بسم الله الرحمن الرحیم

علوم شناختی

جلسه ۱۲ (الف)

علوم شناختی
و سیستم‌های دینامیکی

Cognitive Science and Dynamical Systems

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http://courses.fouladi.ir/cogsci

PART 2:
MODELS AND TOOLS

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Chapter 6:
Applying Dynamical Systems Theory to Model the Mind

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Chapter 6.1: Cognitive science and dynamical systems

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Traditional CogSci

- Basic principles
    - Cognition is a form of information-processing
    - Information-processing involves manipulating representations
- PSSH and artificial neural networks incorporate different models of information-processing (mental architectures)

Dynamical systems hypothesis

- cognitive scientists should understand cognitive agents as dynamical systems embedded in their environment
- cognition is a process that evolves through time, but does not necessarily involve computation or representations
  - at least not as standardly understood
  - DSH sometimes offered as alternative both to PSSH and to ANNs

Dynamical systems

1) A dynamical system is any system that evolves over time

   $\Rightarrow$ trivial that cognitive agents are dynamical systems

   $\Rightarrow$ DST requires a richer notion

2) A dynamical system is a system that can be studied using the tools of dynamical modeling

Dynamical models

Typically use calculus to track the evolving relationship between a small number of variables over time

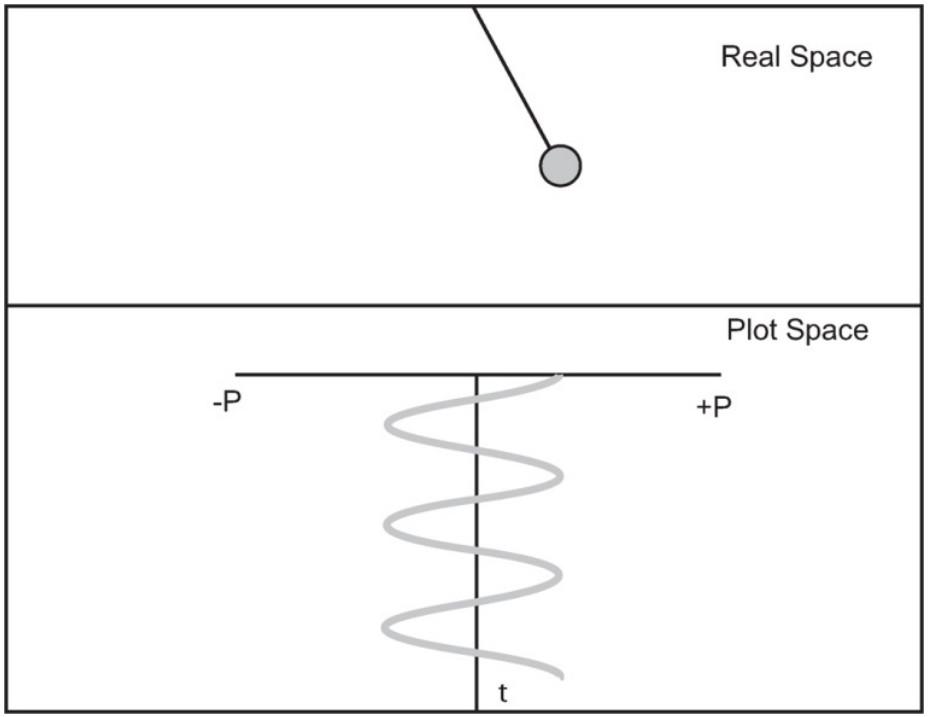
- difference equations
  (for modeling discrete time series)

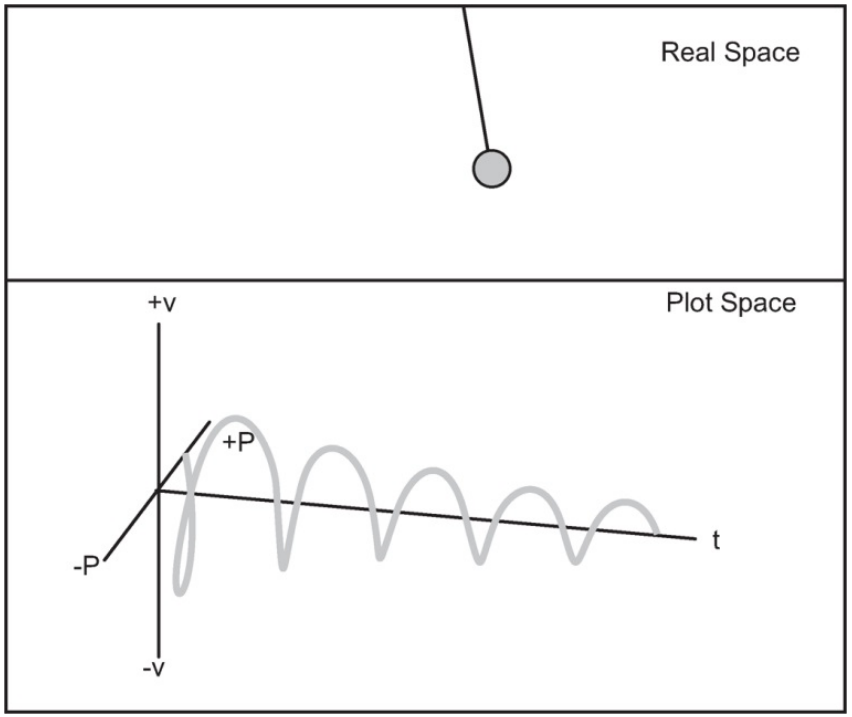
- differential equations
  (form modeling continuous time series)

State space

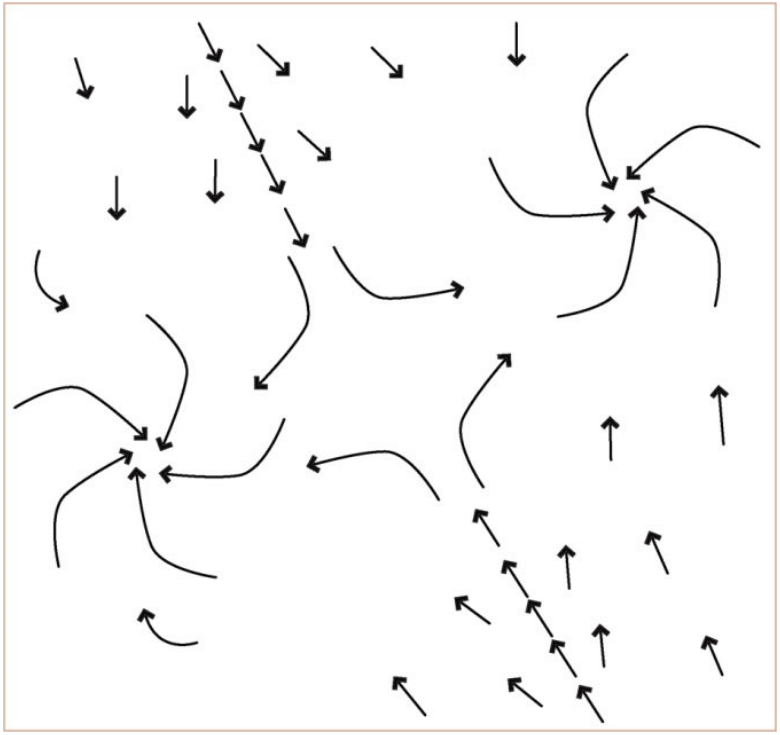
- The state space of a dynamical system is a geometric way of thinking about all the possible states the system can be in
  - As many different dimensions as it has quantities that vary independently of each other
- The state of a system at a time can be identified with a particular set of coordinates in its state space
- The evolution of a system is its trajectory through state space from a set of initial conditions

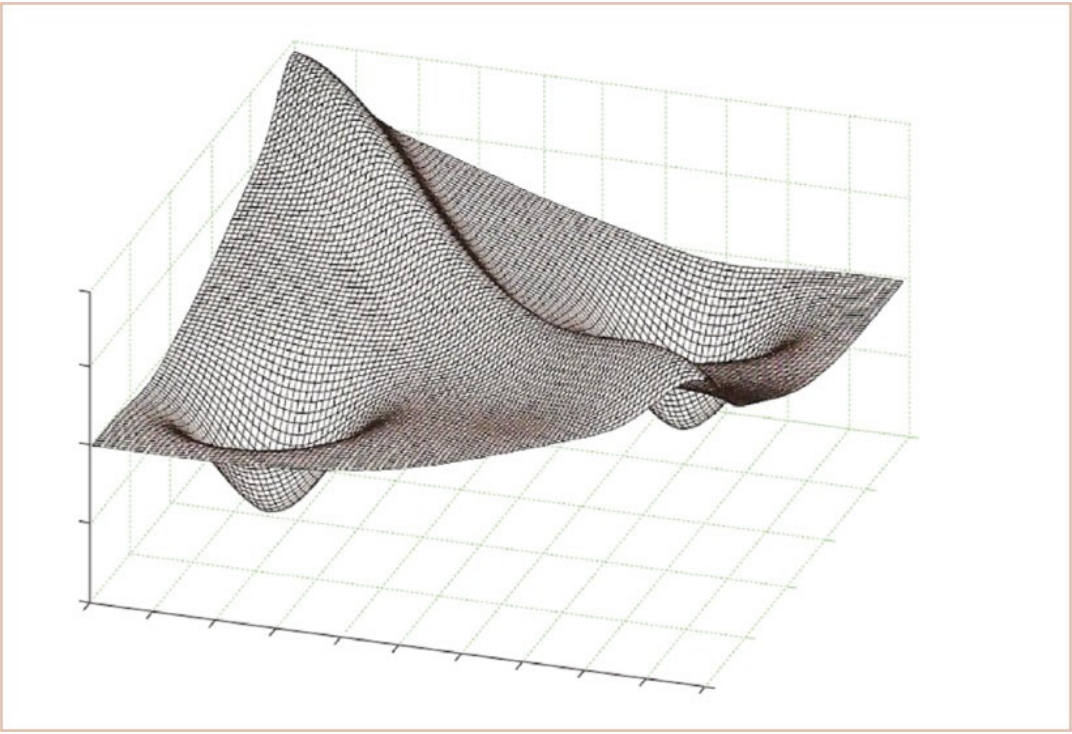
State space of swinging pendulum





Basins of attraction in state space





Similarities to ANNs

ANNs count as dynamical systems

- Dimensionality of the state space given by the number of units-weight space
  - The process of training the network is a way of configuring the energy landscape
  - Information-processing in ANNs is a trajectory through unit space

Dissimilarities

- Dynamical systems theorists are typically interested in lower-dimensionality systems

  i.e. fewer independently varying quantities

- The dimensions in ANNs often correspond to hidden features of the system, whereas dynamical systems theorists tend to study observable quantities

Van Gelder's steam engine analogy

- James Watt designed a gearing system to allow steam engines to drive a flywheel and hence produce rotational power
- Typical applications required power source to be as even as possible
- Need for a governor to regulate the speed of the flywheel

The computational governor

1. Measure the speed of the flywheel.

2. Compare the actual speed S_1 against the desired speed S_2

3. If $S_1 = S_2$, return to step 1

4. If $S_1 \neq S_2$ then
   (a) measure the current steam pressure
   (b) calculate the required alteration in steam pressure
   (c) calculate the throttle adjustment to achieve that alteration

5. Make the throttle adjustment

6. Return to step 1.

The computational governor

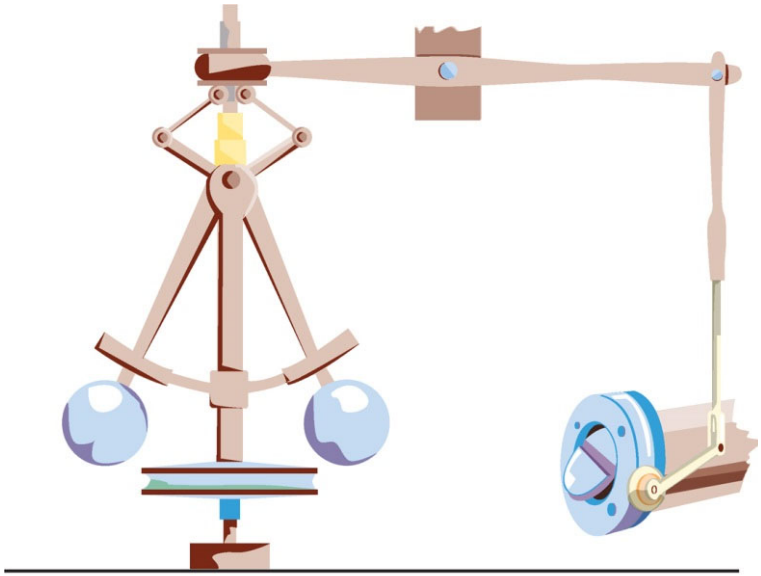
1) Representational

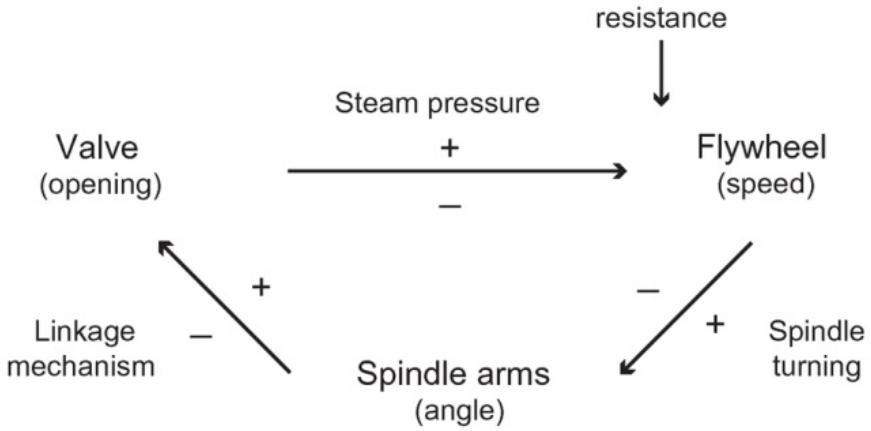
2) Computational

3) Sequential

4) Decomposable (homuncular)

The Watt governor





The governor regulates speed by compensating almost instantaneously when the speed of the flywheel is overshooting or undershooting.

Features

Dynamical system [behavior characterized by differential equation with fixed parameters and a small number of variables]

Real-time functioning [instantaneous adjustment]

Coupled system [interdependence between arm angle, throttle valve, and speed of flywheel]

Attractor dynamics [for any given engine speed there is an equilibrium arm angle – a region in state-space to which many different trajectories converge]

The DST challenge

- Can the Watt governor analogy be extended to cognitive systems?

- Can we find cognitive systems which a dynamical systems model works better than a standard, computational account?

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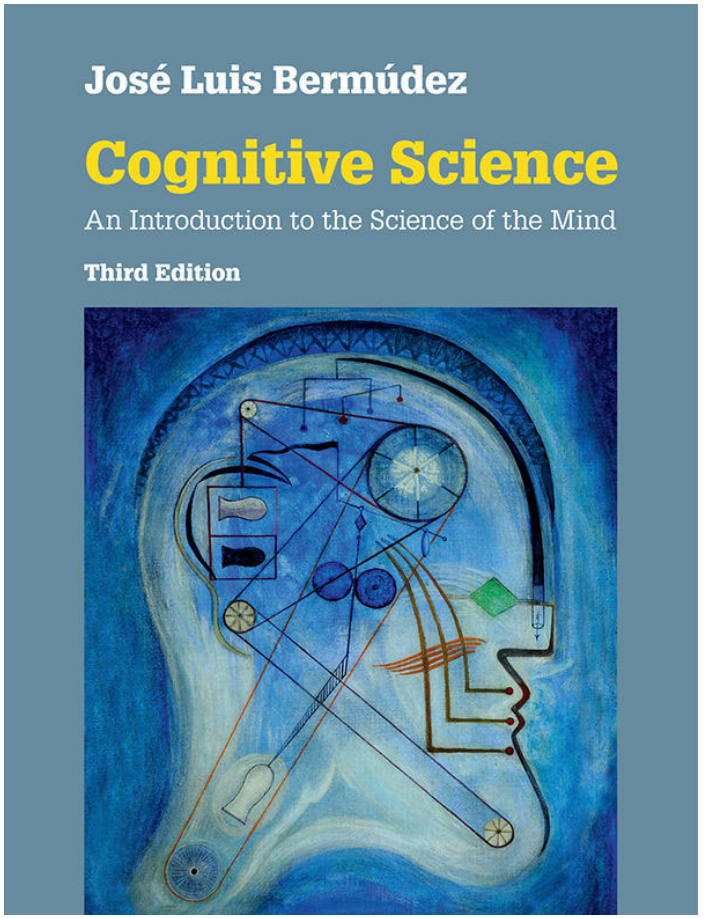
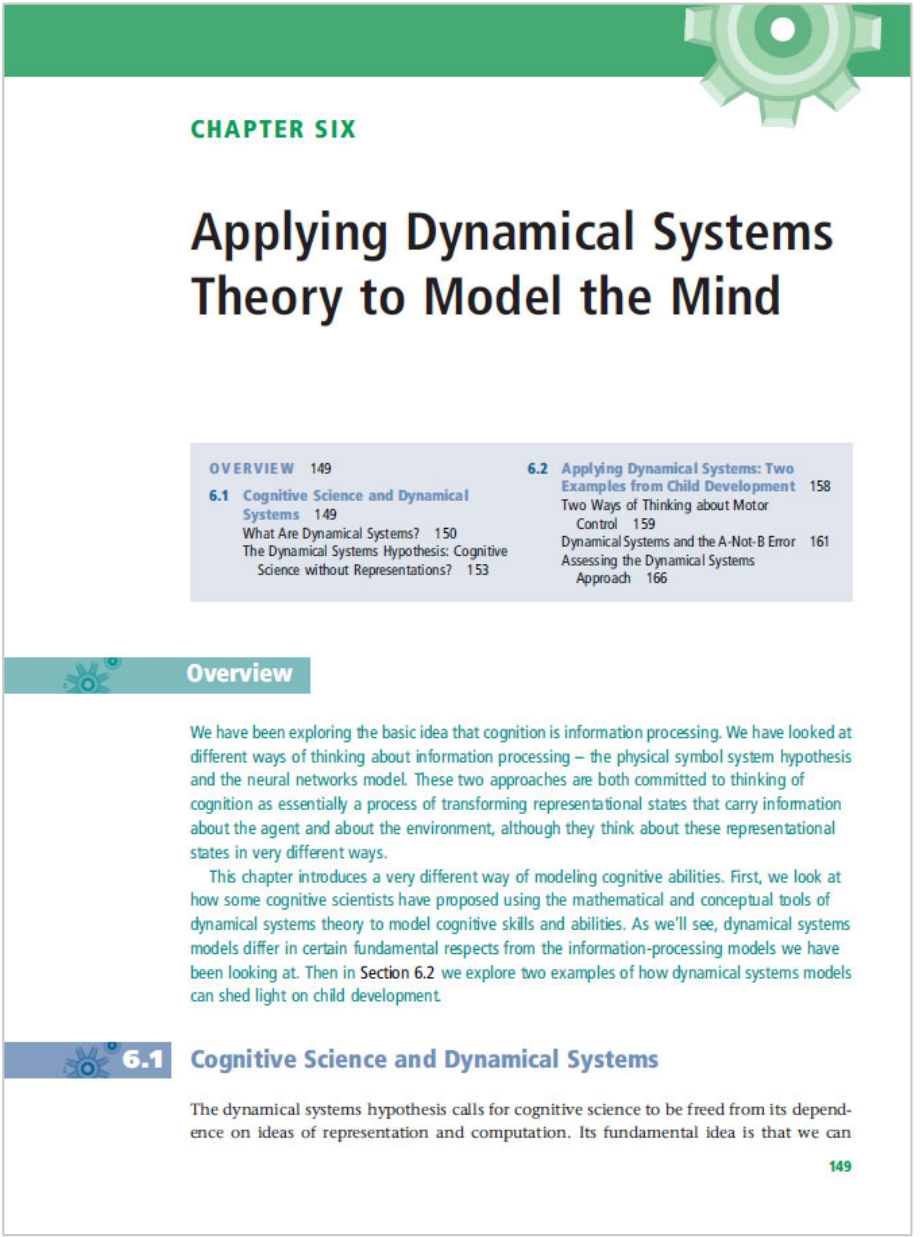


José Luis Bermúdez,
Cognitive Science:
An Introduction to the Science of the Mind,
3rd ed., Cambridge University Press, 2020.
Chapter 6 (Section 6.1)



CHAPTER SIX

Applying Dynamical Systems Theory to Model the Mind

Overview

We have been exploring the basic idea that cognition is information processing. We have looked at different ways of thinking about information processing – the physical symbol system hypothesis and the neural networks model. These two approaches are both committed to thinking of cognition as essentially a process of transforming representational states that carry information about the agent and about the environment, although they think about these representational states in very different ways.

This chapter introduces a very different way of modeling cognitive abilities. First, we look at how some cognitive scientists have proposed using the mathematical and conceptual tools of dynamical systems theory to model cognitive skills and abilities. As we'll see, dynamical systems models differ in certain fundamental respects from the information-processing models we have been looking at. Then in Section 6.2 we explore two examples of how dynamical systems models can shed light on child development.

6.1 Cognitive Science and Dynamical Systems

The dynamical systems hypothesis calls for cognitive science to be freed from its dependence on ideas of representation and computation. Its fundamental idea is that we can

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