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

- Robot

- Heading direction

- Fixed (but irrelevant) world axis
Behavioral variables: example

Constraints: obstacle avoidance and target acquisition

\( \Delta \psi \)

\( \psi_{\text{obs}} \)

\( \psi_{\text{tar}} \)

Robot

Target

Arbitrary, but fixed reference axis
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

Vehicle

Target

\[ \frac{d\phi}{dt} \]

Attractor

\[ \Psi_{\text{tar}} \]
Behavioral dynamics: example

- behavioral constraint: obstacle avoidance
each contribution is a “force-let” with
- specified value
- strength
- range

Behavioral dynamics

\[
\frac{d\phi}{dt} \sim \text{strength}
\]

\(\Psi_{\text{tar}}\) specified value

range

\(\phi\)
Behavioral dynamics

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

![Diagram showing behavioral dynamics with vehicle, targets, and attractors.](image-url)
Behavioral dynamics

- decision making

- target 1
- target 2

- vehicle

- repellor = attractor boundary

- individual attractors = resultant attractors => bistable
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
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
2.1 The dynamic approach: stimuli as forces

The abstract problem addressed here is reconciling stability and the forward and rotation velocities of the robot. The hysteresis of the dynamics suppresses oscillations of the behavior generated exclusively through the asymptotically stable solutions of the dynamical systems, its attractors. Fixed point attractors are the primary design tool. Sensors contribute forces to the dynamics that are designed from all relevant sources of sensory or internal information. The desired and undesired behaviors must be expressible as points or simple sets in the space defined by the variables. On the other hand, it must be possible, of course, to transform values of these variables into appropriate actions. The analysis is developed semantically with cases in which such specification was possible, at least, in principle.

We briefly present the main concepts of the dynamic approach (Schöner, Dose, 1992). For homing this allows the computation of large jumps of the robot position or because of an occluding obstacle. The robot is heading towards the home base while avoiding an obstacle. After it reaches the home base it starts a new excursion. The forward and rotation velocities of the robot. The hysteresis of the dynamics suppresses oscillations of the behavior generated exclusively through the asymptotically stable solutions of the dynamical systems, its attractors. Fixed point attractors are the primary design tool. Sensors contribute forces to the dynamics that are designed from all relevant sources of sensory or internal information. The desired and undesired behaviors must be expressible as points or simple sets in the space defined by the variables. On the other hand, it must be possible, of course, to transform values of these variables into appropriate actions. The analysis is developed semantically with cases in which such specification was possible, at least, in principle.

Visual information is obtained from two video cameras with current views. The visual information permits continuously available dead-reckoning information with fluctuating sensory information is not available (because a memorized scene is faced by a mobile robot: avoiding obstacles and achieving a goal position (homing). For obstacle avoidance, time-to-contact estimates. Hysteresis of the dynamics, which manages the motion planning dynamics. The driving speed is adjusted to allow for a temporal averaging of time-to-contact estimates is addressed by an appropriate design of the forward and rotation velocities of the robot. The hysteresis of the dynamics suppresses oscillations of the behavior generated exclusively through the asymptotically stable solutions of the dynamical systems, its attractors. Fixed point attractors are the primary design tool. Sensors contribute forces to the dynamics that are designed from all relevant sources of sensory or internal information. The desired and undesired behaviors must be expressible as points or simple sets in the space defined by the variables. On the other hand, it must be possible, of course, to transform values of these variables into appropriate actions. The analysis is developed semantically with cases in which such specification was possible, at least, in principle.
[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

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

![Graph showing turning rate and angular acceleration](image)
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
A Dynamical Framework for Steering

Consider an agent moving through a simple environment. We next develop a model in the form of a system of differential equations that describes how the behavioral variables change over time, analogous to a mass-spring system. Broadly speaking, the model consists of three components: a goal component, an obstacle component, and a damping term. The damping term opposes turning, and we assume it is a monotonically increasing function of the current angular acceleration.

Parameter values in the dynamical model.

The agent-environment system is thus completely described by a four-dimensional system of equations, for the complete set of equations.) Note, however, that at this stage the agent and objects are simply treated as parameter values in the dynamical model.

The precise manner in which the agent turns toward a goal and away from obstacles is determined by the turning function, which we will refer to as the fixed allocentric reference axis. To steer toward the goal, the agent must turn in the direction of goal motion, and is assumed to be a function of the current goal angle and obstacle angle, and the avoided state of steering toward the goal, such that the agent must turn away from the obstacle, such that the obstacle can be expressed by different values of φ.

The agent must turn away from the obstacle, such that the goal distance − φ, and is assumed to be a function of the distance to goals and obstacles in the environment. Although the distances to goals and obstacles in the environment will alter parameter values in the dynamical model.

Plan view of an observer moving through an environment. The dotted line is a trajectory through the space of behavioral variables. To predict the agent's future position we need to know the index of each obstacle in the scene. Although the index of each obstacle in the scene is assumed to be a function of the current path the agent and objects are currently accessible. Navigation in complex environments (e.g. mazes) is likely to require more sophisticated strategies based on more global knowledge of the scene in which the locations of goals and obstacles are currently accessible.

The observations were then used to specify the form of each function, and reselected the form of each function, and reselected the form of each function, and reselected the form of each function.
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

\[
\ddot{\phi} = -b\dot{\phi} - k_g(\phi - \psi_g)(e^{-c_1d_g} + c_2) + k_o(\phi - \psi_o)(e^{-c_3|\phi - \psi_o|})(e^{-c_4d_o})
\]

inertial term

damping term

attractor goal heading

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

\[
\ddot{\phi} = -b\dot{\phi} - k_g(\phi - \psi_g)(e^{-c_1d_g} + c_2) + k_o(\phi - \psi_o)(e^{-c_3|\phi - \psi_o|})(e^{-c_4d_o})
\]

attractor goal heading
repellor obstacle heading
model-experiment match: goal

experiment

model
model-experiment match: obstacle

experiment

model

![Graphs showing model-experiment match for obstacle behavior.](image-url)
and 10

initial goal angle constant at 15° and obstacles similar to those in Fig. 9. Keeping the
distances and switches to an inside route for smaller

Figure 5

15° in Simulation #1.

agent selects an outside route for offset angles
parameters determined in Simulations #1 and #2, the
goal distance and initial offset angle. Using the
gle between 1

distance betweene 2

cle distance constant at 4 m, we varied the initial goal

Figure 6

7°, 20°, and 25°. Paths produced by model around obstacles located at 4
Simulation #2.

paths produced by the model to goals located at 15

Figure 7

and 3, 4 or 5 m in
Simulation #2.

Figure 8

and 15°. For angles between 7°, and

Figure 9

large offset angles, the goal angle is relatively large
domains as the agent heads toward the obstacle. For

model: paths

Hence, obstacle repulsion overcomes goal attraction,
relatively small as the agent turns toward the obstacle.

Figure 10

inside route. For small offset angles, the goal angle is
traction overcomes obstacle repulsion resulting in an

paths

To evaluate the model

Behavioral configurations of goals

as the goal gets nearer. The effect of offset angle is

curves correspond to (a) initial obstacle angle in

To evaluate the model

as predictive ability, we tested

configuration of goal and obstacle used in Simulation

paths and (b)

Figure #3a.
model-exp: decision making

- inside vs. outside path
Conclusion

The attractor dynamic model can account for human locomotory behavior in target acquisition and obstacle avoidance.