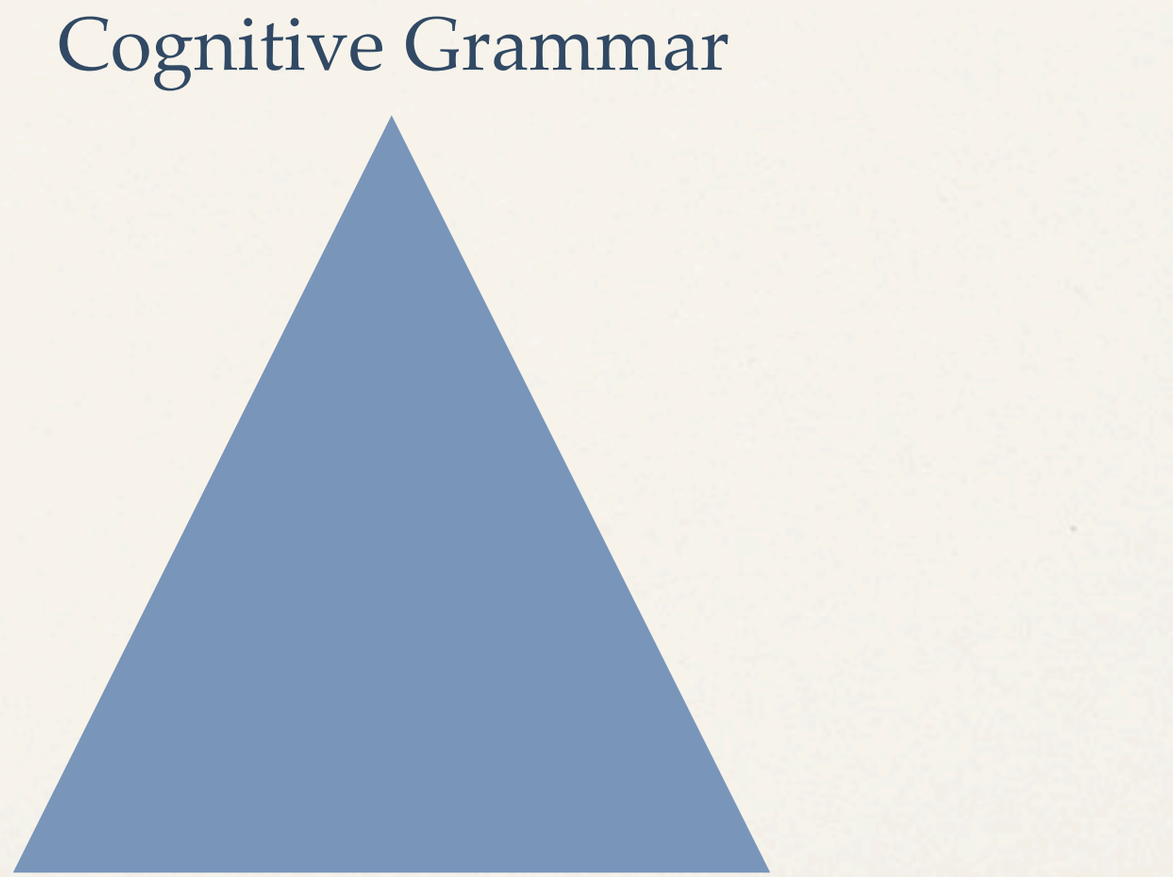
Dynamic Systems Theory

Lecture 9

Sherman Wilcox — Beijing, China

Setting language in motion



Cognitive grammar

- "Grammar is a structured inventory of conventional linguistic units."
- Linguistic patterns, whether specific or schematic, acquire *unit status* through the process of **entrenchment**.

Language is skilled performance

- "Constituting the more specific abilities are recurring patterns of activity, which emerge with increasing robustness as we develop them and continue to refine them. Among these patterns are those we reify and identify as the units of a language. Such units thus consist in recurring aspects of processing activity. To different degrees, these patterns of neural processing have coalesced as entrenched cognitive routines that can be activated whenever needed. They might be thought of as mental or mentally directed skills employed in various combinations in the complex task of talking. *Knowing a language is a matter of controlling a vast repertoire of skills collectively used for talking in certain sociocultural contexts*."

(R. Langacker, *Cognitive Grammar: A Basic Introduction*, 2008)

Undoing the reification

Setting language in motion

- The double entendre

- “Motion” as a trajectory

- Dynamic systems as the framework for modeling trajectories in a changing system.

Kinematics & dynamics

- **Kinematics**: (from Greek κινεῖν, *kinein*, to move) is the branch of classical mechanics or mechanical engineering that describes the motion of bodies (objects) and systems (groups of objects) without consideration of the forces that cause the motion.

- **Dynamics**: (from Greek δυναμικός - dynamikos *powerful,* from δύναμις - dynamis *power*) is the study of the causes of motion and changes in motion; the study of the relationship between the motion of objects and its causes.

What is dynamic systems theory?

- The study of complex systems and how they produce *patterns that evolve over time*

Dynamics: The Geometry of Behavior

- "The key to the geometric theory of dynamical systems created by Poincare is the phase portrait of a dynamical system. The first step in drawing this portrait is the creation of a geometric model for the set of all possible states of the system. This is called the state space. On this geometric model, the dynamics determine a cellular structure of basins enclosed by separatrices. Within each cell or basin is a nucleus called the attractor. The states that will actually be observed in this system are the attractors. Thus, the portrait of the dynamical system, showing the basins and attractors, is of primary importance."

Abraham & Shaw, 1992

- "Because dynamicists focus on how a system changes from one total state to another, it is natural for them to think of that change as a matter of movements in the *space* of all possible total states of the system; and since the phase spaces of their systems are numerical, natural notions of *distance* apply. Thus, dynamicists conceptualize cognitive processes in *geometric* terms. The distinctive character of some cognitive process as it unfolds over time is a matter of how the total states the system passes through are spatially located with respect to one another and the dynamical landscape of the system."

  - van Gelder & Port, "It's About Time: An Overview of the Dynamical Approach to Cognition"

Systems and state spaces

- A dynamical system is a system with states that evolve over time.

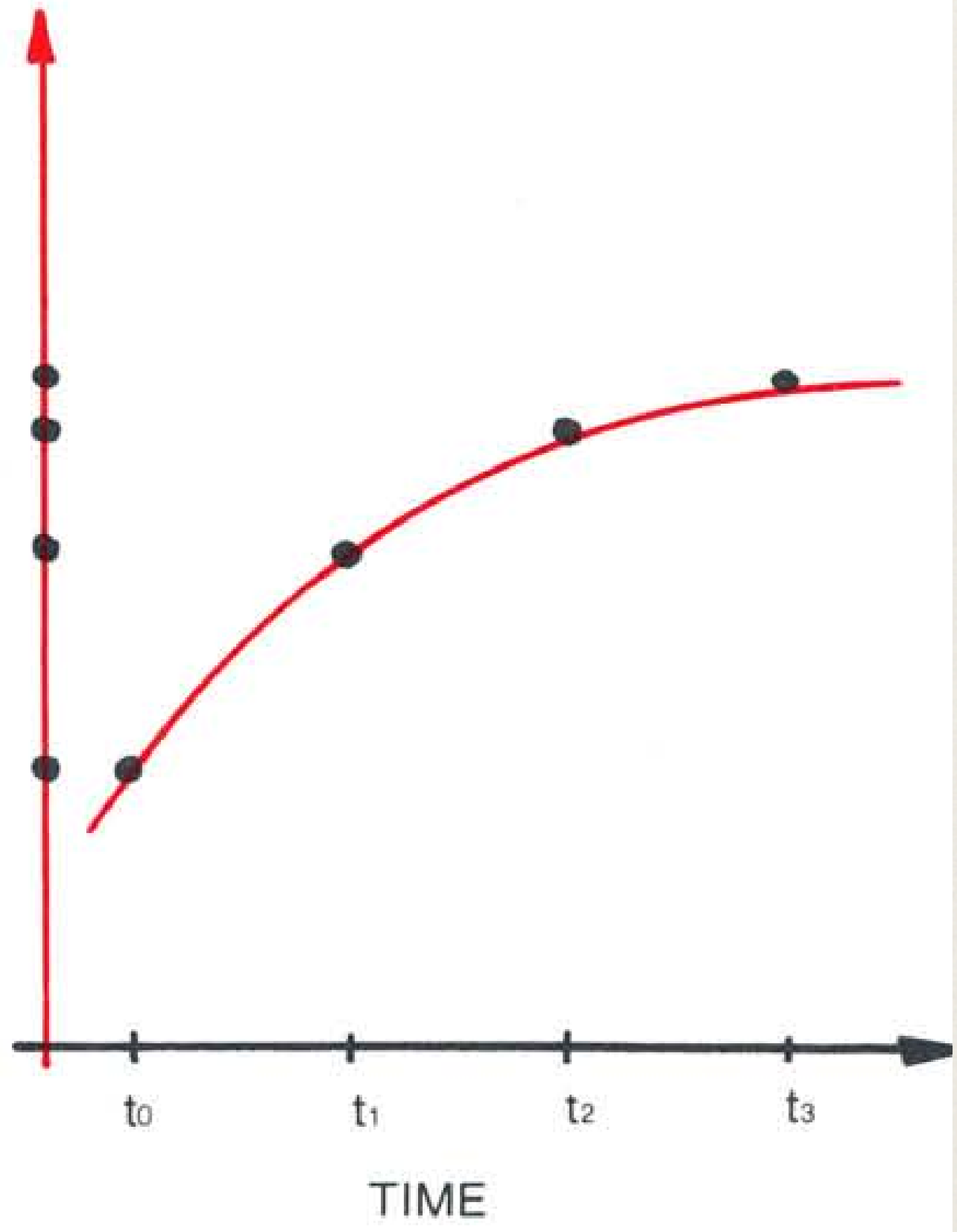
- A system is a set of changing aspects of the world. The overall *state* of the system at a given time is just the way these aspects happen to be at that time. The *behavior* of the system is the change over time in its overall state.

- The totality of overall states the system might be in makes up its *state space*. Thus, the behavior of the system can be thought of as a sequence of points in its state space.

Temperature

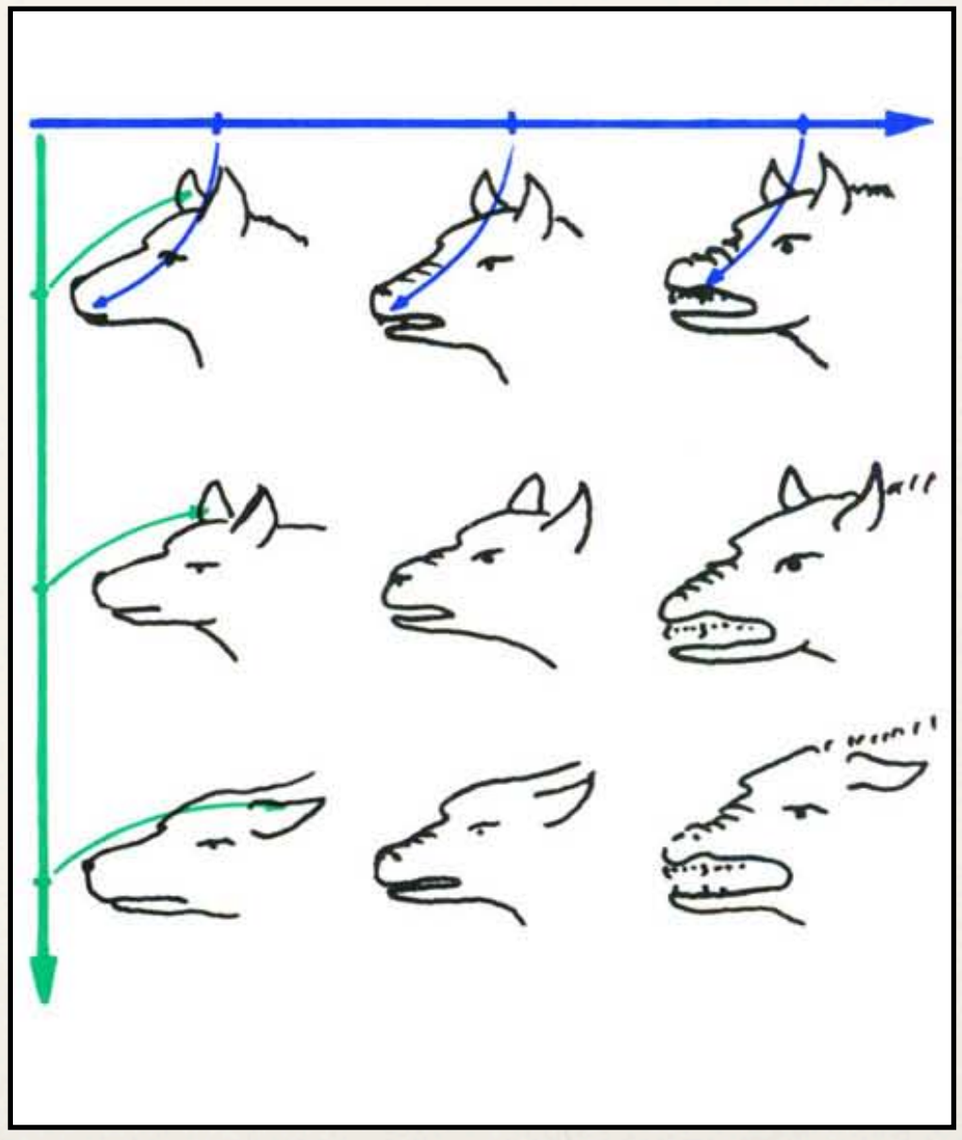
- A single parameter system.
- The correlation between this single parameter and the overall complex system (the girl) may be very good or very bad. For the girl, temperature correlates better with her health than with her honesty.


TEMPERATURE
t3
t2
t1
t0


t0
t1
t2
t3
TIME

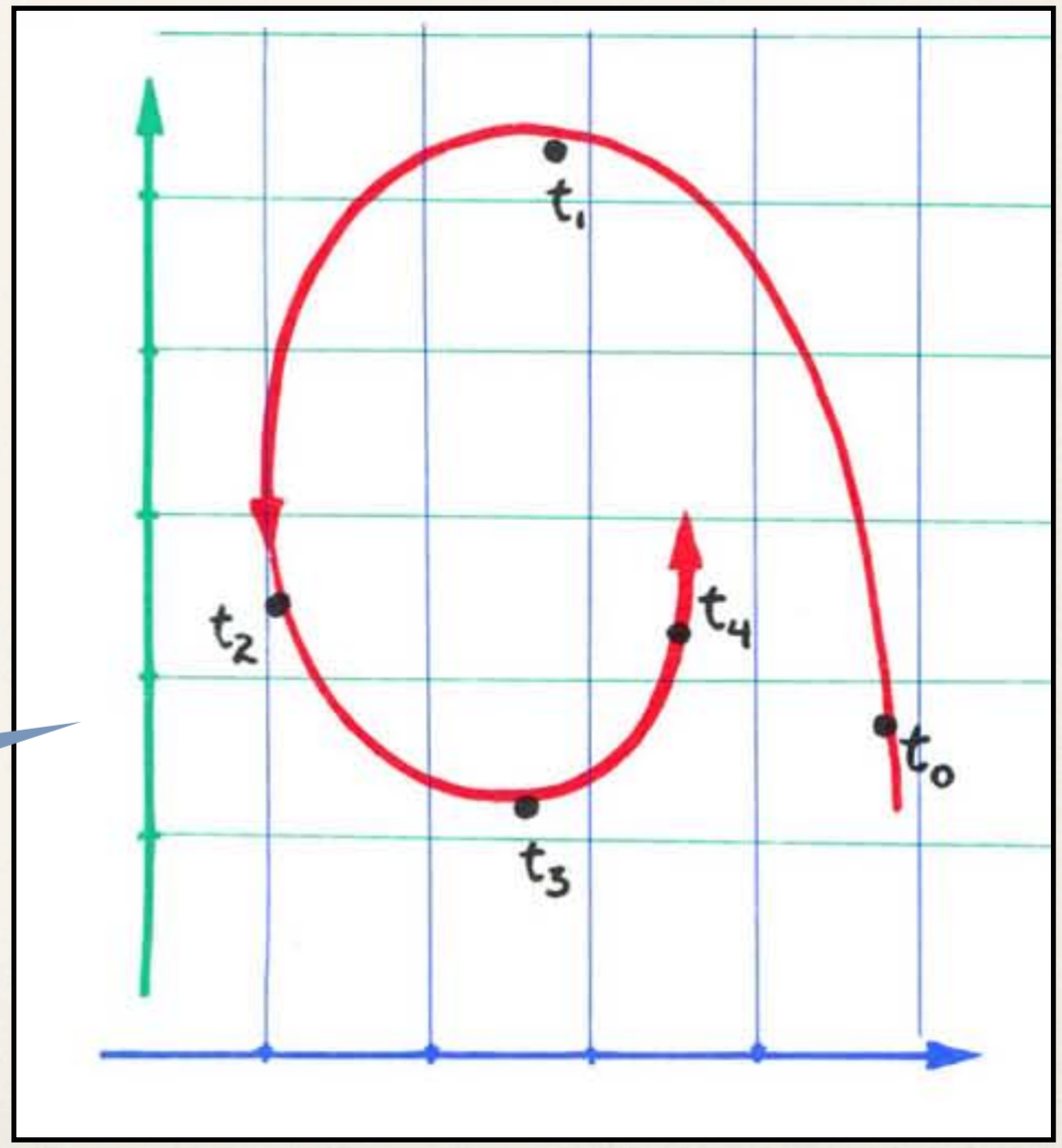
A more complex system

- Two parameters model the emotional state of a dog.
- *Ear attitude* correlates with the emotional state of fear
- *Fang exposure* correlates with the degree of rage

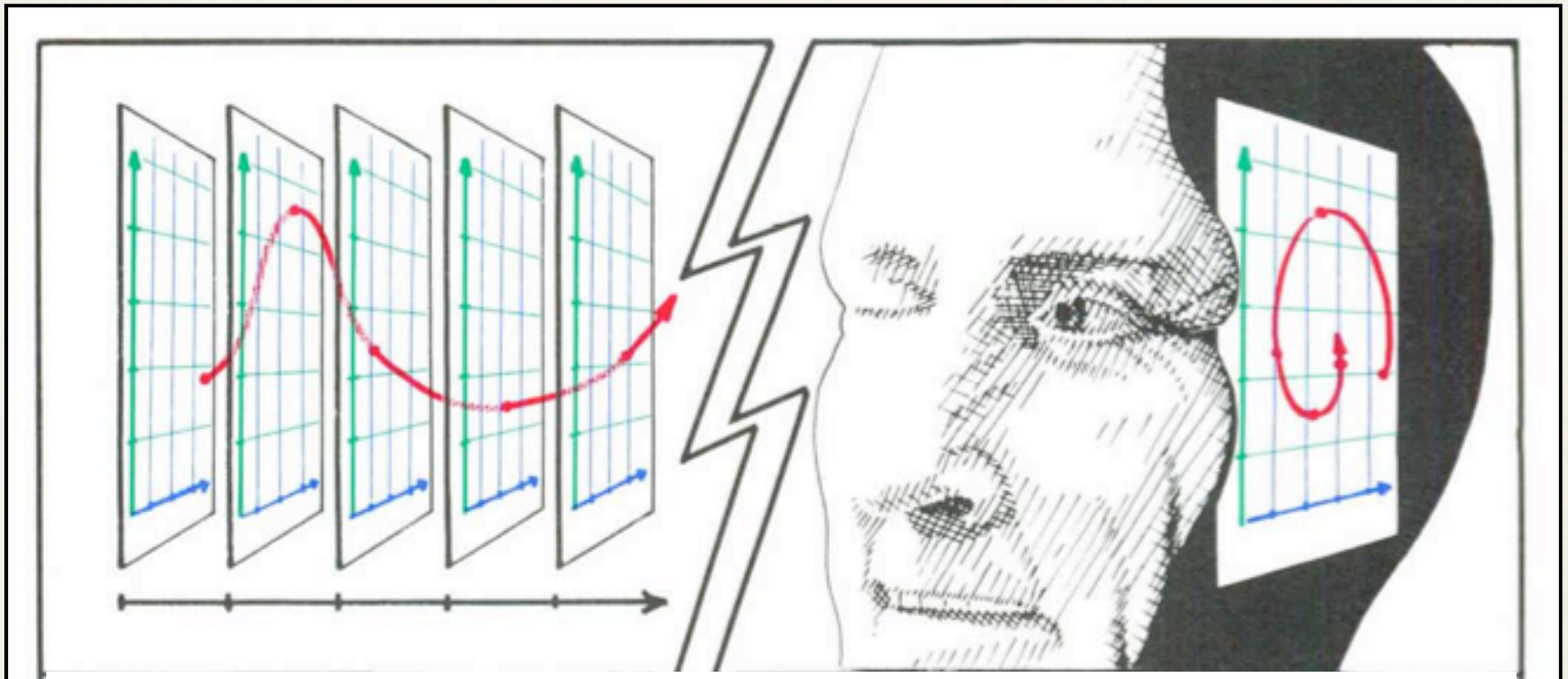


A more complex system

- If the two parameters representing the emotional state of the dog are observed at successive times and plotted, a trajectory of the model is obtained.



Phase plane portrait



The trajectory may be obtained from the time series of observations by viewing it from straight down the time axis

Attractors

- An attractor is a set towards which a dynamical system evolves over time. That is, points that get close enough to the attractor remain close even if slightly disturbed.

- Geometrically, an attractor can be a point, a curve, a manifold, or even a complicated set with a fractal structure known as a strange attractor.

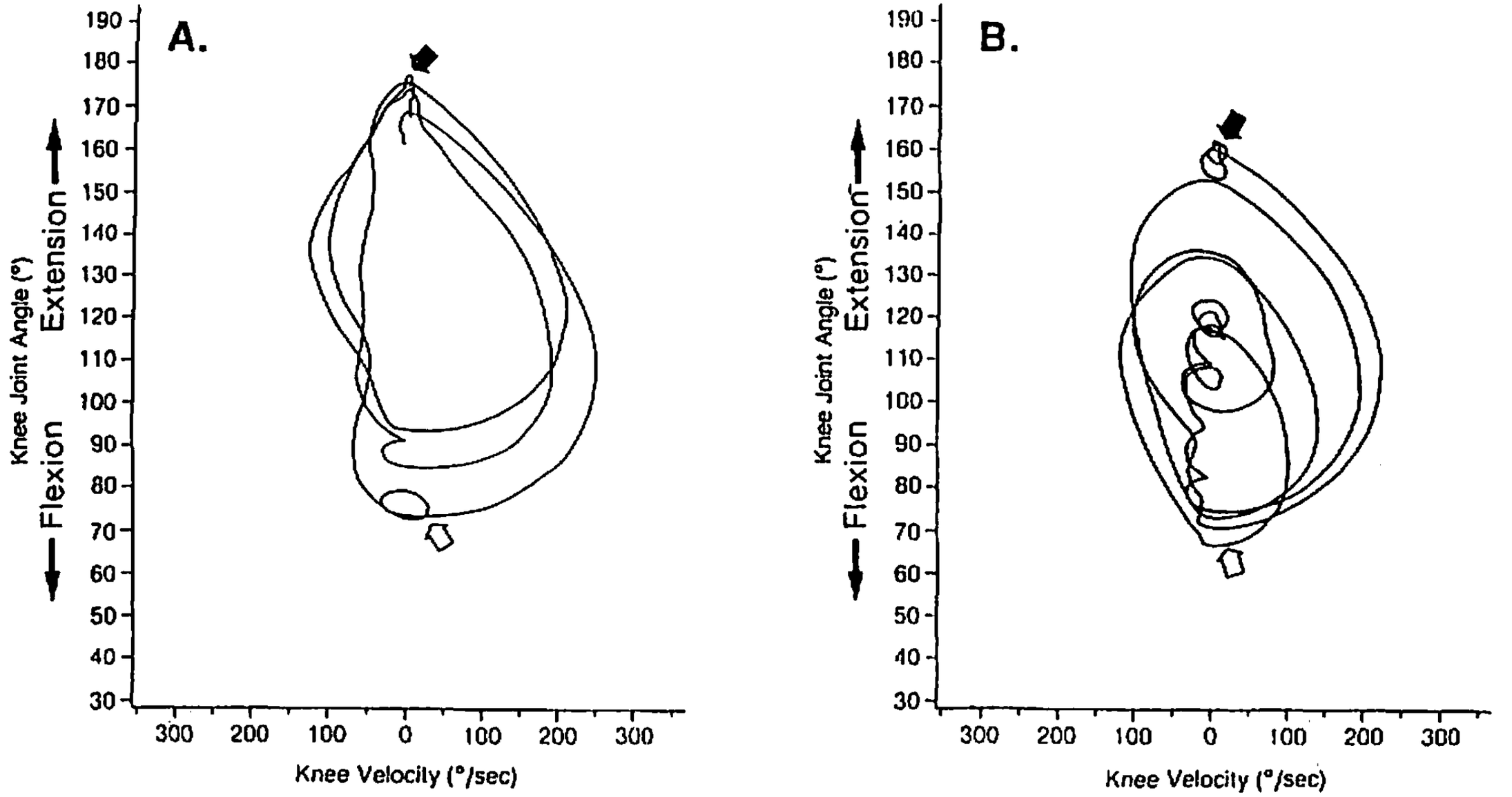
Self-organization

Infant Kicking

Date

Premature (40 weeks)

Full-term newborn



The phase plane portraits of infant kicking are highly uniform across different postures and ages

What explains the kicking pattern?

- Is it hard-wired by some some central pattern generator?
- Or is it evidence of a *dynamically self-organized system*?

Dynamically self-organized system

- Esther Thelen and her colleagues demonstrate that it is a dynamically self-organized system based on several constraints:
  - Anatomical and muscular properties of the infant leg: spring-like
  - Properties of the neuromuscular system: neural firing timing
  - Gravity: posture (supine, held upright, etc.)

Dynamically self-organized system

- "The cooperative result — the reduction of degrees of freedom — was an identifiable topography of movement."
- This self-organization is the feature that gives behavior its rule-based appearance without the need for specific rules.
- The behavior — the trajectory of kicking movements — is emergent

Phase Shifts

- Consider the gait of horses: As a horse continuously increases its speed, its gait shifts discontinuously from a walk to a trot to a gallop with no stable intermediate pattern.

- Or, try this: the alternating finger exercise. Or the foot/hand circle game.

- How do we explain these phase shifts?

Dynamic stability

- When systems self-organize, they "settle into" one or a few modes of behavior (which themselves may be quite complex) that the system prefers over all the possible modes. In dynamic terminology, this behavioral mode is an *attractor* state, as the system — under certain conditions — has an affinity for that state. Again in dynamic terminology, the system prefers a certain topology in its *state space*.

Dynamic Systems

- The Belousov-Zhabotinskii reaction

- "As the chemists increase the flow of the reactants in a smooth and continuous manner, they find remarkable and curious results. Although they increase the reactants gradually, the oscillation periods increase by *precise doublings* of the original period. Then, at a critical flow rate, the reaction seems to go wild; the ions fluctuate erratically and seemingly randomly."

Emergent structure

- “The temperature changes were continuous, but the behavior of the system was dramatically discontinuous.”

- "Natural cognitive systems sometimes change state in continuous ways; sometimes, on the other hand, they change state in ways that can appear discrete. Dynamics provides a framework within which continuity *and* discreteness can be accounted for, even within the same model."

  - (van Gelder & Port, "It's About Time: An Overview of the Dynamical Approach to Cognition")

Case Study #1: Language Acquisition

Is Language 'Built Up' or 'Built In'?

- Laura Petitto: *From gesture to symbol: The relation of form to meaning in acquisition of personal pronouns in American Sign Language*
- Acquisition of personal pronouns by deaf children in ASL
- The gestural system vs. the linguistic system

- “Traditional models of child language acquisition differ with respect to what is assumed about the knowledge underlying acquisition and how this knowledge changes over time.”

- “In one view (the interactionist-based models), language is seen as a part of the child’s general cognitive capacity … Linguistic structures are regarded as derivative of general cognitive structures rather than as reflecting specific linguistic capacity; language is ‘built up’ from the child’s interaction with the environment and from her prelinguistic knowledge of relations among objects and events.”

- “In another view, the child-based models, language emerges from knowledge structures specific to language; these constitute a distinct task-specific mental capacity. Language is seen as qualitatively distinct from the child’s prelinguistic knowledge of the world.”

- “Further, the child is assumed to possess an innate knowledge of the possible forms of human languages (so-called universal grammar), and her task is to infer the structure of the particular language to which she is exposed. This view emphasizes the child’s contribution to the acquisition process — through its biologically given linguistic capacity — while minimizing, although not eliminating entirely, the role of experience.”

- “These models of language acquisition lend themselves to testable hypotheses about the language acquisition process. The interaction-based model implies that the child’s transition from prelinguistic communication to linguistic competence should be relatively smooth. That is, if linguistic structures are derived from prelinguistic forms, there should be no abrupt discontinuity in the use of these differing forms.”

- “On the other hand, if language is a distinct formal system reflecting a particular mental capacity, not wholly built up from early communicative competence, one would predict a discontinuous transition from early prelinguistic to linguistic expression. That transition would be marked by evidence of the reorganization of knowledge regarding the function and use of linguistic forms once they become part of a formal grammatical system.”

- The signed language key to unlocking this puzzle: prelinguistic gestural forms for YOU, ME are the same as the linguistic (ASL) forms for YOU and ME.

- **Interactionist-based**: if language is 'built up' from general cognitive capacity, interaction with environment, and prelinguistic knowledge, then language acquisition will be smooth, no abrupt discontinuities in the use of prelinguistic (i.e., gestural) and linguistic forms

- **Formalist**: if language is "built in' and language is a distinct, innate mental capacity, then language acquisition will be discontinuous in its transition from early prelinguistic (gestural) to linguistic (ASL) expression.

The data

- Early Period: at 0;6 the child didn't point; by 0;10 she pointed to things around her, at times to direct her mother's attention, at times pointing to herself and other people

- Middle Period (1;0 to 1;6): the child stopped pointing to refer to people (mother, father, self) and only used pointing to reference objects, locations, and events. No use of the signs YOU and ME. She did use signs MOTHER, FATHER, and GIRL in linguistic contexts that would normally require pronouns.

- Error Period (1;10 to 1;11): Began pointing to people again but in a manner different from adult usage. E.g., she used YOU to indicate herself while signing to her mother that she (the child) wanted to eat.

- Correct Use: from 2;3 the child produced and comprehended the full set of personal pronouns. She produced ME in self-reference, YOU to refer to mother and father.

The Implications

- ‘Building up’ language from general cognition **requires** a *continuous* development

- Discontinuous development **requires** two distinct systems: general cognition and an innate linguistic capacity

- Pettito claims she found *discontinuous* development

- The conclusion: "... linguistic knowledge ... is not merely constructed out of the prelinguistic materials at hand. In this sense, the acquisition process is discontinuous with other forms of knowledge."

- Therefore: **language is not built up, it's built in.**

Is there another explanation?

- Can a gradual increase in general cognitive abilities lead to discontinuous development?

Dynamic Systems Theory I

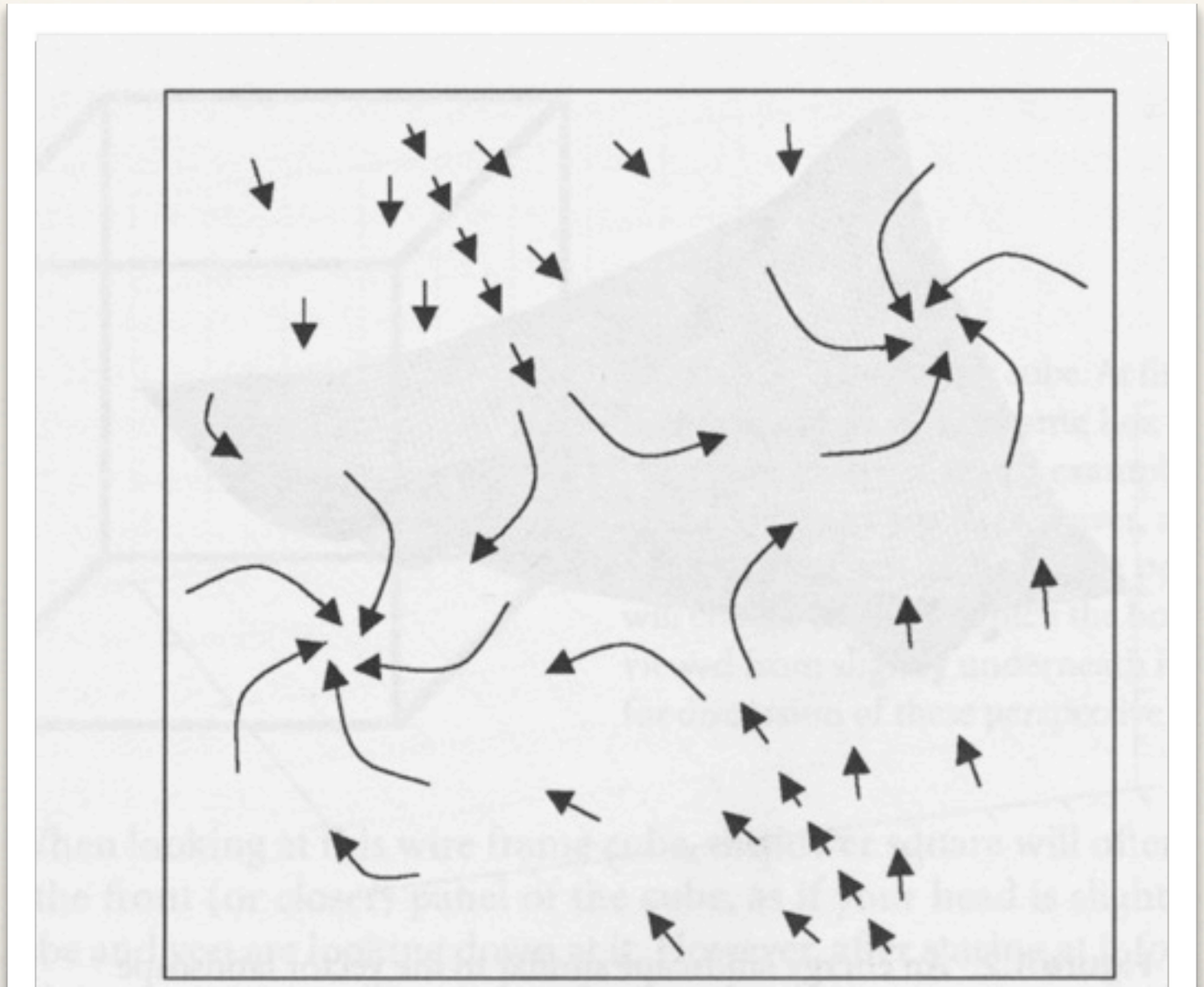
- Attractors, Phase Shifts, Dynamic Stability / Instability

Attractors

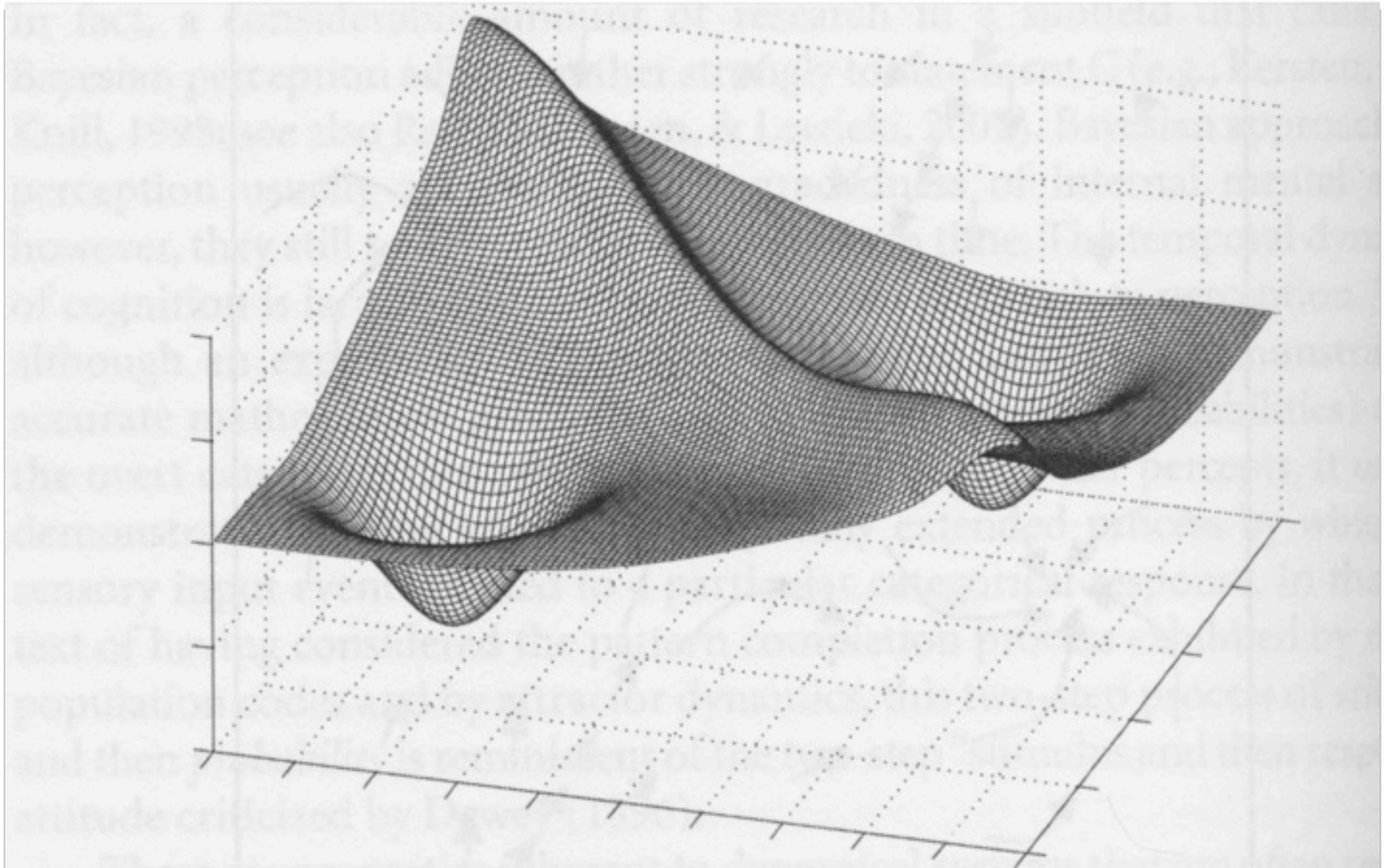
- An attractor is a set towards which a dynamical system evolves over time. That is, points that get close enough to the attractor remain close even if slightly disturbed.

- Geometrically, an attractor can be a point, a curve, a manifold, or even a complicated set with a fractal structure known as a strange attractor.

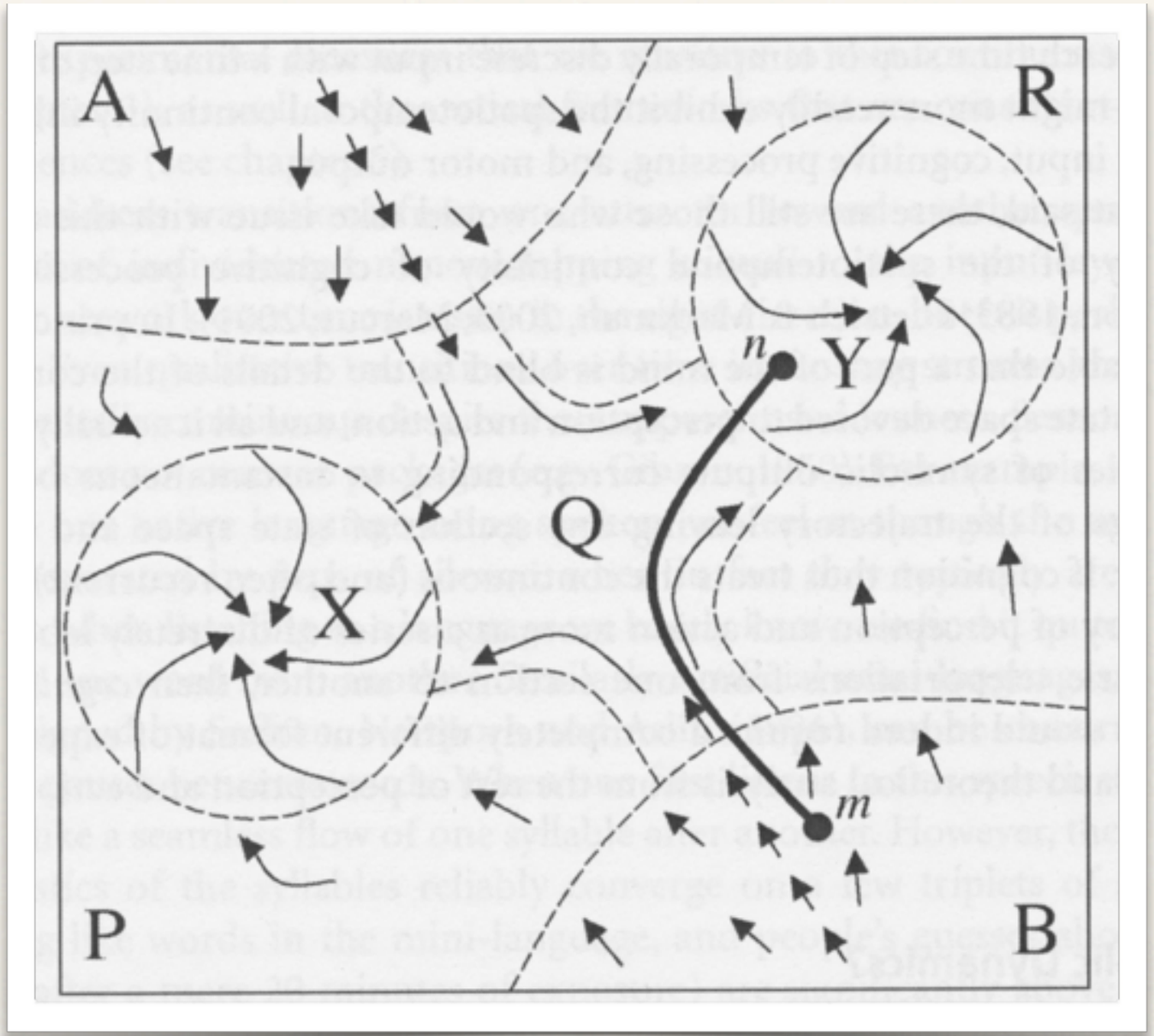
Attractors



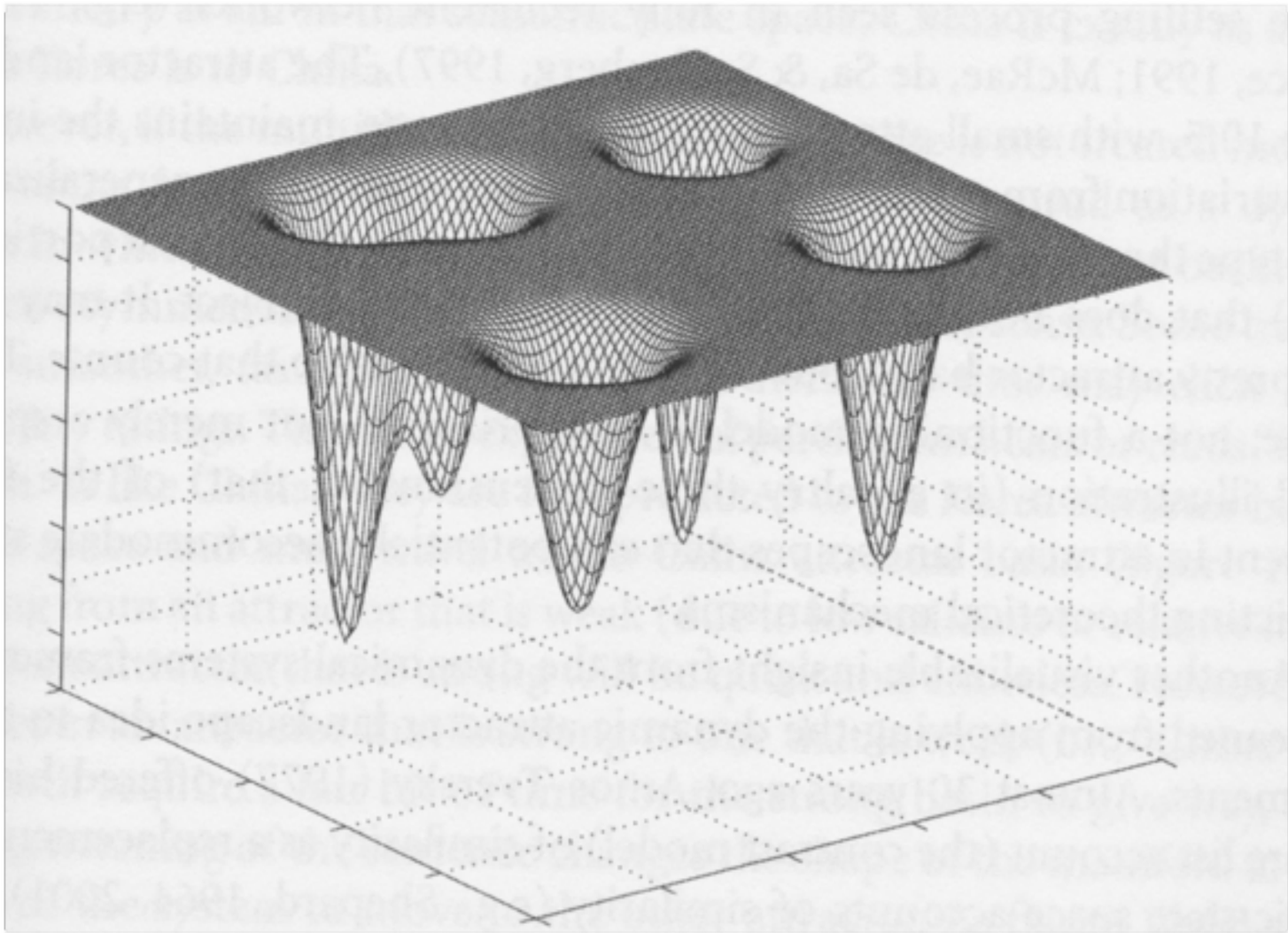
Phase Shifts



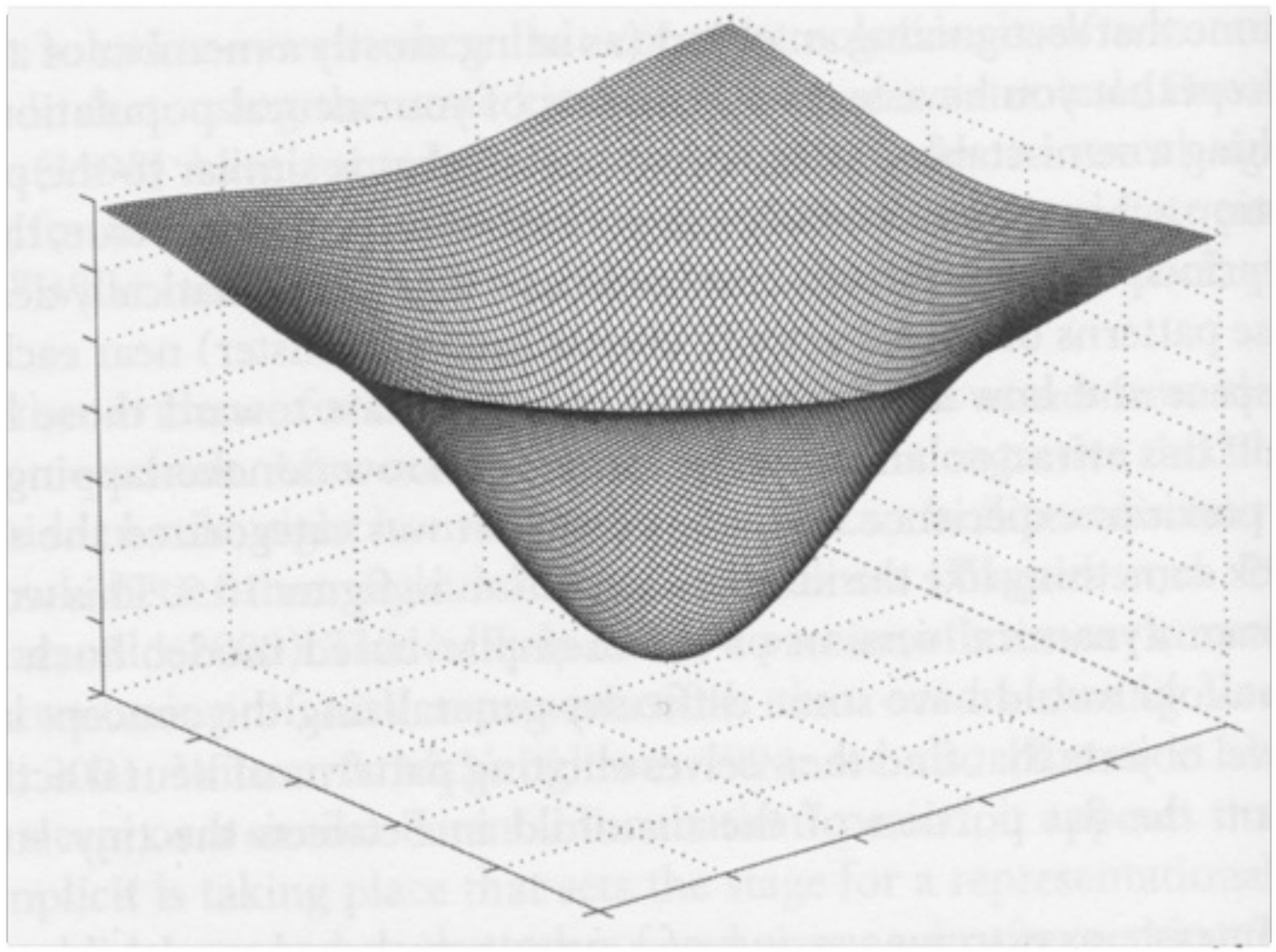
Attractors as symbols



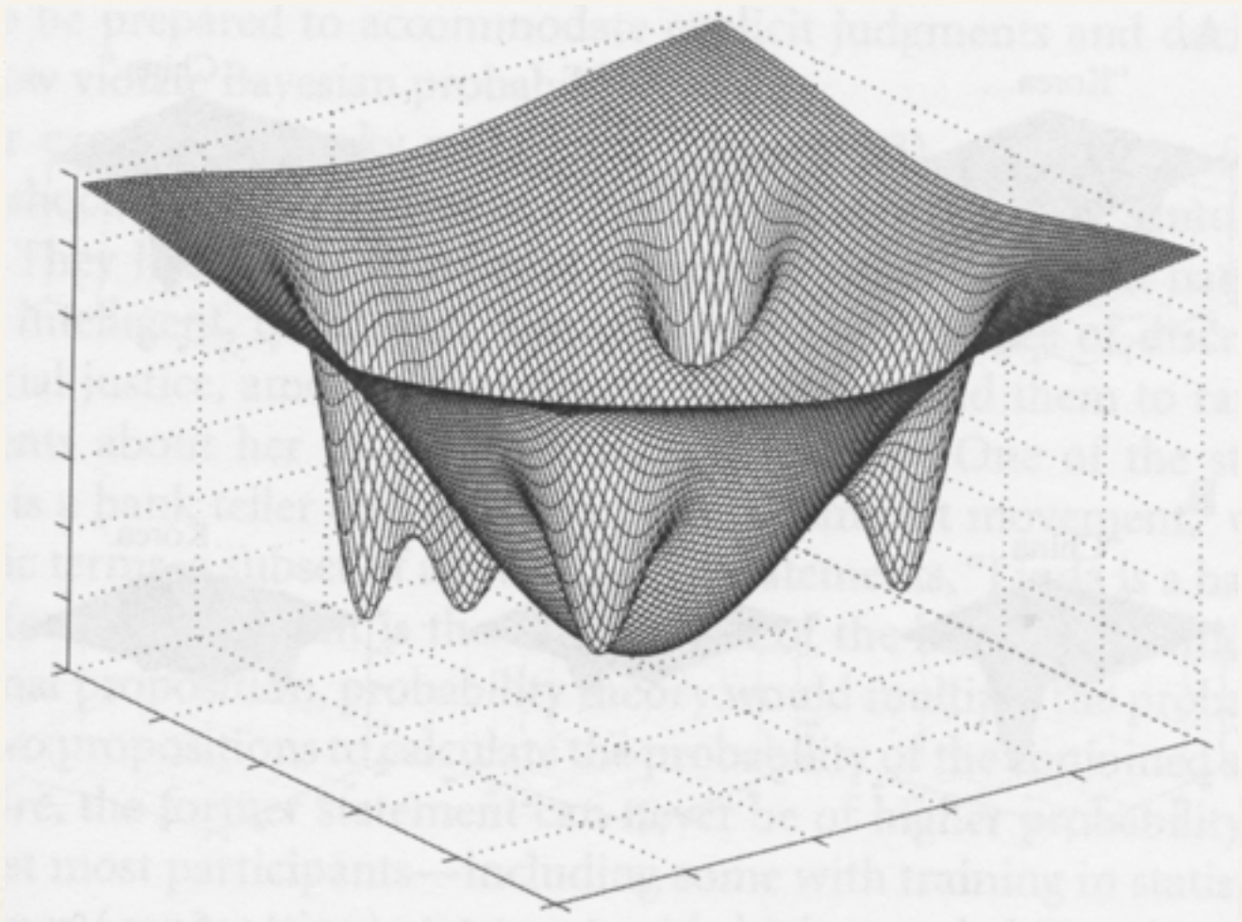
Attractors as Exemplars



Attractors as Prototypes



Prototype and Exemplar



Attractors and Semantic Space

- Asymmetries in linguistic similarity and acceptability judgments
- Acceptability for “Korea is like China” is reliably higher than for “China is like Korea.”
- People conceive of Korea as being more similar to China than China is to Korea

Attractors and Semantic Space

- But if concepts (Korea, China) are represented in a semantic space, and proximity in that space is equivalent to their similarity, then there should not be any asymmetry. People should judge Korea as the same semantic distance from China as China is from Korea.

Attractors and Semantic Space

- What if semantic space is not static?

- Rather, “thought itself is a trajectory from one attractor basin to the next” (Spivey 2007: 273)

- Then some trajectories are smoother, faster, and easier than others.

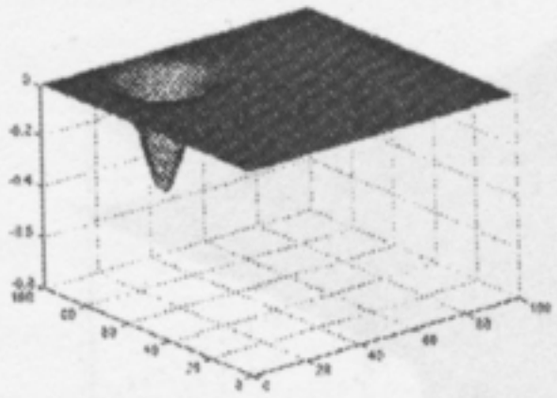
Attractors and Semantic Space

- "Traversing from an attractor that is weak (due to low salience or relative importance) to an attractor that is strong will be quick and effortless."

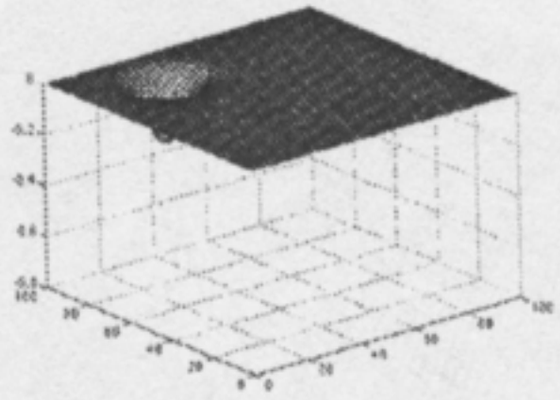
- "Traversing from an attractor that is strong to one that is weak (i.e., "China is like Korea") will require a fair bit of time for the strong basin to give way."

A.

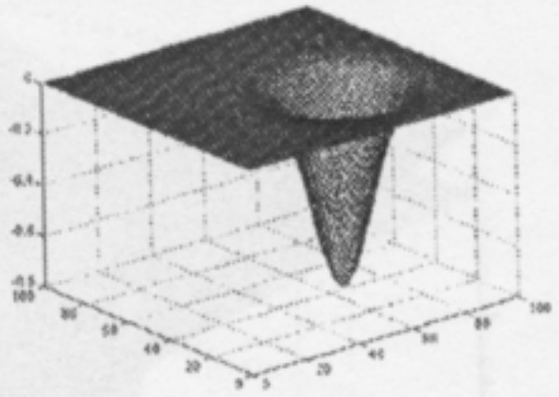
"Korea…



…is like…

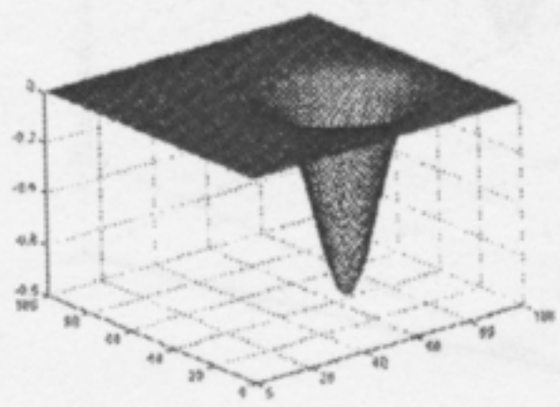


…China."

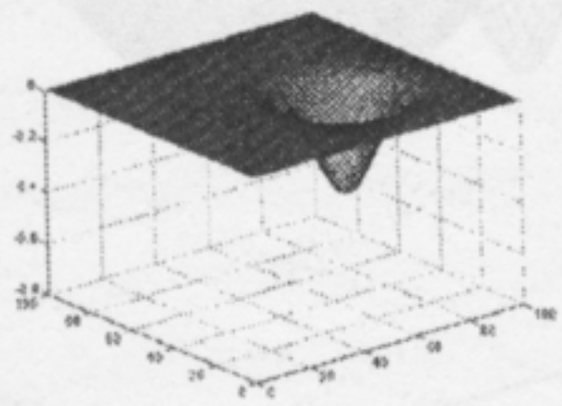


B.

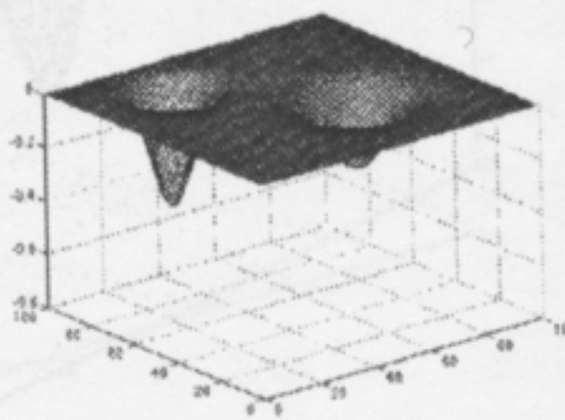
"China…



…is like…



…Korea."

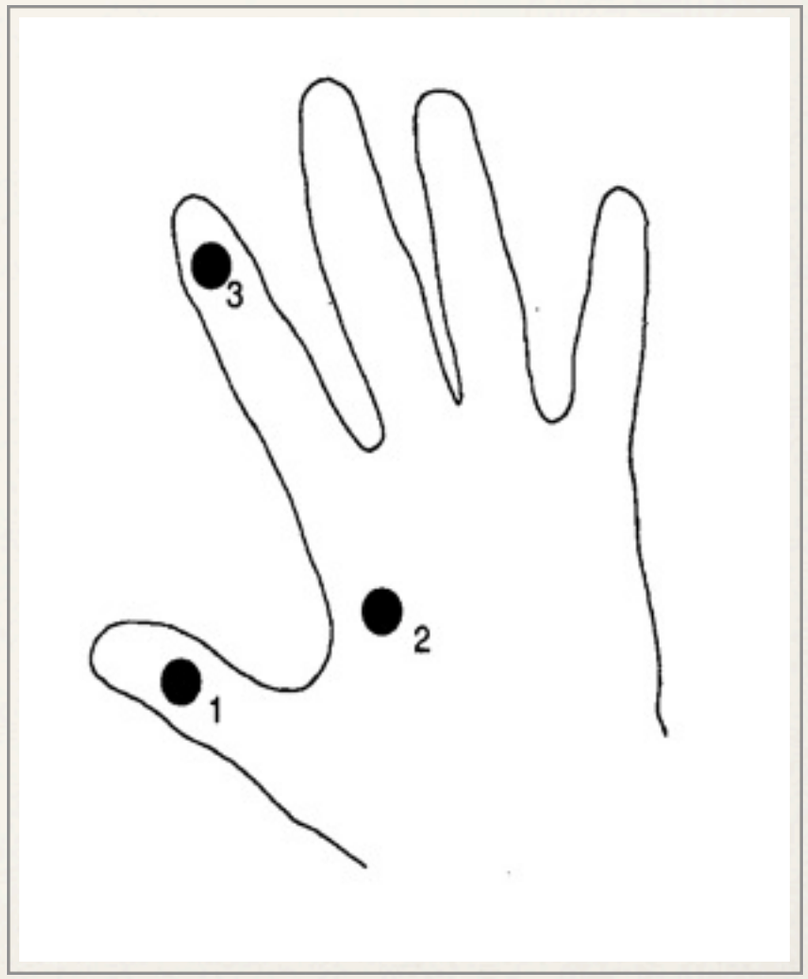


Case Study #2: Fingerspelling

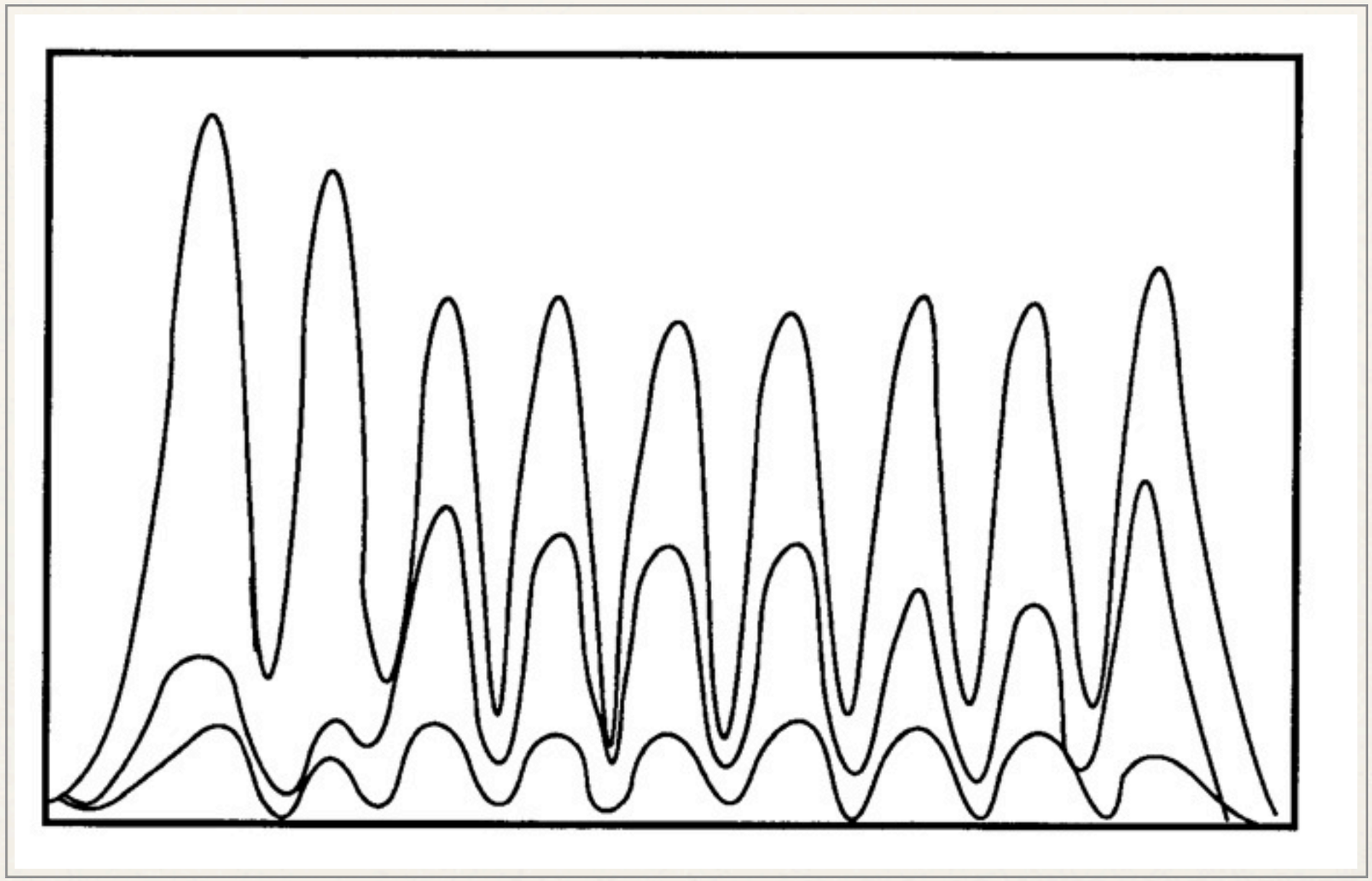
DST and Fingerspelling

- **The Phonetics of Fingerspelling**

- Motion tracking system tracked articulatory movement of the fingers

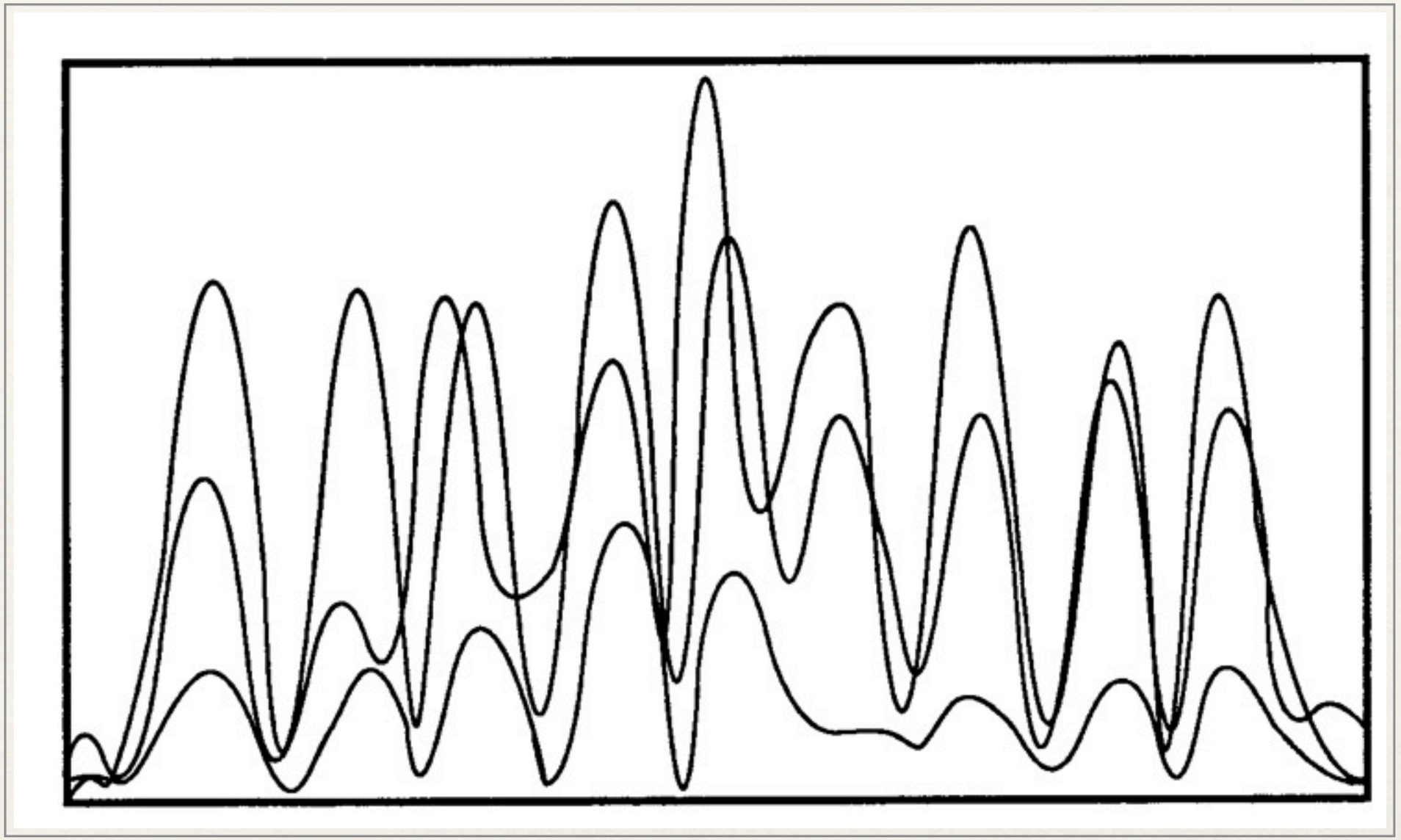


Measurement of articulatory motion



Fluent productions

Measurement of articulatory motion



Non-fluent productions

Timings across articulators

Fluent	Non-fluent
18.6 ms	40.3 ms

Dynamic Systems Theory II

- Coordinative Structures and Skill
- Entrainment and Entrenchment
- Functional Grouping, Muscle Synergies, Gestures

Language Production as a Dynamic System

- "Much linguistic phonetic research has attempted to characterize phonetic units in terms of measurable physical parameters or features. Basic to these approaches is the view that a phonetic description consists of a linear sequence of static physical measures, either articulatory configurations or acoustic parameters. The course of movement from one such configuration to another has been viewed as secondary."

(Browman & Goldstein, *Dynamic Modeling of Phonetic Structure*, 1985)

Language Production as a Dynamic System

- "We have proposed an alternative approach, one that characterizes phonetic structure as patterns of articulatory movements, or gestures, rather than static configurations. ... In our view, then, a phonetic representation is a characterization of *how a physical system* (e.g., a vocal tract) *changes over time.*"

Articulator entrainment

- Synchronicity across multiple articulators suggests **functional entrainment.**

- The articulators have been harnessed to produce task-specific patterns of coordinated motion.

- This functional entrainment results in a reduction of degrees of freedom.

Coordinative structures

- Individual articulators work together in a functional grouping — they are *entrained*

Functional Assemblies

- Instead of controlling each articulator individually, **we acquire the skill to control functional assemblies of articulators.**

Articulatory gestures

- "A gesture is a functional unit, an equivalence class of coordinated movements that achieve some end." (M. Studdert-Kennedy, 1987)

- "By *vocal tract* (or *phonetic*) *gestures*, we mean coordinated actions of vocal tract articulators that achieve some linguistic goal." (Galantucci, Fowler, & Turvey, 2006)

Coordinative structures

- Dynamic systems can also account for coordinative structures — dynamic stabilities, action units, attractor states — in *muscle synergies*:

- "A muscle collective … that is successful in achieving some purpose is a muscle synergy." (Rudolfo Llinás)

Muscle synergies

- How does the brain control complex reflexes such as the vestibulo-spinal reflex (you automatically correct your body position when you begin to lose your equilibrium — if riding a bicycle, lean when turning!)

- These reflexes engage collections of muscles that span multiple joints and are innervated by motor neurons from different spinal levels

- The stereotyped and time-locked performance of multiple, clearly independent muscles in these reflexes suggest that the muscles are controlled as a *single, functional entity*.

Gesture

- "A gesture is a functional unit, an equivalence class of coordinated movements that achieve some end."

Gestures, synergies, and the brain

- Edelman: synergies are *classes of movement patterns* or gestures. Synergies are not controlled in a one-to-one fashion but are tightly constrained among themselves, sharply reducing the number of degrees of freedom of movement.

- We will discuss this more in Lecture 10

Looking ahead

- Lecture 10 will relate the concepts of dynamic systems, that we have seen have relevance to cognitive linguistics and cognitive grammar, to Edelman's Theory of Neuronal Group Selection or "Neural Darwinism."