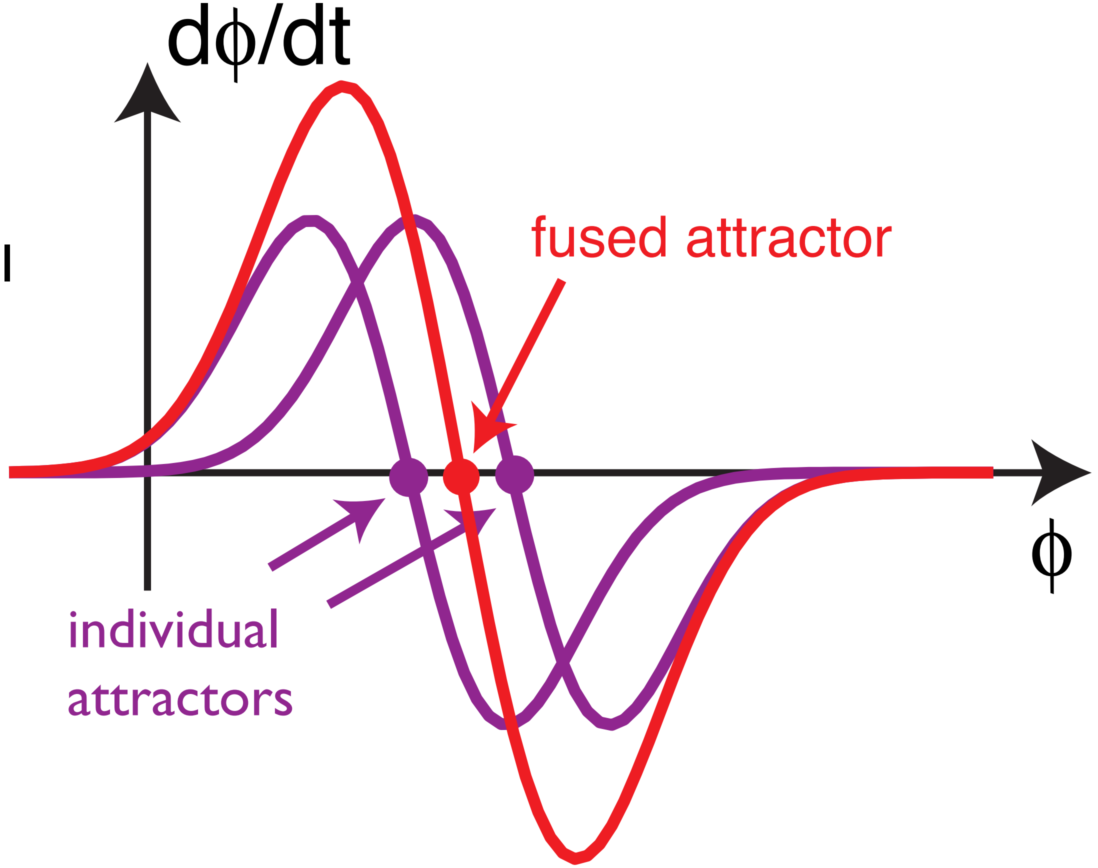
- each constribution is a "force-let" with
  - specified value
  - strength
  - range



Behavioral dynamics

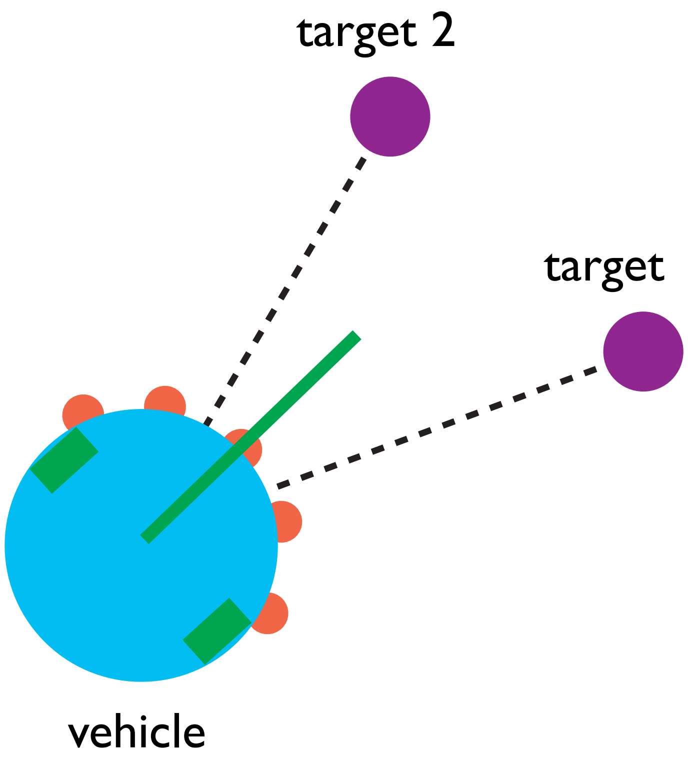
- multiple constraints: superpose “force-lets”
- fusion

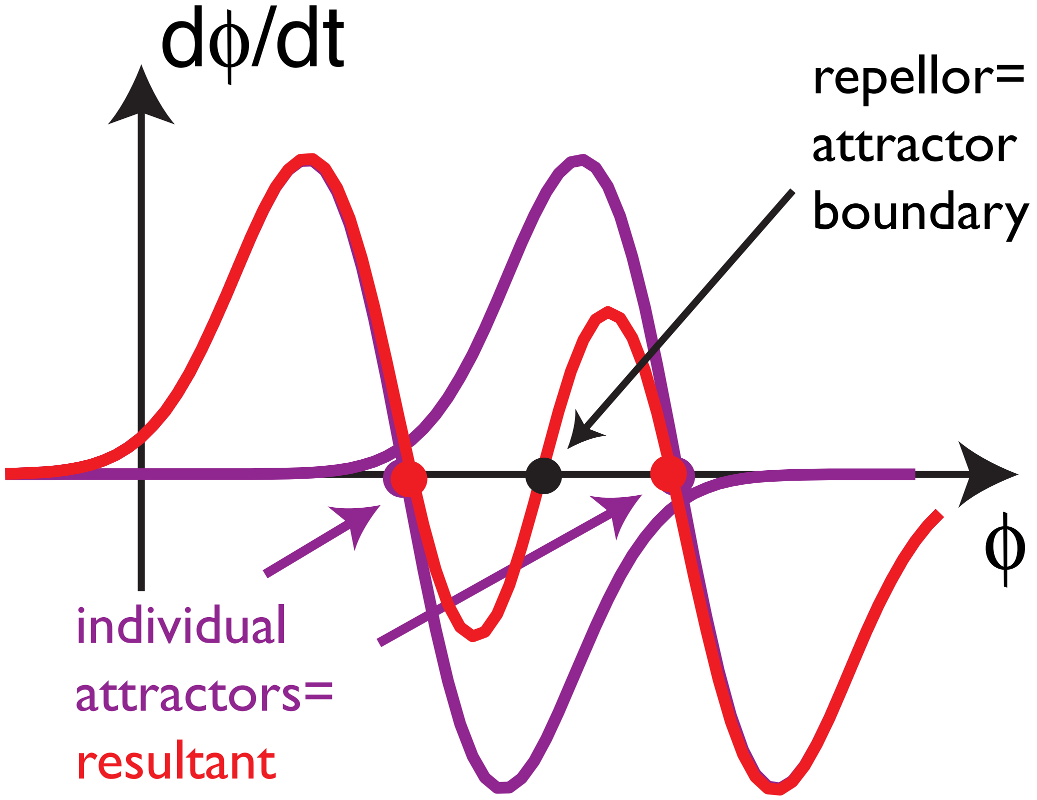




Behavioral dynamics

- decision making



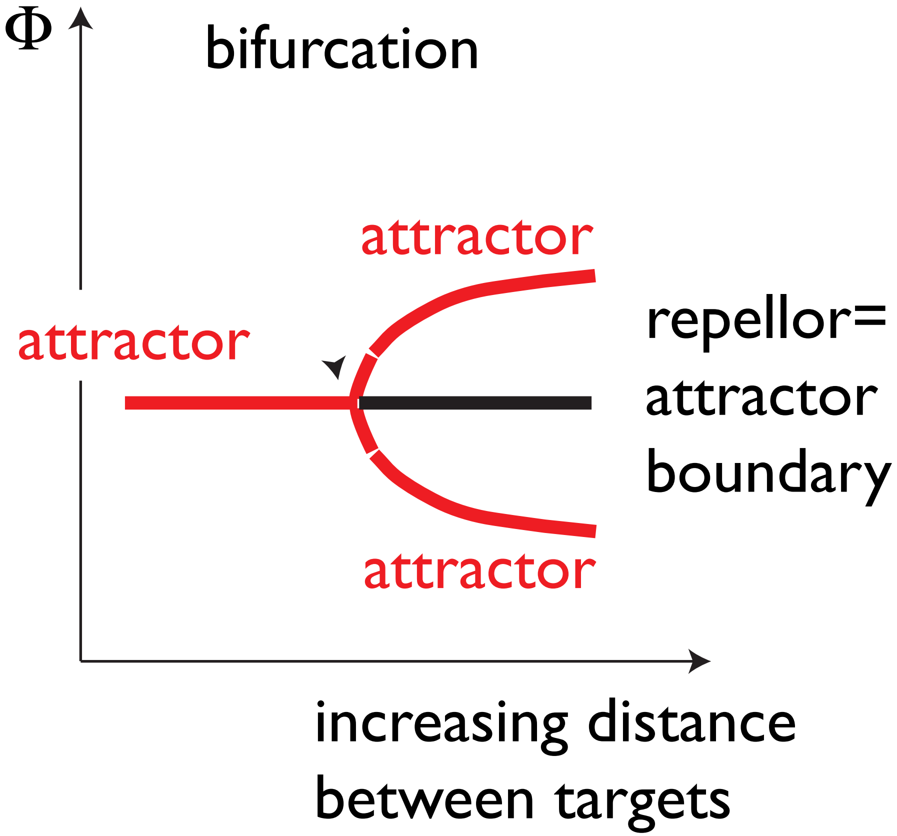


repellor=
attractor
boundary

individual
attractors=
resultant
attractors
=> bistable

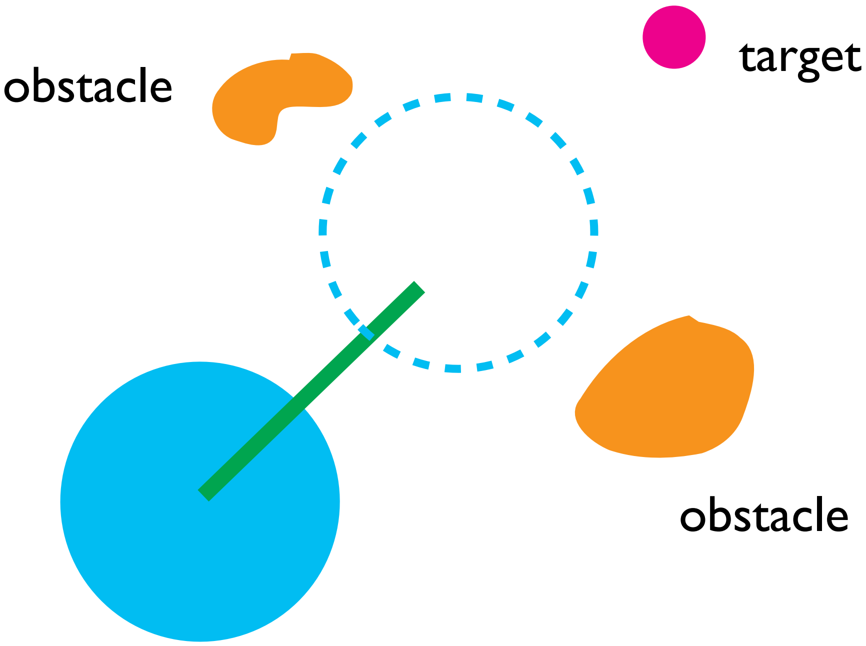
Behavioral dynamics

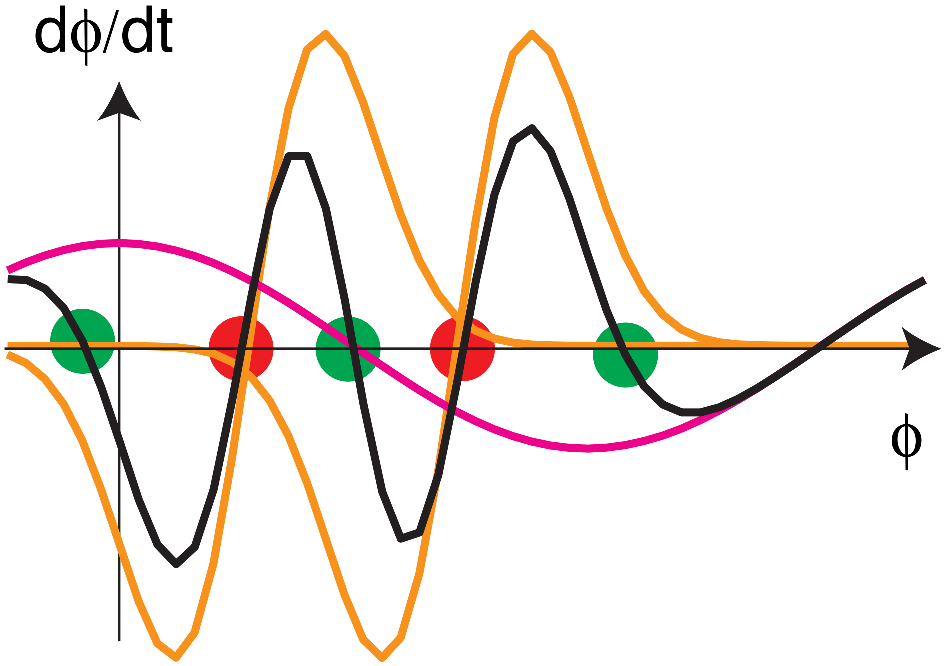
- Bifurcations switch between fusion and decision making



Behavioral dynamics

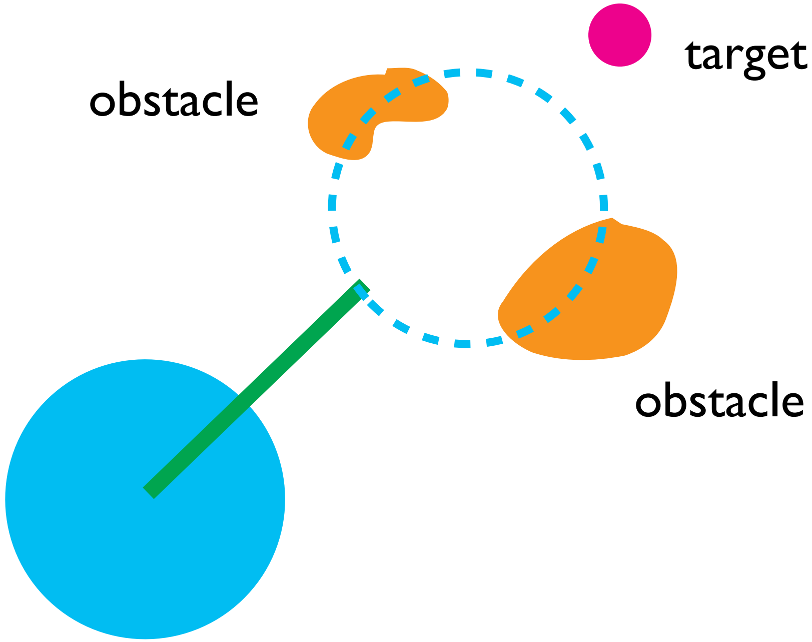
- an example closer to “real life”: bifurcations in obstacle avoidance and target acquisition
- constraints not in conflict

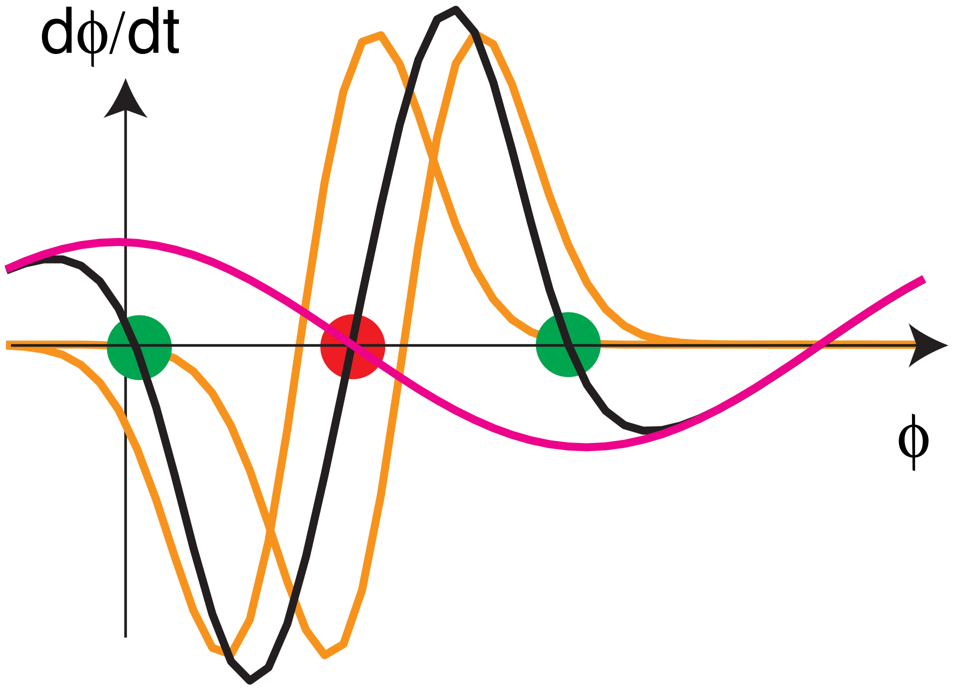




Behavioral dynamics

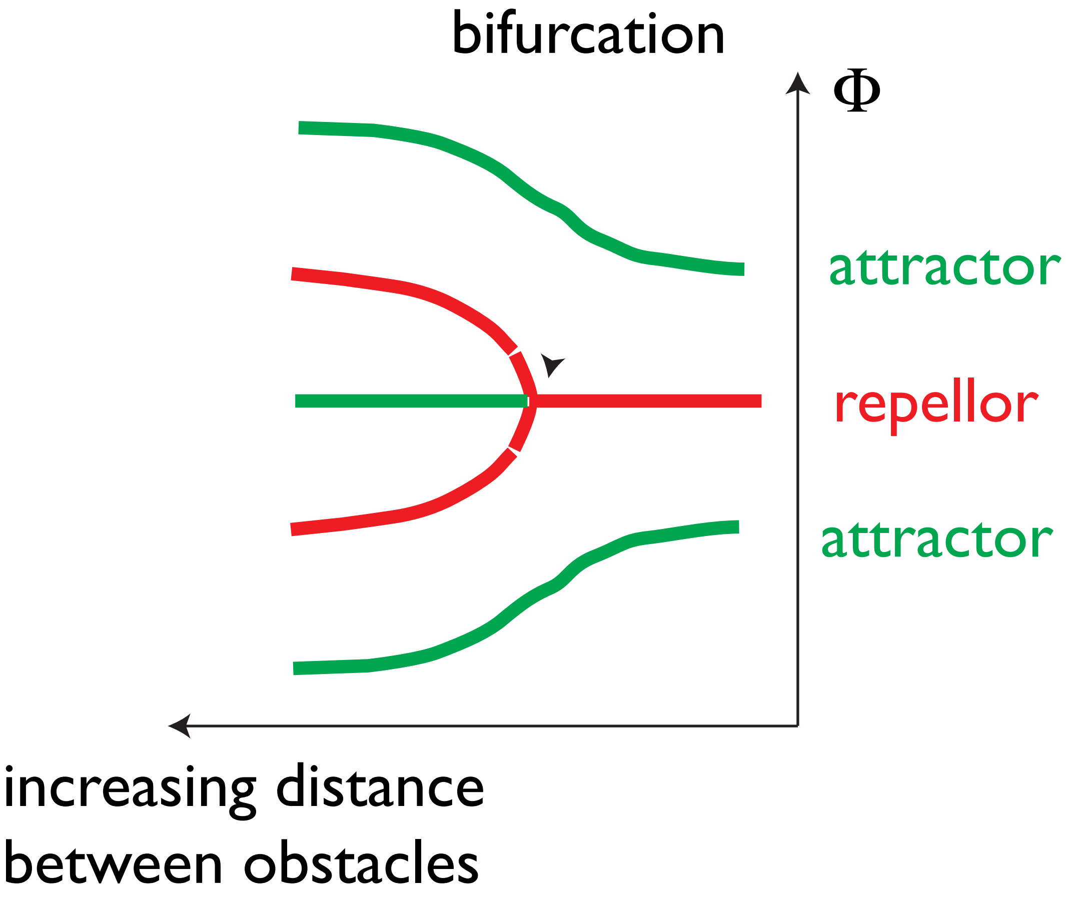
- constraints in conflict





Behavioral dynamics

- transition from "constraints not in conflict" to "constraints in conflict" is a bifurcation

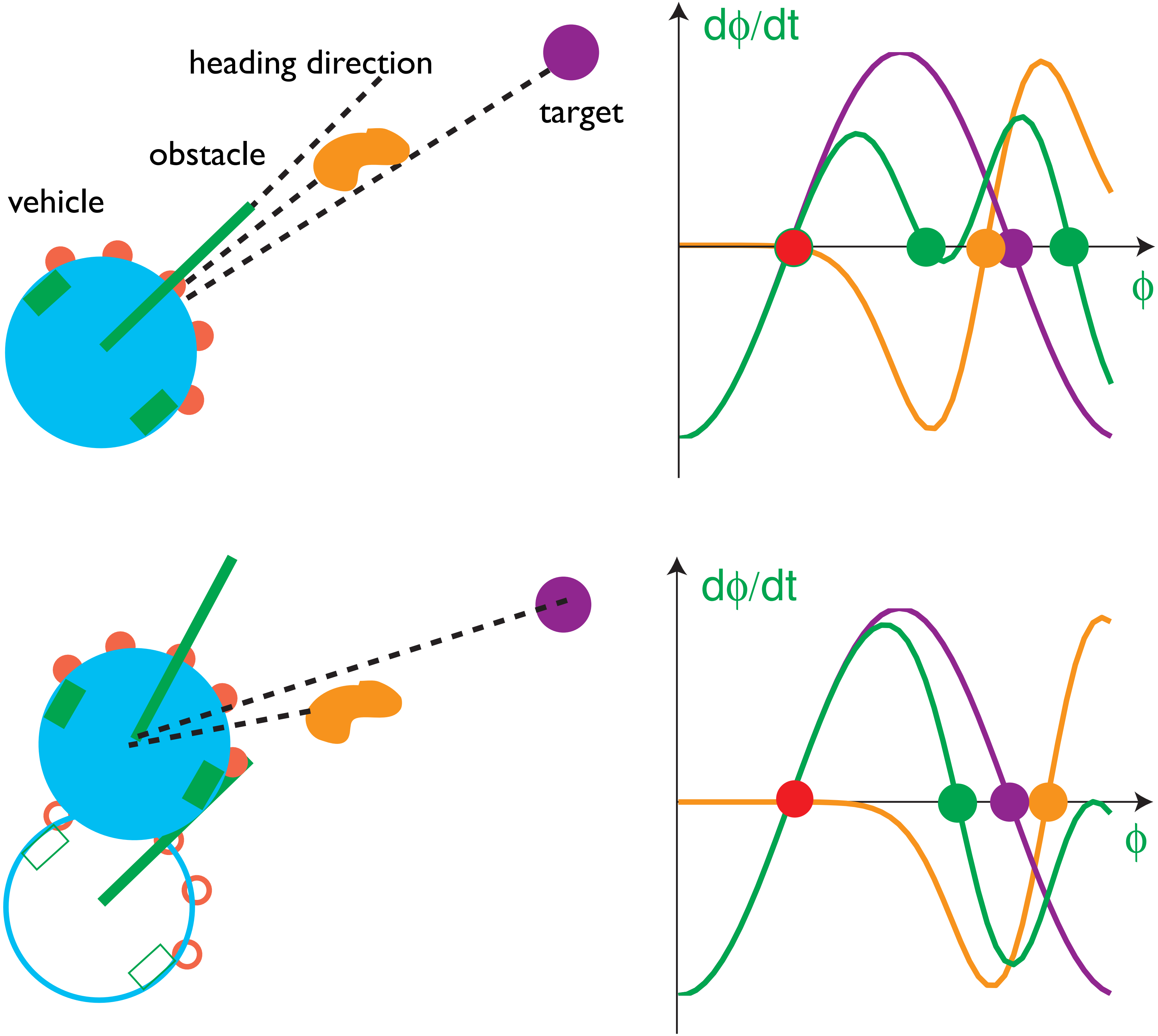


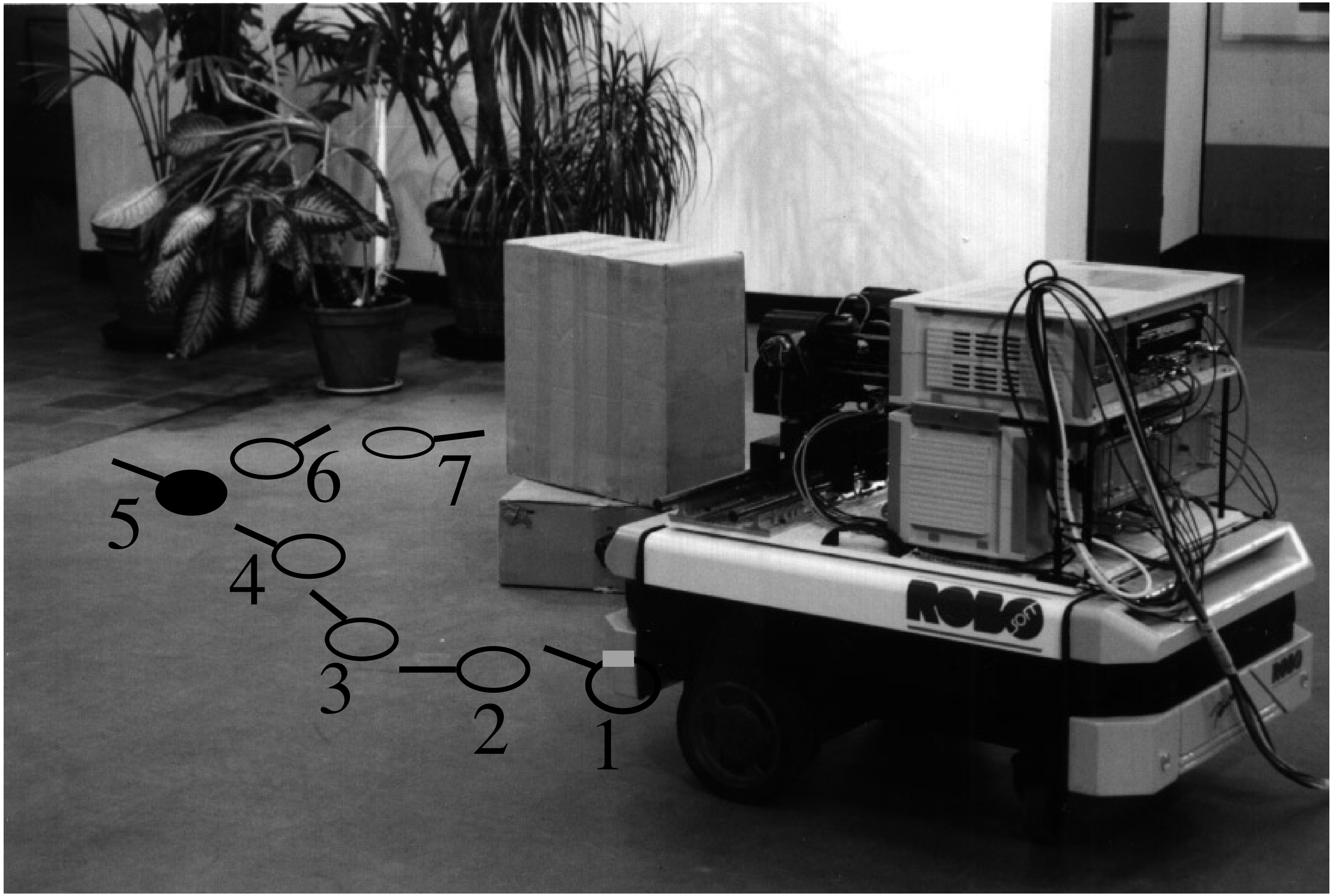
Behavioral dynamics

- 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).

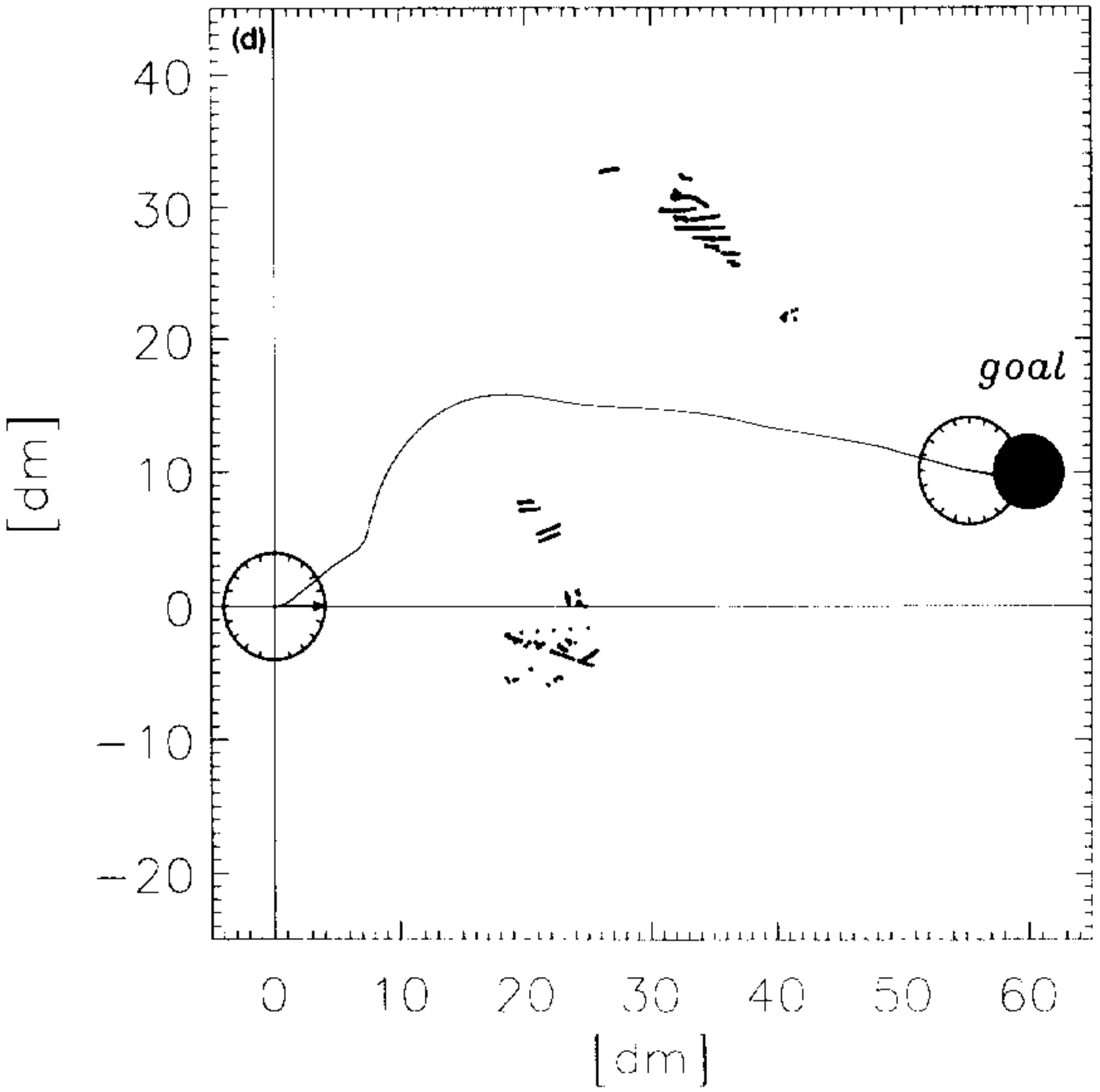
Behavioral dynamics

- 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


heading direction
target
obstacle
vehicle
dφ/dt
φ
dφ/dt
φ



[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

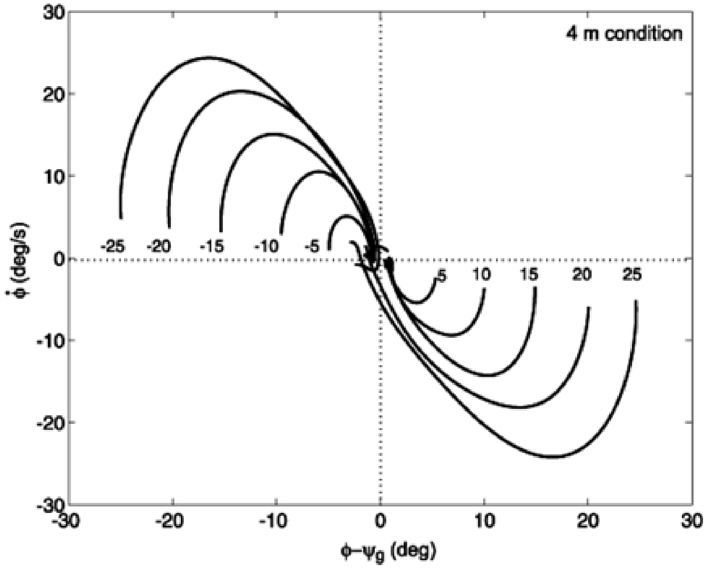
- Bill Warren and Bret Fajen have used the attractor dynamics approach to account for how humans locomote in virtual reality

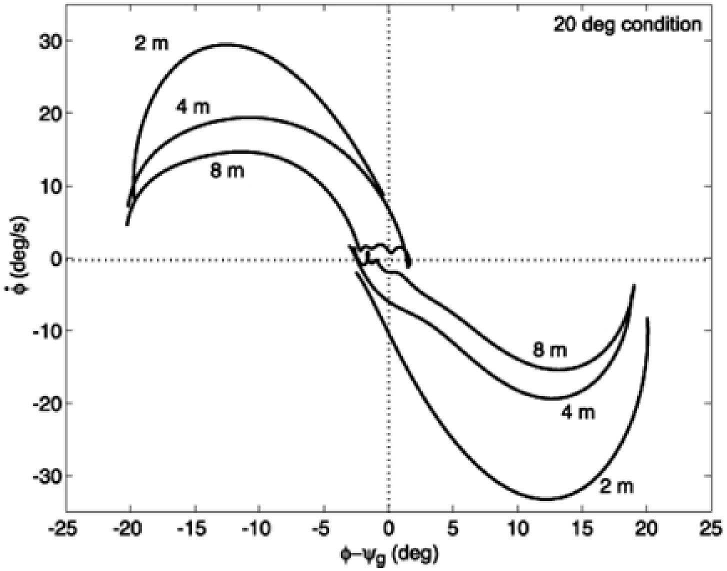
human locomotion to goal

- 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 form goal



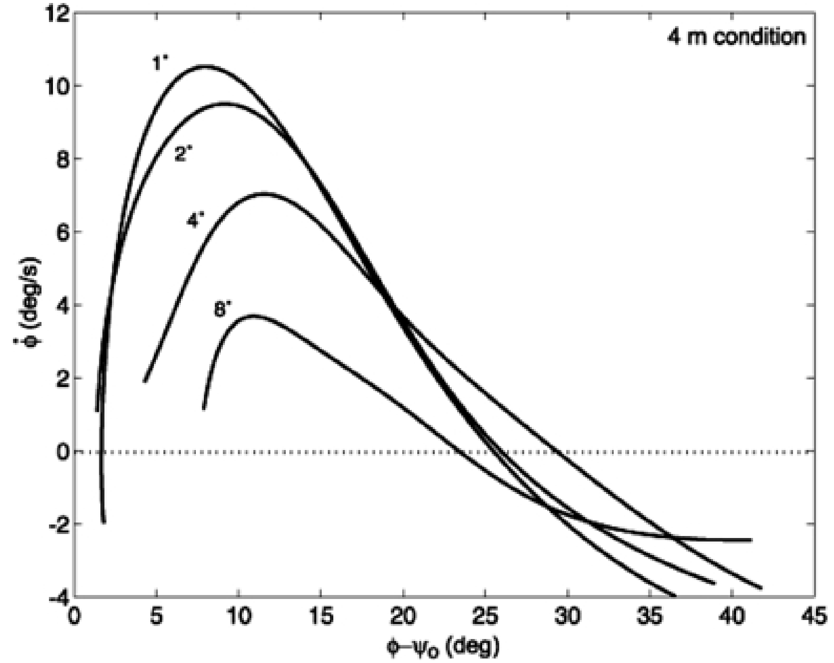


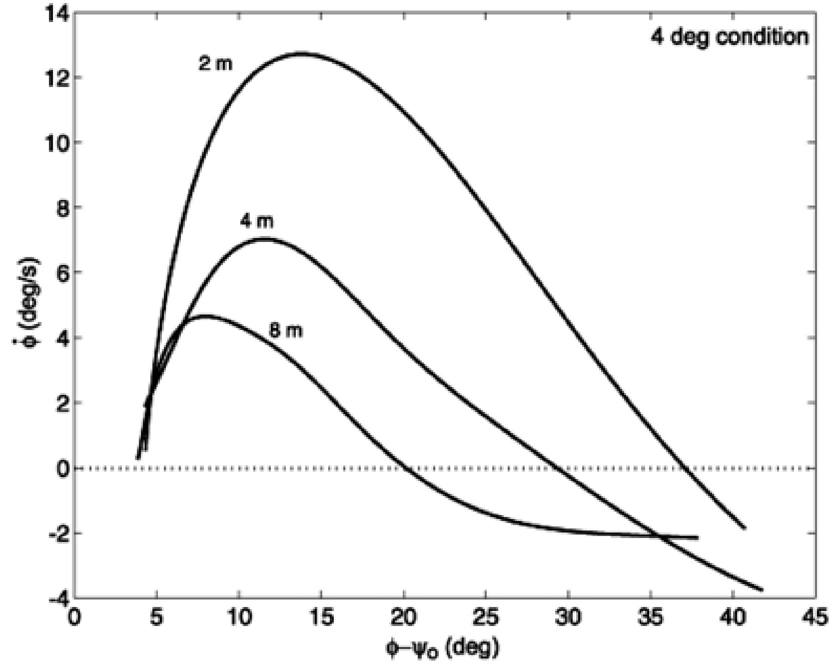
human locomotion: obstacle

- 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

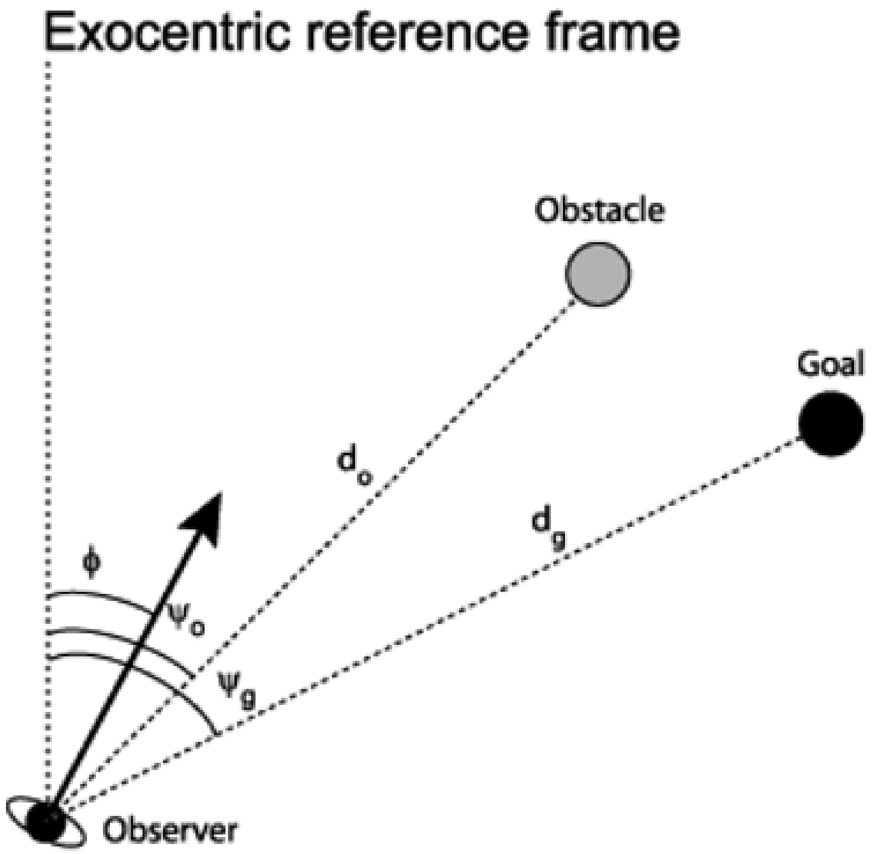
- => turning rate away from obstacle decreased with obstacle angle
- => and with obstacle distance





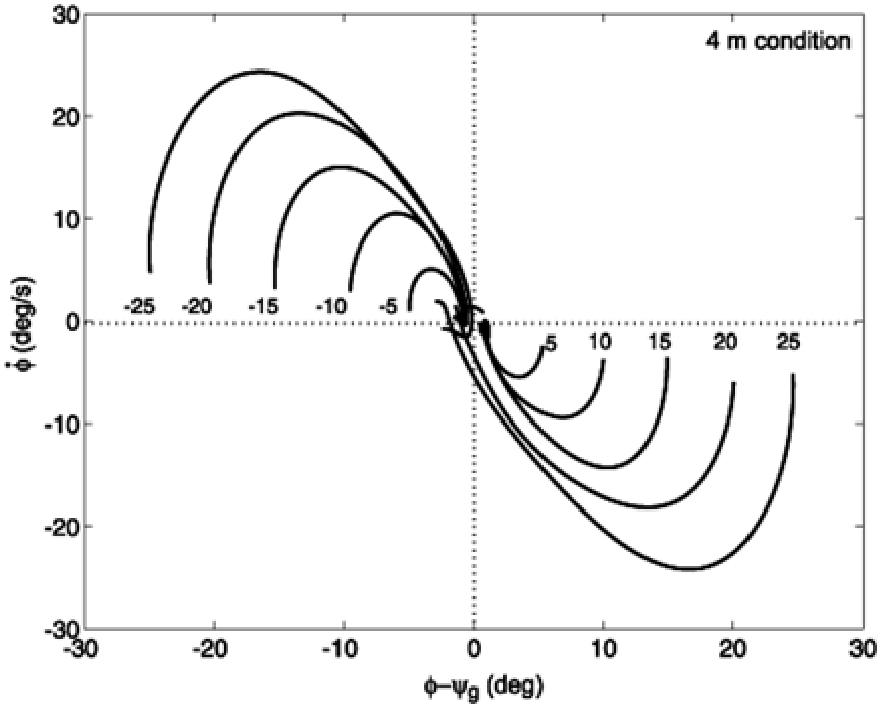
model

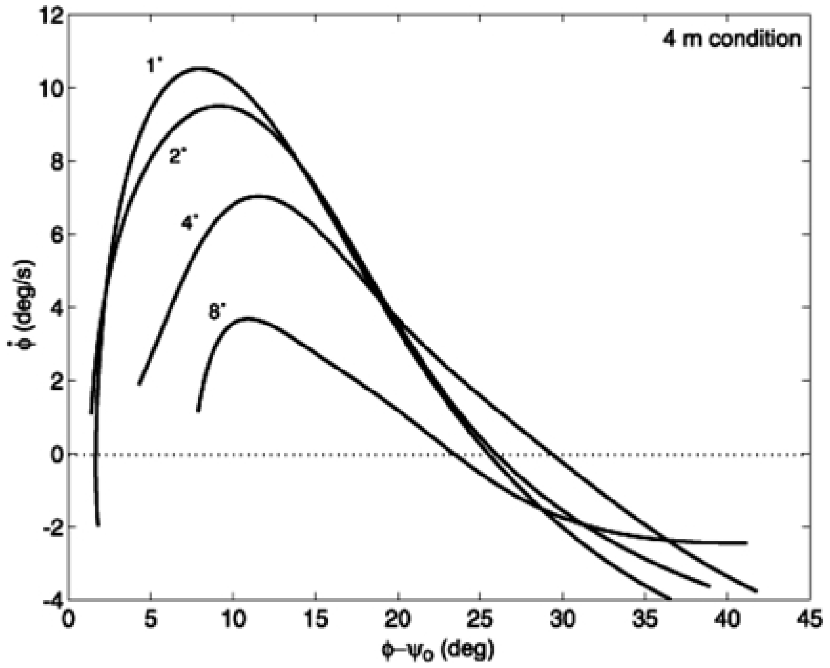
- heading direction as dynamical variable



model

- first order dynamics dot phi = f(phi) not quite consistent with dependence on initial heading…
- but overall shape of phidot vs phi and distance dependence consistent with attractor dynamics approach to heading direction





attractor dynamics model

- solution: 2nd order dynamics in heading

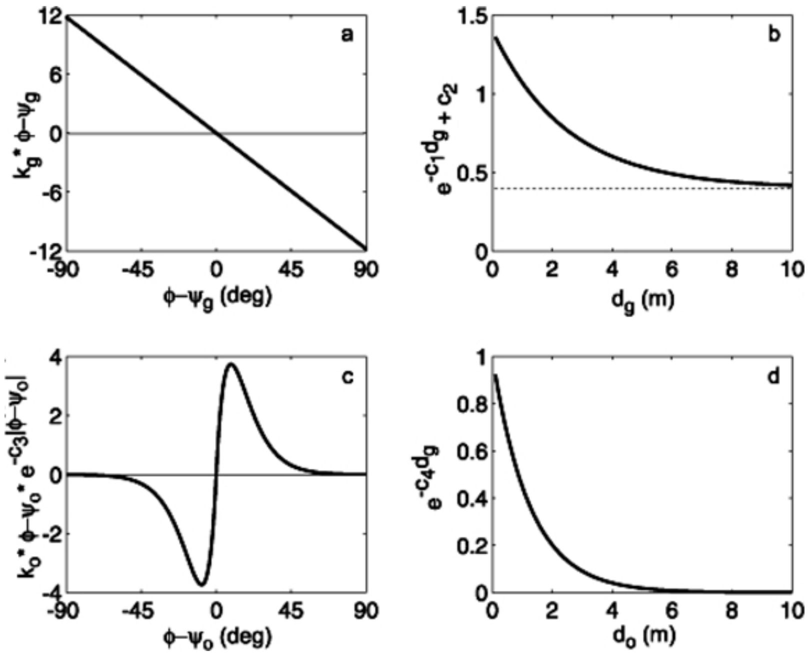
inertial term

damping term

attractor goal heading

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

repellor obstacle heading



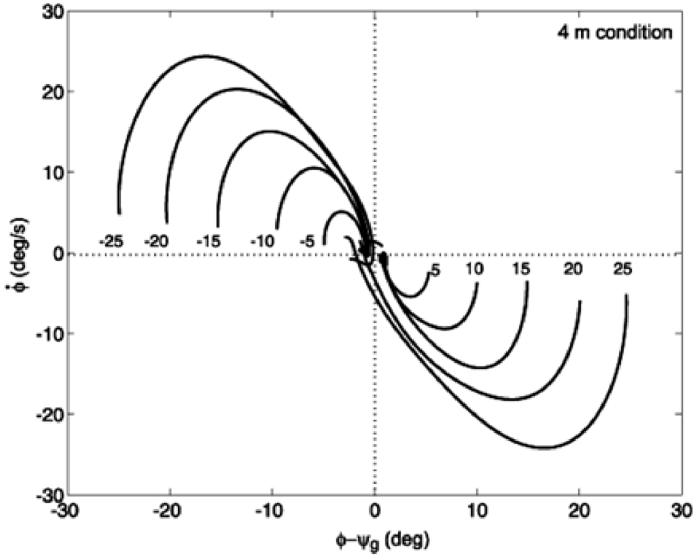
attractor dynamics model

- 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

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

model-experiment match: goal

experiment



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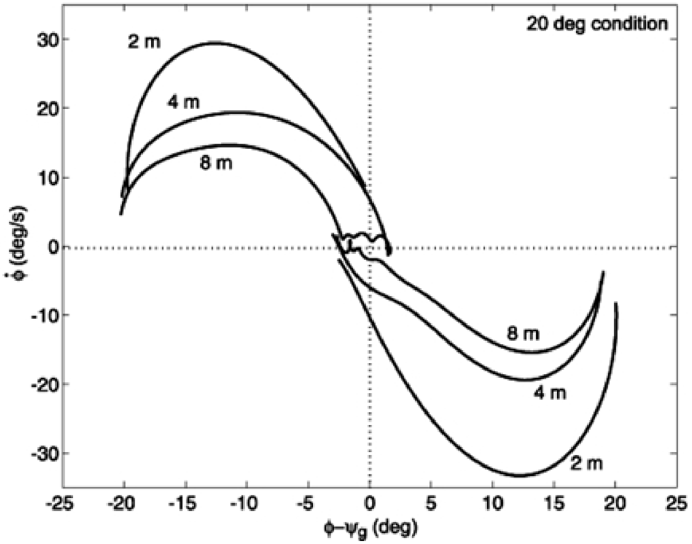
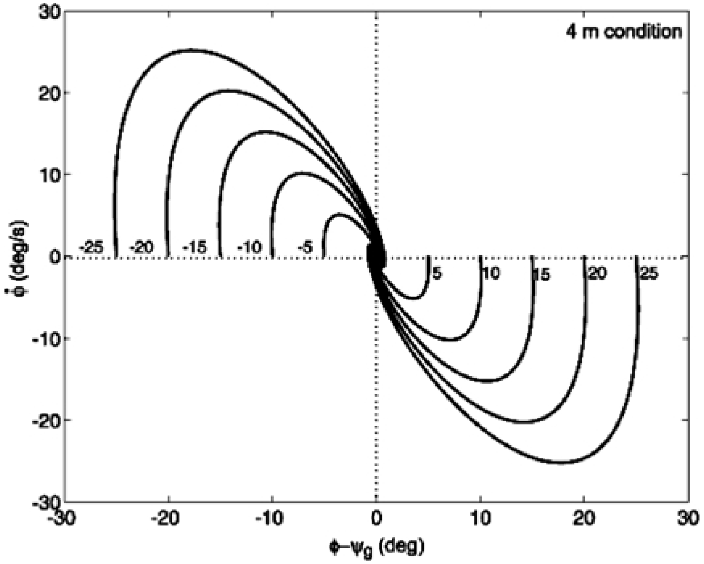


(b)

model



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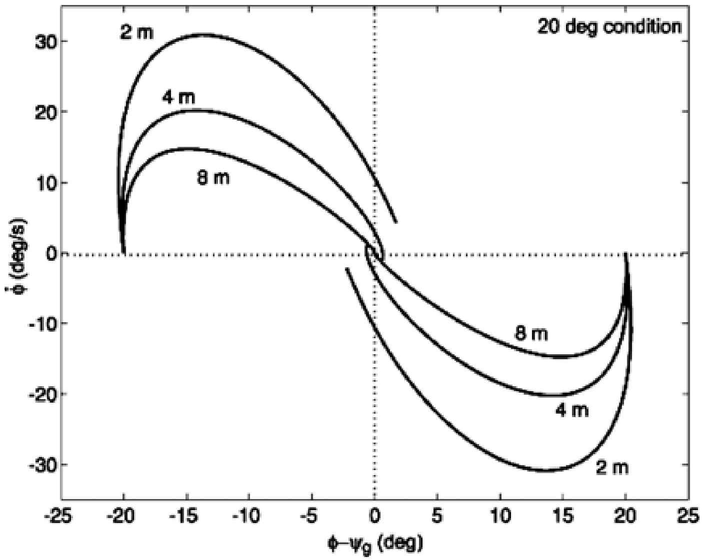
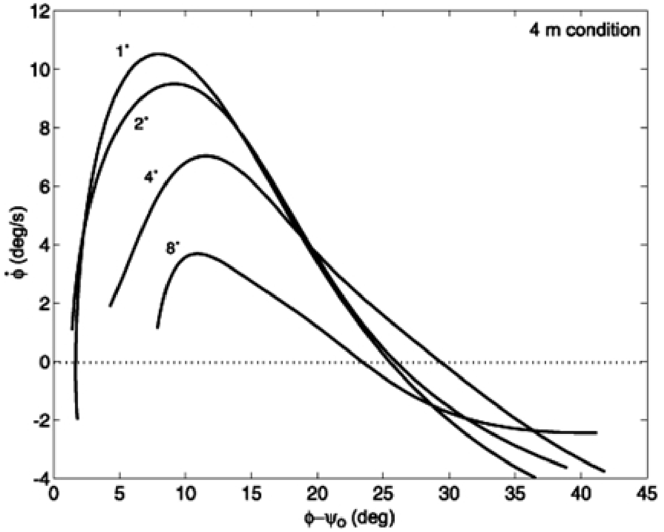


(b)

model-experiment match: obstacle

experiment



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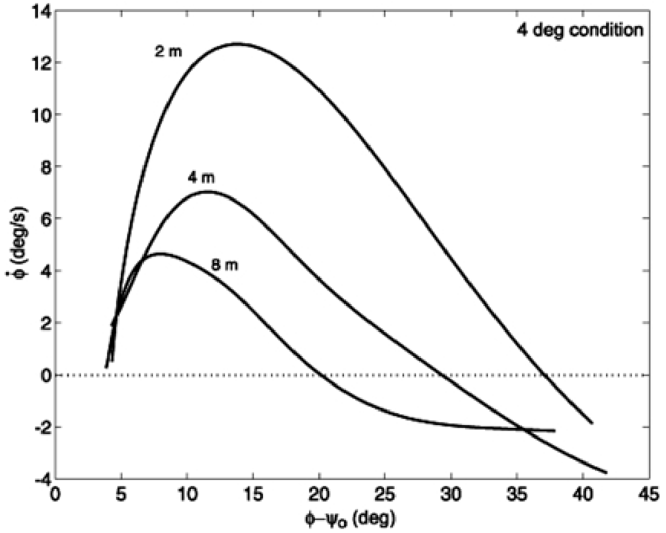
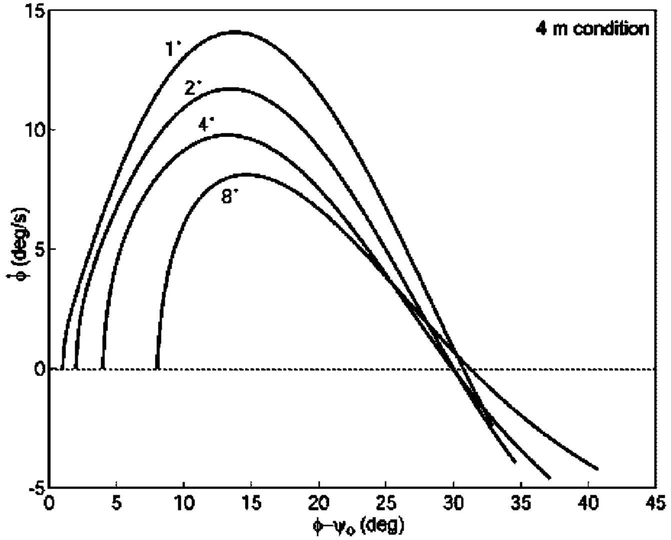


(b)

model



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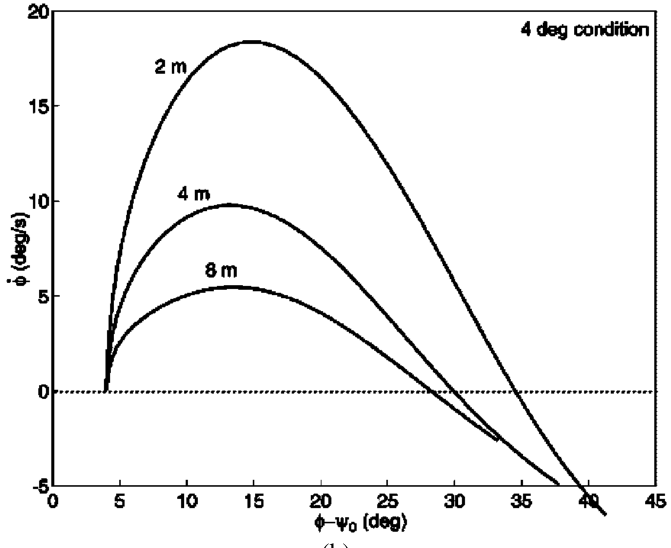
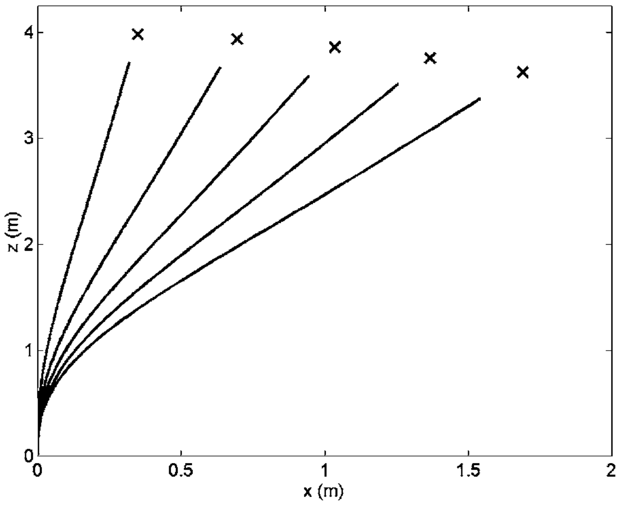


(b)

model: paths



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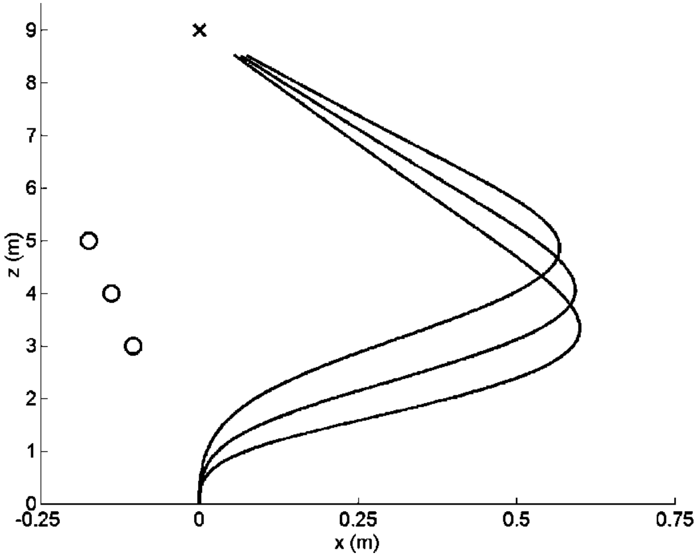

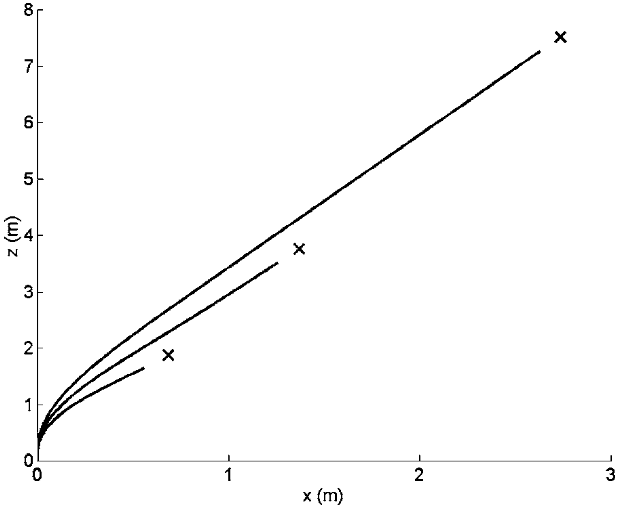

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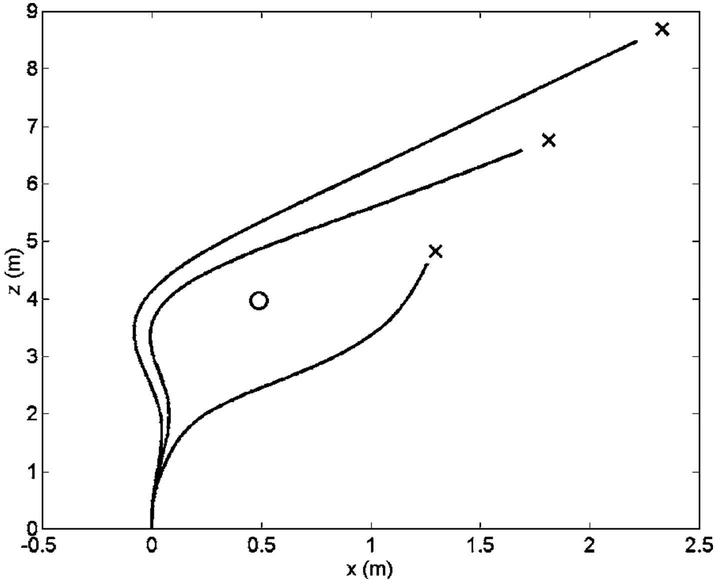
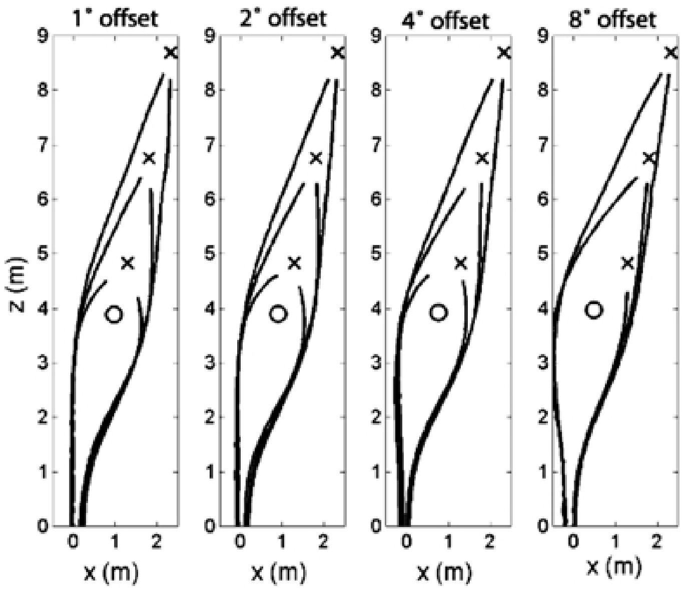


model-exp: decision making

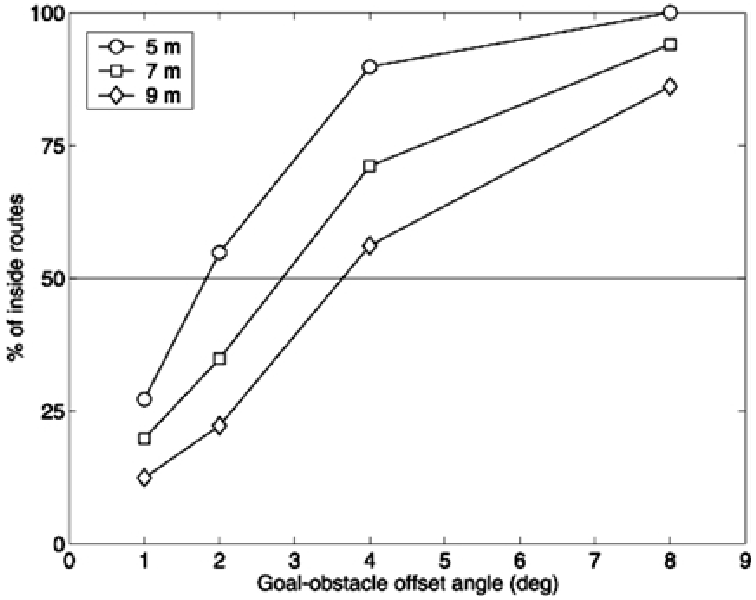
- inside vs. outside path

model



(a)

exp



(b)

Conclusion

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