Attractor dynamics approach to behavior generation: vehicle motion
Part 2: sub-symbolic approach
So far: “symbolic” approach

- high-level implementation: knowledge about objects in the world ("obstacles", "targets", etc)
Now: “sub-symbolic” approach

- low-level implementation: use sensory information directly, not via objects
Target acquisition: still symbolic

- targets are segmented… in the foreground
- => need neural fields to perform this segmentation from low-level sensory information: Dynamic Field Theory …
Obstacle avoidance: sub-symbolic

- obstacles need not be segmented
- do not care if obstacles are one or multiple: avoid them anyway…

\[
\theta_{\text{obs}} \quad \Psi_{\text{obs}}
\]

\[
\Psi_{\text{obs}} \quad \text{repellor}
\]
Obstacle avoidance: sub-symbolic

- Each sensor mounted at fixed angle $\theta$
- That points in direction $\psi = \Phi + \theta$ in the world
- Erect a repellor at that angle

[from: Bicho, Jokeit, Schöner]
Obstacle avoidance: sub-symbolic

\[ f_{\text{obs},i}(\phi) = \lambda_i (\phi - \psi_i) \exp \left[ -\frac{(\phi - \psi_i)^2}{2\sigma_i^2} \right] \quad i = 1, 2, \ldots, 7 \]

- **Note:** only \( \Phi - \psi = -\theta \) shows up, which is constant!
- \( \Rightarrow \) force-let does not depend on \( \Phi \)!

[from: Bicho, Jokeit, Schöner]
Obstacle avoidance: sub-symbolic

\[ f_{\text{obs},i}(\phi) = \lambda_i(\phi - \psi_i) \exp \left[ -\frac{(\phi - \psi_i)^2}{2\sigma_i^2} \right] \quad i = 1, 2, \ldots, 7 \]

\[ \lambda_i = \beta_1 \cdot \exp \left[ -\frac{d_i}{\beta_2} \right] \]

- Repulsion strength decreases with distance, \( d_i \)
- \( \Rightarrow \) only close obstacles matter

[from: Bicho, Jokeit, Schöner]
Obstacle avoidance: sub-symbolic

\[ f_{\text{obs}, i}(\phi) = \lambda_i(\phi - \psi_i) \exp \left[ -\frac{(\phi - \psi_i)^2}{2\sigma_i^2} \right] \]

\[ \sigma_i = \arctan \left[ \tan \left( \frac{\Delta \theta}{2} \right) + \frac{R_{\text{robot}}}{R_{\text{robot}} + d_i} \right]. \]

- angular range depends on sensor cone \( \Delta \theta \) and size over distance

[from: Bicho, Jokeit, Schöner]
Obstacle avoidance: sub-symbolic

=> as a result, range becomes wider as obstacle moves closer

[from: Bicho, Jokeit, Schöner]
Obstacle avoidance: sub-symbolic

- summing contributions from all sensors

\[
\frac{d\phi}{dt} = f_{\text{obs}}(\phi) = \sum_{i=1}^{7} f_{\text{obs},i}(\phi)
\]

[from: Bicho, Jokeit, Schöner]
Obstacle avoidance: sub-symbolic

but why does it work?

shouldn’t there be a problem when heading changes (e.g. from the dynamics itself)?

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to a sensible avoidance behavior: The extended obstacle "bleeds over" to other sensors with different sensitivity, and hence erected (solid thin lines). The solid bold line shows the resultant repeller is at the sensed distance is added to the net contribution is zero.

Thus, when no obstacle is within the range of the distance sensor, the corresponding forcelet inside an attractive region and itself) does not matter. The weighting the superposition in Equation (9), which is mounted at angle \( \psi \), from the virtual obstacle at direction \( \theta \), is a decreasing function of the distance, and on the constraint of passing next to the virtual obstacle without on the spot obstacle dynamics. The resultant repeller is at \( \psi \) and \( \psi \) respectively.

Each sensor \( i \) contributes \( f_i \) from the virtual obstacle at direction \( \theta \), sensed distances are both \( \psi \) and \( \psi \) for \( \psi \) and \( \psi \). The resultant repeller is at \( \psi \) and \( \psi \)

Thus, the angular range over which a forcelet acts decreases by half the vehicle's width and on the constraint of passing next to the virtual obstacle without over" to other sensors with different sensitivity, and hence erected (solid thin lines). The solid bold line shows the resultant repeller is at the sensed distance is added to the net contribution is zero.

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integrating the two behaviors

\[ \frac{d\phi}{dt} = f_{\text{obs}}(\phi) + f_{\text{tar}}(\phi) \]
Bifurcations

- bifurcation as a function of the size of the opening between obstacles
Bifurcations

- Bifurcation as a function of the size of the opening between obstacles
- => Tune distance dependence of repulsion so that bifurcation occurs at the right opening
Bifurcations
Bifurcation on approach to wall

- Initially attractor dominates: weak repulsion
- Bifurcation
- Then obstacles dominate: strong repulsion and total repulsion
Bifurcation on approach to wall

same with small opening
Bifurcation on approach to wall

at larger opening: repulsion weak all the way through: attractor remains stable
Tracking attractor

as robot moves around obstacles, tracks the moving attractor
Tracking attractor

As robot moves in between obstacles, the dynamics change but not the attractor.
Tracking attractors

Figure 19:
Observation:

- even though the approach is purely local, it does achieve global tasks
- based on the structure of the environment!
Conclusion

- attractor dynamics works on the basis low-level sensors information

- as long at the force-lets model the sensor-characteristics well enough to create approximate invariance of the dynamics under transformations of the coordinate frames
Summary

- behavioral variables
- attractor states for behavior
- attractive force-let: target acquisition
- repulsive force-let: obstacle avoidance
- bistability/bifurcations: decisions
- can be implemented with minimal requirements for perception