Dynamic field theory (DFT) … attractor dynamics for perception and cognition

Gregor Schöner
The dynamics activation fields

- Field dynamics combines input
- With strong interaction:
  - Local excitation
  - Global inhibition
- => Generates stability of peaks

\[ u(x) \]
Amari equation

\[ \tau \dot{u}(x, t) = -u(x, t) + h + S(x, t) + \int w(x - x') \sigma(u(x', t)) \, dx' \]

where

- time scale is \( \tau \)
- resting level is \( h < 0 \)
- input is \( S(x, t) \)
- interaction kernel is

\[ w(x - x') = w_i + w_e \exp \left[ -\frac{(x - x')^2}{2\sigma_i^2} \right] \]

- sigmoidal nonlinearity is

\[ \sigma(u) = \frac{1}{1 + \exp[-\beta(u - u_0)]} \]
=> simulations
• attractor states
  • input driven solution (sub-threshold)
  • self-stabilized solution (peak, supra-threshold)

• instabilities
  • detection instability (from localize input or boost)
  • reverse detection instability
  • selection instability
  • memory instability
Vehicle

Robot

Microphones

[from Bicho, Mallet, Schöner, Int J Rob Res, 2000]
sensory surface

Each microphone samples heading direction

Sensitivity cone of each microphone
and provides input to the field

activation field

heading direction

input from sensory surface

heading direction

two sound sources
detection instability on a phonotaxis robot

target selection on phonotaxis vehicle
robust estimation
tracking
memory & forgetting on phonotaxis vehicle

a robotic demo of all of instabilities
back to attractor dynamics of heading

- couple peak in direction field into dynamics of heading direction as an attractor
transition from DFT to DST

peak specifies value for a dynamical variable that is congruent to the field dimension
from DFT to DST

- treating sigmoided field as probability: need to normalize

  => problem when there is no peak: divide by zero!
from DFT to DST

- solution: peak sets attractor
  - location of attractor: peak location
  - strength of attractor: summed supra-threshold activation

\[
\begin{align*}
x_{\text{peak}} &= \frac{\int dx \ x \ \sigma(u(x, t))}{\int dx \ \sigma(u(x, t))} \\
\dot{x} &= -\left[\int dx \ \sigma(u(x, t))\right] (x - x_{\text{peak}}) \\
\Rightarrow \dot{x} &= -\left[\int dx \ \sigma(u(x, t))\right] x + \left[\int dx \ x \ \sigma(u(x, t))\right]
\end{align*}
\]
from DFT to DST

activation field

specified value

dimension

activation field

no value specified

dimension

dx/dt

x
this is how target acquisition is integrated into obstacle avoidance on the robot

\[
\frac{d\phi}{dt} = \sum_{i=1}^{7} f_{\text{obs},i} + f_{\text{tar}}. \\
\psi_{\text{tar}} = \int_{0}^{2\pi} \psi H(u(\psi))d\psi / N_u \\
f_{\text{tar}} = \begin{cases} 
-\lambda'_{\text{tar}}(N_u \phi - \int_{0}^{2\pi} (H(u(\psi))\psi)d\psi) & \text{for } \psi_{\text{tar}} - \pi/2 < \phi \leq \psi_{\text{tar}} + \pi/2 \\
\lambda'_{\text{tar}}(N_u (\phi - \pi) - \int_{0}^{2\pi} (H(u(\psi))\psi)d\psi) & \text{for } \psi_{\text{tar}} + \pi/2 < \phi \leq \psi_{\text{tar}} + 3\pi/2 
\end{cases}
\]
Conclusion

- Neural dynamics for the inner loops that endow perception and cognition with stability
- Behavioral dynamics for the outer loops that generate behavior in closed loop….
- So far: all in closed loop: sensor moves with the actuator…
- Next: look at situations in which that is not the case: grasp an object…