Cybernetics, neurosemiotics, and neurophenomenology

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Happy to be at a (virtual) biosemiotics meeting!

I am an auditory and theoretical neuroscientist, largely retired from teaching, actively doing research & writing.

Courses taught in recent years:

1. Music perception & cognition
2. Neuropsychology of the temporal arts (music, dance)
3. Consciousness studies (neural correlates of conscious awareness)

Gatherings in Biosemiotics, July 28, 2021 (Stockholm & Virtual)

Who I am – Peter Cariani, Ph.D.

Undergraduate:	Biology @ MIT (UROP: aging in nematodes)
Graduate:	Systems Science @ SUNY-Binghamton Computer models of protein folding
Doctoral thesis:	Epistemology of “evolutionary robotics” – self-constructing systems (theoretical biology, cybernetics, systems theory, functional emergence) Thesis advisor: Howard Pattee
Postdoctoral:	Eaton-Peabody Laboratory for Auditory Physiology (Harvard, MIT, MEEI) Temporal coding of pitch and vowels in the auditory nerve Work with Bertrand Delgutte, Mark Tramo, Nelson Kiang (EPL director)

Biosketch

Peter Cariani is an auditory and systems neuroscientist who has taught courses related to the neuropsychology of music in the Boston area (Tufts, MIT, Harvard, Boston Conservatory/Berklee) since 2003. His research has involved neural models of musical pitch and consonance, temporal coding schemes, adaptive temporal correlation models of rhythmic pattern induction, and proposal of time-domain, neural timing nets. He has written on a variety of other subjects that include auditory scene analysis, theoretical biology, cybernetics and system theory, biosemiotics, epistemology and evolutionary robotics, and the neural basis of conscious awareness. His training is in biology (B.S., MIT, 1978), systems science/biological cybernetics (Ph.D., SUNY-Binghamton, 1989) and auditory neurophysiology (Post-doc, Eaton Peabody Labs for Auditory Physiology, MEEI-MIT-Harvard, 1990-1996). He is currently a Senior Research Scientist at the Hearing Research Center at Boston University and is a member of the faculty of the Speech, Hearing, Biosciences, and Technology (SHBT) Program at Harvard Medical School.

ABSTRACT

Cybernetics, neurosemiotics, and neurophenomenology

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A general, *systems semiotics* is proposed as a conceptual, heuristic framework for understanding how signs are used in natural and artificial informational systems. Signs are regarded as materially embodied distinctions that reliably switch the subsequent behavior of a system (as recognized by some observer through some observational frame). In biological systems, signs guide the construction of the organism (genetic codes), mediate cellular signaling operations (molecular codes), coordinate organismic behavior (neural codes), and subserve the contents of conscious awareness (neurophenomenal bridge laws).
Drawing from Uexkull, Morris, Pattee, Rosen, classical cybernetics, theoretical biology, pragmatism, operationalism, and psychological constructivism, I propose a taxonomy of adaptive, self-modiying and self-constructing percept-coordination-action (observer-actor) systems. These functional organizations utilize three primitive semiotic operations that mediate relations between internal signs and with the external world. In "measurement" (sensing), contingent interaction of a sensory receptor with the external world produces sensory sign. In "computation" (coordination) internal signs are reliably mapped to other signs. In "action, " an internal command-sign directs an effector that causes a change in the external world.
Systems are purposive by virtue of evaluative, switching, and construction operations that adaptively adjust the organization and behavior of the system to realize internal embedded goals. Evaluations are performance-related measurements used to steer behavior towards goal satisfaction. Switching changes percept-action mappings using existing signs, whereas construction changes physical substrates that can enlarge the set of available sign-primitives. Switching enables combinatoric creativity within existing sets of primitives (Piagetian assimilation), whereas physical construction enables new primitives to be formed (emergent creativity, Piagetian accommodation).
Neurosemiotics involves the role of signs in nervous systems. The (unsolved) problem of neural coding entails identification of which aspects of neural (spiking) activity subserve informational functions, i.e., that switch internal functional states and subsequent behaviors. We will discuss prospective types of neural codes. Rate-channel codes and connectionist networks encode distinctions using patterns of firing rates across neurons, whereas temporal codes and neural timing nets encode distinctions using patterns of spike timings. Both rate-channel and temporal codes can support iconic, form-preserving representations or arbitrary "symbolic" representations. However, temporal codes enable multiplexing of signals and broadcast coordination mechanisms that can liberate signals from wires (as in a radio network). In contrast, channel codes and connectionist networks must precisely regulate specific connectivities and transmission paths (as in a telegraph network or telephone switchboard). Whereas connectionism are channel-centric (which neuron does what is critical), timing nets are signal-centric (spike patterns irrespective of specific neurons are critical). Conceivably, neural timing networks can create new sign-primitives by selecting or tuning delays within local neural assemblies to produce new temporal patterns that function as tags that signify new concepts (semantic pointers).
Neurophenomenology involves the dependence of conscious awareness and specific experiential states on patterns of neural activity. The neurophenomenal neural coding problem entails formulation of neurophenomenal bridge laws that predict 1) what organization of neural activity is necessary and sufficient for there to be any conscious awareness (NCCs) and 2) what specific patterns of neural activity correspond to particular experiential, phenomenal states (NCCCs). In line with neural global workspace theories, I hypothesize that those sets of temporally-coded neural signals that are stabilized in recurrent global circuits through active regeneration constitute the neurophenomenological contents of short-term memory and conscious awareness.

Cariani, P. (2012). Creating new primitives in minds and machines. In J. McCormack & M. D'Inverno (Eds.), *Computers and Creativity* (pp. 395-430). Springer.
Cariani, P. (2015). Outline of a cybernetic theory of brain function based on neural timing nets. *Kybernetes*, *44*(8/9), 1219-1232.
Cariani, P. (2015). Sign functions in natural and artificial systems. In P. P. Trifonas (Ed.), *International Handbook of Semiotics* (pp. 917-950). Springer.

OUTLINE

Cybernetics, neurosemiotic & neurophenomenology

Semiotics: "systems semiotics" as a general heuristic framework

- Sign-distinctions as switches, meanings as consequences
- Semiotic operations (sensing, coordination, action, construction)

Cybernetics: signs in purposive percept-action systems

- Adaptive & self-constructing systems
- New signs: Combinatoric vs. emergent creativity

1980's on

Neurosemiotics: Reverse-engineering brains as informational engines

- Neural coding: identifying signals of the system
- Temporal codes & neural timing nets
- Sketch of a temporal, signal-centric theory of brain function

1990's on

Neurophenomenology

- Neural substrates of awareness NCCs & experiential states NCCCs
- Bridge laws: neural activity patterns → experiential states
- Organizational closure through signal regeneration
- An autopoiesis of neural signal productions

2000's on

SEMIOTICS

Semiotic systems switch behavior on the basis of materially-realized distinctions

Not all material systems lend themselves to descriptions as semiotic systems
We are justified in labeling a system or process as "semiotic" only if we can identify material vehicles of sign distinctions & their differential consequences for behavior

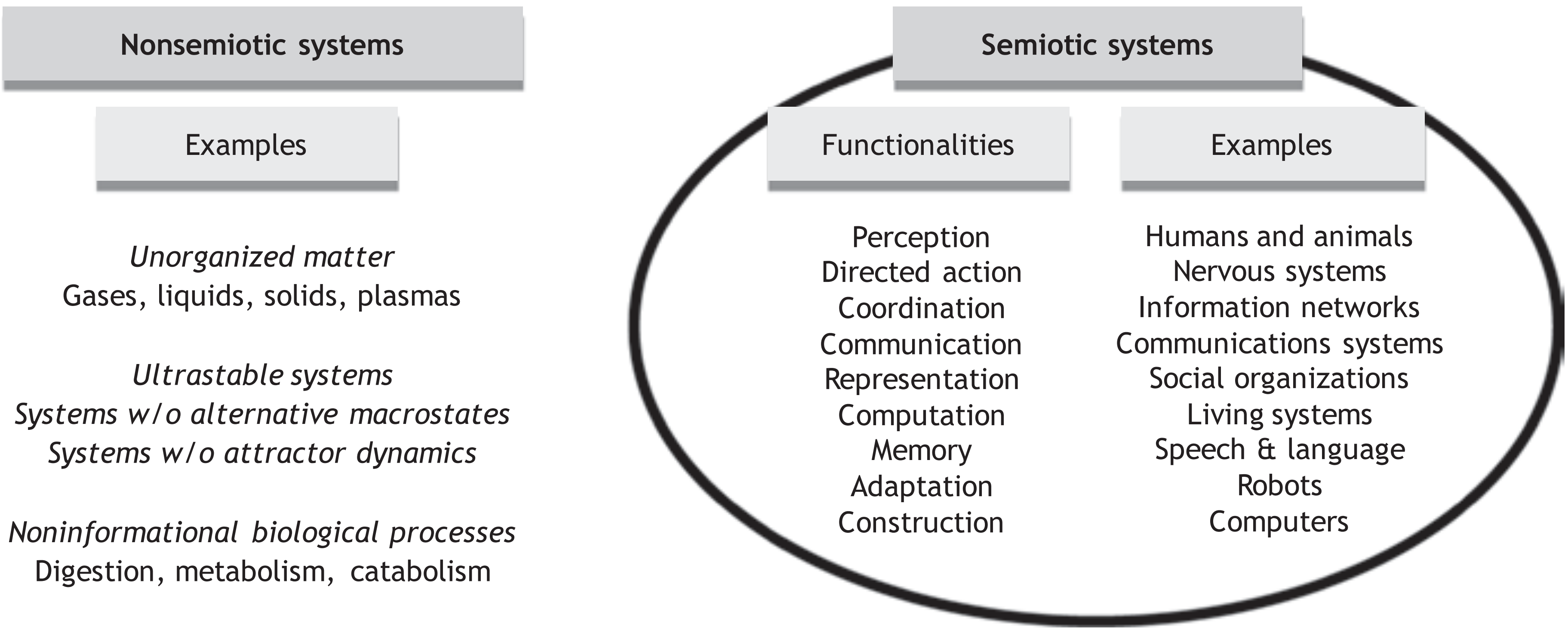


Fig. 42.1 Semiotic and nonsemiotic systems. Systems can be divided by whether their organizational structures and dynamics support signs and sign functions. Basic functionalities of signs, signals, and symbols in semiotic systems. Examples include natural, social, and artificial sign-using systems

Systems semiotics: a *conceptual, heuristic framework* for understanding how signs are used in both natural & artificial informational systems.

Based on sign-mediated operations.

Signs are materially-embodied distinctions that reliably switch the internal organization & behavior of a system.

Systems are semiotic by virtue of their internal organization, such that they show observable, sign-mediated behavior.

Sign-mediated processes

Different modes of sign-use achieve different functions

- ***constructive functions*** in biological organisms (genetic codes)
- ***internal regulation*** (gene expression, neural regulation)
- ***epistemic functions*** in modeling relations, nervous systems
- ***steering functions*** in purposive animal behavior and robots
- ***mediation of informational organization*** (neural codes, computers)
- ***representational & compositional functions*** (brains, computers)
- ***mnemonic functions*** (genetic inheritance, memory traces)
- ***anticipatory functions*** (steer behavior based on past experience)
- ***information processing*** pattern recognition in animals & machines
- ***communicative functions*** (formulate, send, transmit, receive, interpret messages in/amongst animals, humans, machines)
- ***social coordination, cooperation, command***
- ***construct new distinctions***, concepts, categories (semiogenesis)

Some basic concepts

Interpretation: the process of “reading-out” the sign, i.e. switching behavior contingent on the sign vehicle presented.

Meaning: the manifold differential consequences of a sign-distinction for the system’s state/behavior

Purpose: end-state of an internal goal-seeking mechanism.

SYSTEMATIC SETS OF DISTINCTIONS

Representation: set of mutually-exclusive sign-distinctions

neuroscience, *non-referentialist* sense -- <u>not</u> “aboutness” –

linkages to sensorimotor states, not external events & objects *per se*

Language: A semiotic system of sign combinations and/or sequences to compose & express complex distinctions.

SOURCES OF INSPIRATION (spiritually, I am a theoretical biologist)

THEORETICAL BIOLOGY Pattee, Rosen, Conrad

Modeling relations, multiple descriptions, symbols & dynamics, emergence-relative-to-a-model, Measurement Problem, non-reductionist/relational biology

SEMIOTICS Morris, Uexküll syntactics-semantics-pragmatics, pragmatism

PHILOSOPHY OF SCIENCE Hertz, Bohr, Bridgman, van Fraassen, von Glasersfeld, Feyerabend (theory creation), **Maruyama** (paradigmatics)

CYBERNETICS & SELF-ORGANIZING SYSTEMS Pask, Ashby

Purposive systems, feedback control, feedback to material structure

BIOLOGICAL EVOLUTION Gould, Riedl adaptivity vs. evolvability, micro vs macro-evolution, modularity, open-ended functional emergence

PSYCHOLOGY Boring, Piaget, Gestaltists, Gibsonians, Uttal percept-coordination-action, assimilation/accommodation, constructivism, open-endedness

NEUROSCIENCE Licklider, Lettvin, McCulloch, Lashley, Pribram, ER John, Abeles, Braitenberg neural codes, networks, temporal codes

PHILOSOPHY: EPISTEMOLOGICALLY-ORIENTED (operationalist)

MULTIPLE DESCRIPTIONS EXPLAIN DIFFERENT ASPECTS

Physical descriptions depict trajectories of physical states.

Semiotic descriptions depict functional, informational organizations that switch behavior.

HYLOMORPHIC WORKING ONTOLOGY

- **Organization embedded in matter**
- **Functional properties supervene on material organization**
- **Mind is the semiotic, informational organization of brain**
- **Mental processes and conscious awareness supervene on specific organizations of neural activity.**
- **No "downward causation" per se:** material action is closed under physical process (Kim); consciousness doesn't Δ physics

Definitions depend on functional organization

Life → autopoietic, regenerative self-production (M & V)

→ sign-mediated self-production, codes are essential (Pattee)

Purposive → by virtue of embedded goal-seeking mechanism

Agent → system w. embedded goals & autonomy of action

Semiotic system → behaves contingent on observed & identified sign-distinctions & vehicles

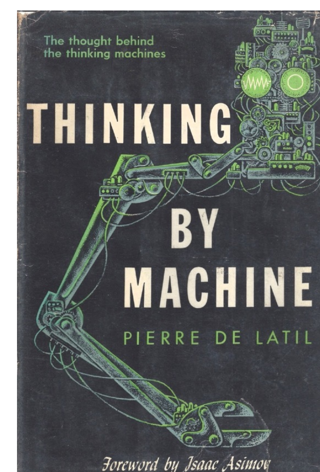
Adaptive → a system that can alter its own internal signs & sign-relations in order to better achieve goals

Although all living organisms are autonomous, purposive, semiotic systems, in my view semiosis does not require life, agency, purpose, or consciousness.

CYBERNETICS

Purposive systems:
autonomous percept-action
systems that use
internal feedback mechanisms
for steering & modification
to reliably attain
embedded goals

de Latil (1956) clear
exposition of
classical cybernetics



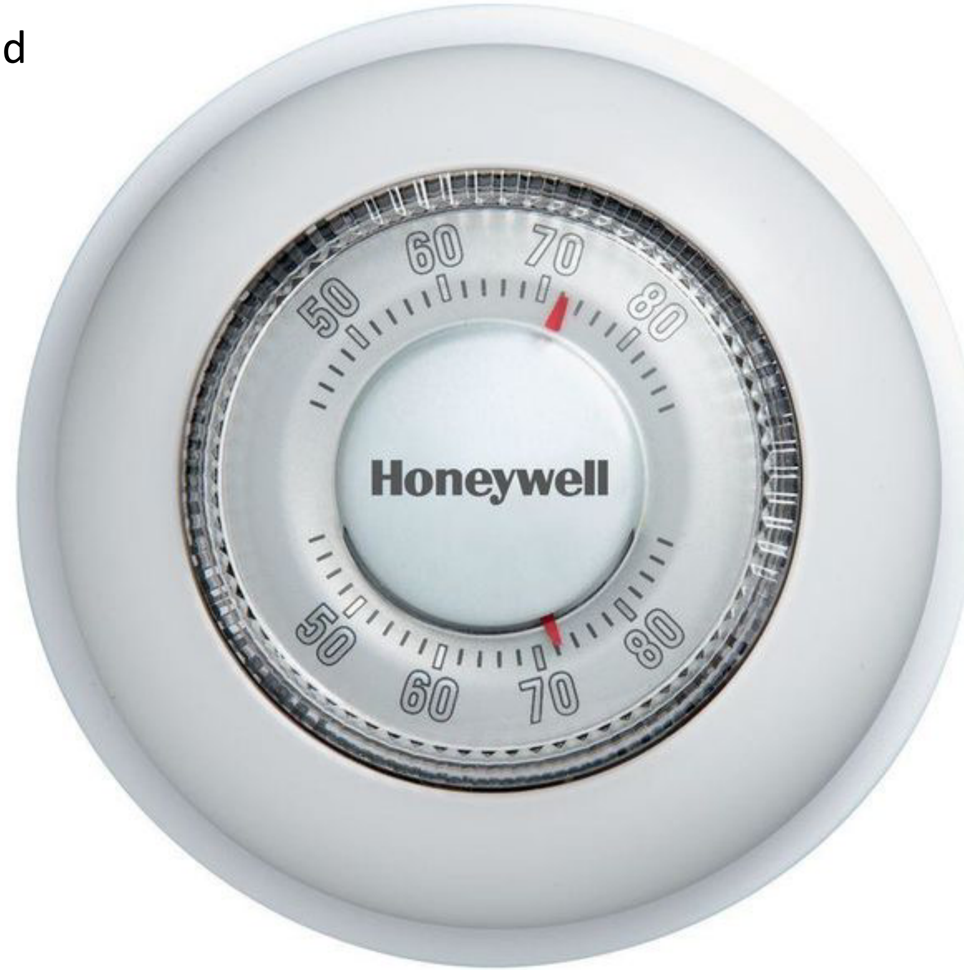
A thermostat for controlling a heating system is a simple, semiotic, purposive system.

Purposive: has embedded goal state
Semiotic: switches behavior based on distinction

It makes one sensory distinction that is related to the temperature in the room.

The sensory sign-vehicle is the output state (position) of the sensor element.

It compares the sensory sign-vehicle with the goal set-point sign-vehicle and makes one evaluative distinction: *room too cold* (re: goal temp) vs. *room hot enough*

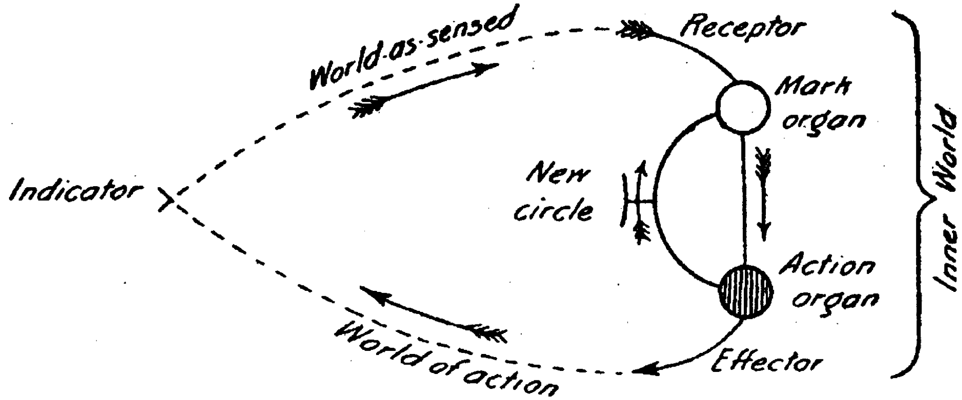


The evaluative distinction is interpreted to switch subsequent action.

Contingent on the difference between the goal temperature (position of goal element) and the observed temperature (position of sensor readout), an action-sign is produced that either turns the heating element on or off (differential action).
The meaning of the action-sign is the respective effect on the heater that it produces.

Semiotics of percept-action loops

Uexküll (1928)



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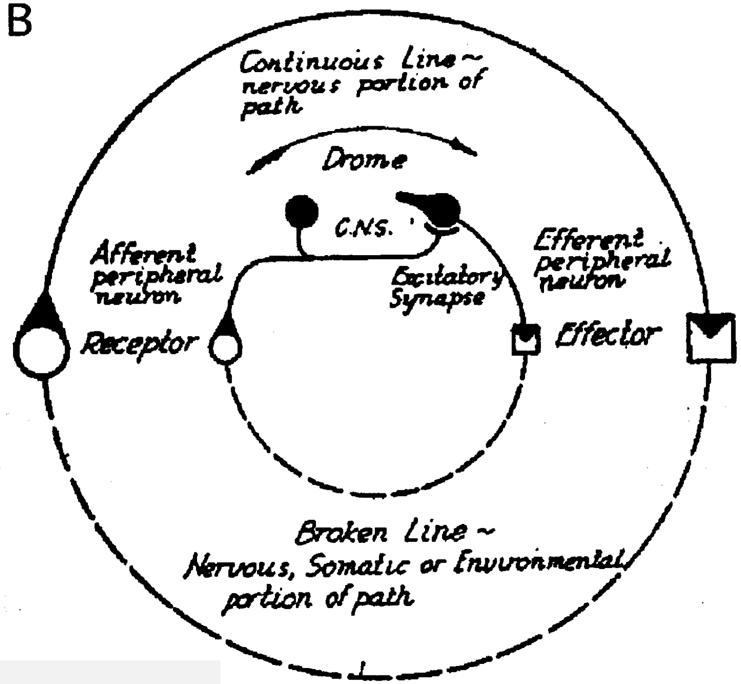

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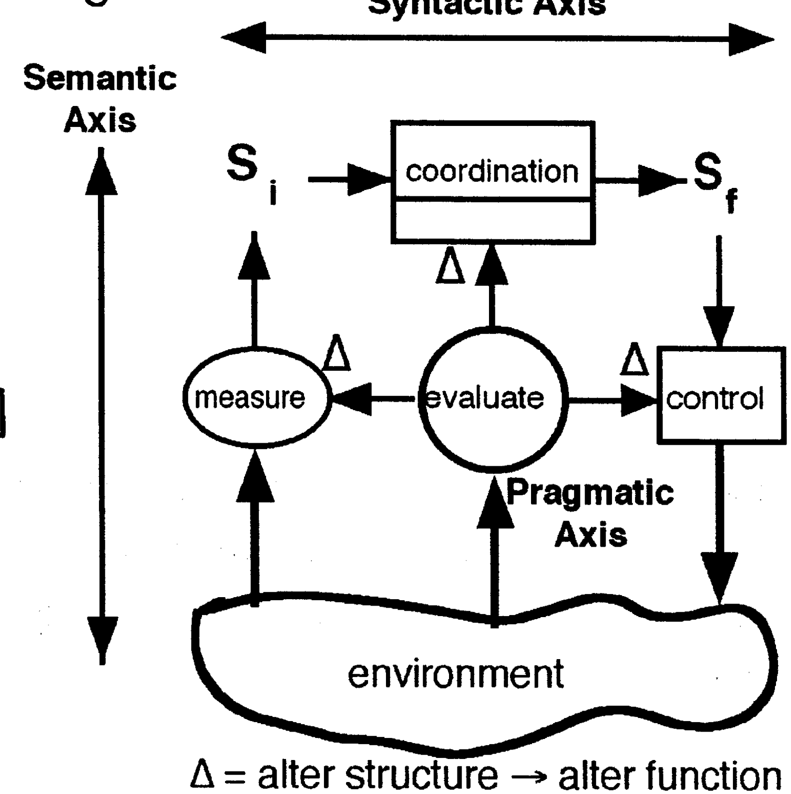
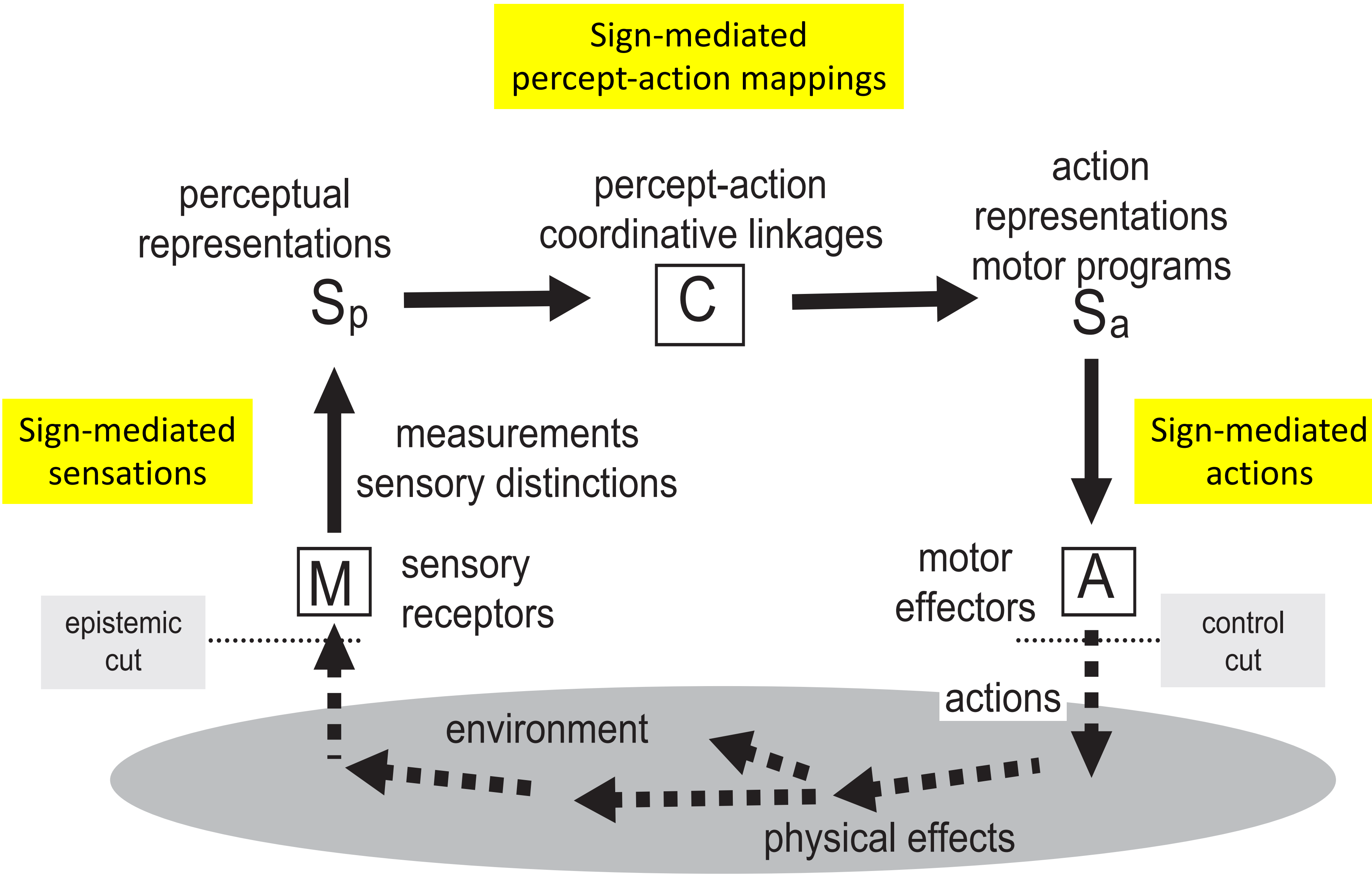
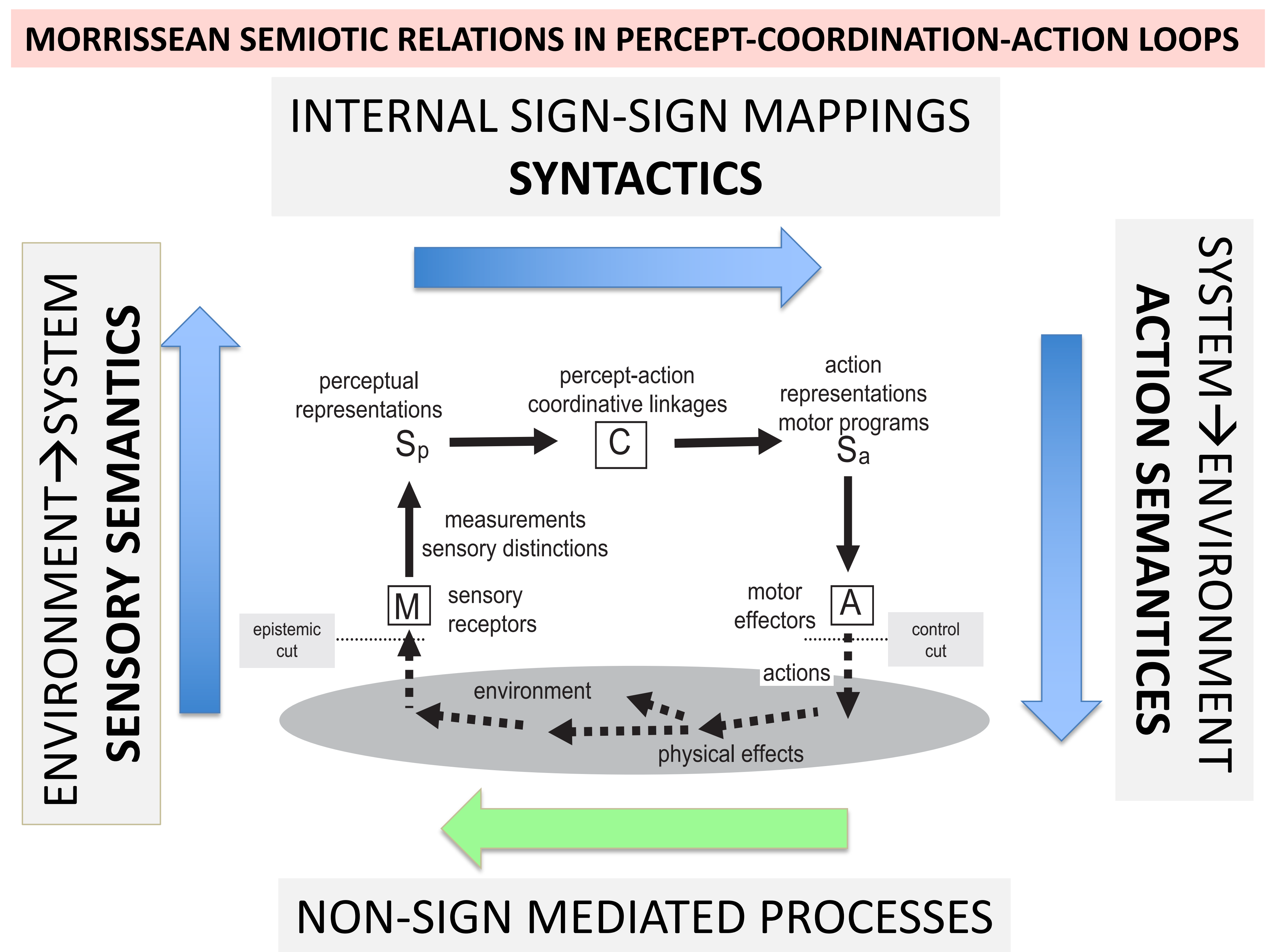


McCulloch (1946)

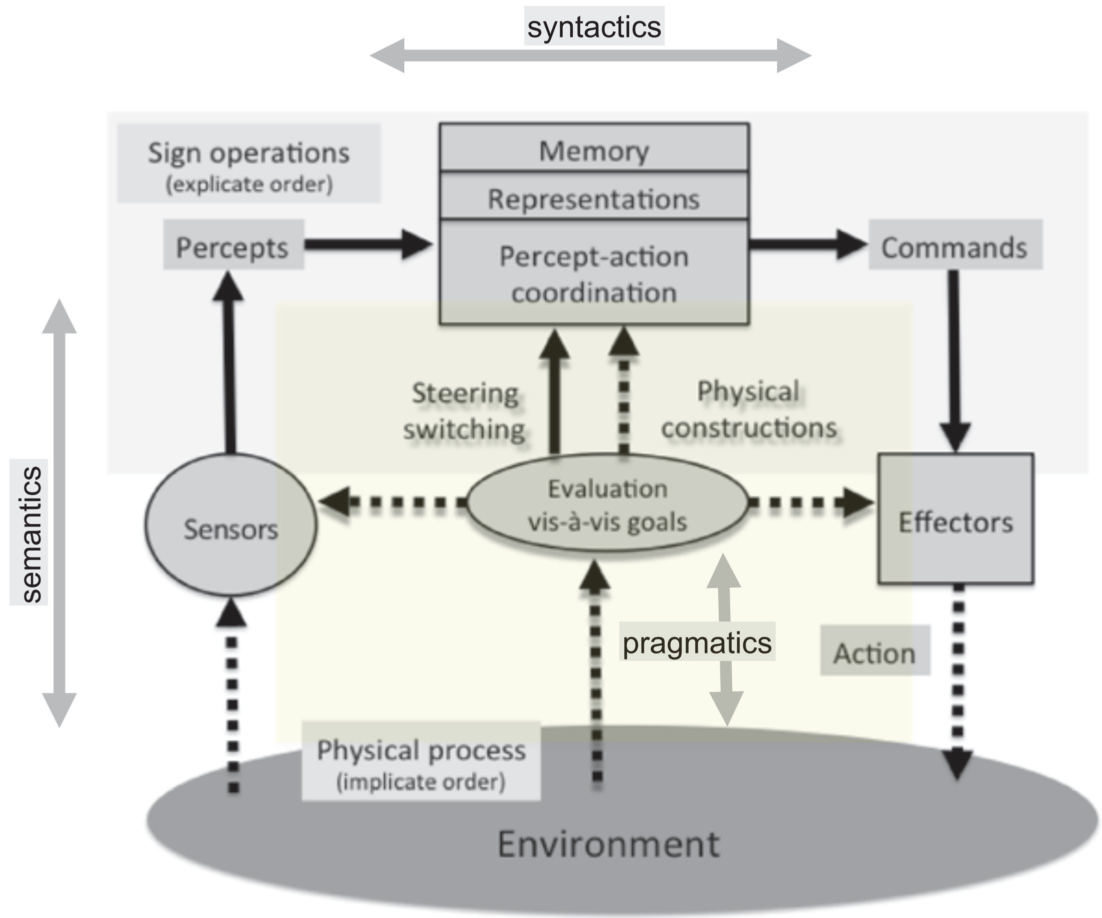
OPERATIONAL STRUCTURE OF PERCEPT-COORDINATION-ACTION SYSTEMS

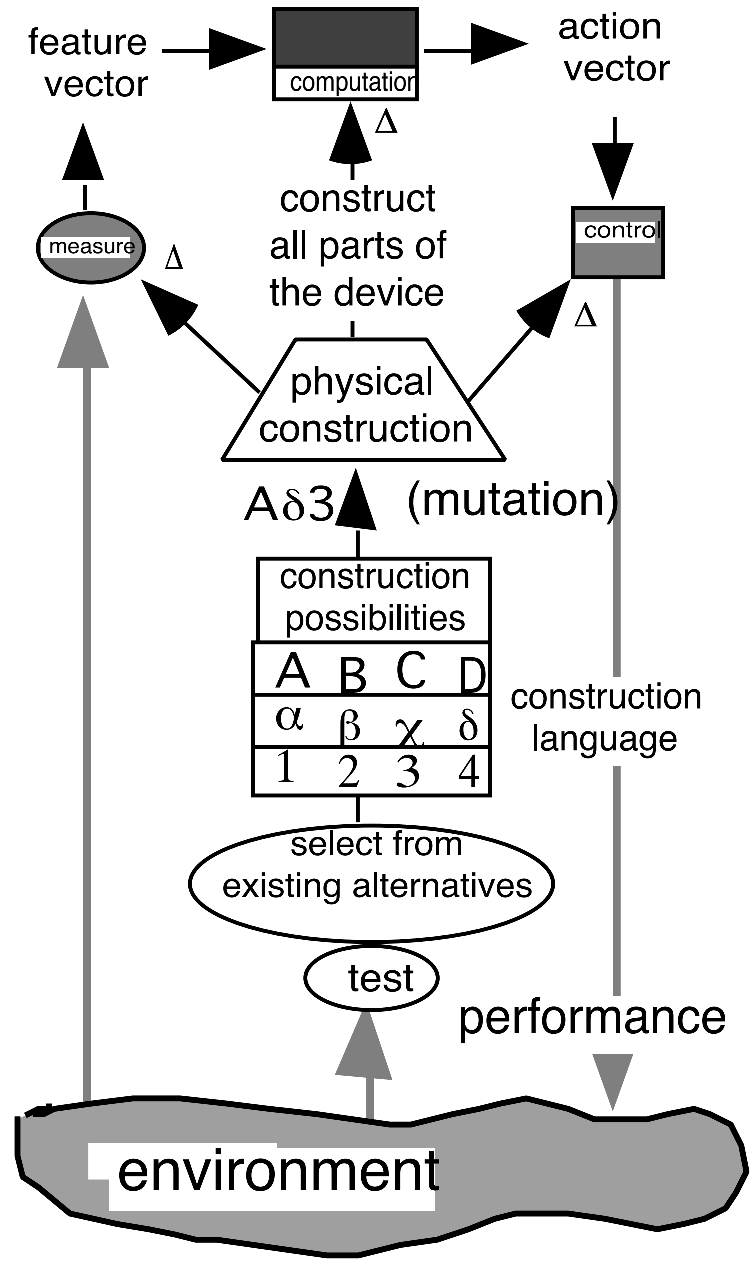



MORRISSEAN SEMIOTIC RELATIONS IN PERCEPT-COORDINATION-ACTION LOOPS
INTERNAL SIGN-SIGN MAPPINGS
SYNTACTICS
ENVIRONMENT→SYSTEM
SENSORY SEMANTICS
SYSTEM→ENVIRONMENT
ACTION SEMANTICES
perceptual representations
Sp
percept-action coordinative linkages
C
action representations motor programs
Sa
measurements
sensory distinctions
M
sensory receptors
epistemic cut
motor effectors
A
control cut
actions
environment
physical effects
NON-SIGN MEDIATED PROCESSES

PRAGMATIC DIMENSIONS

Steering, self-modification and construction to better achieve goals



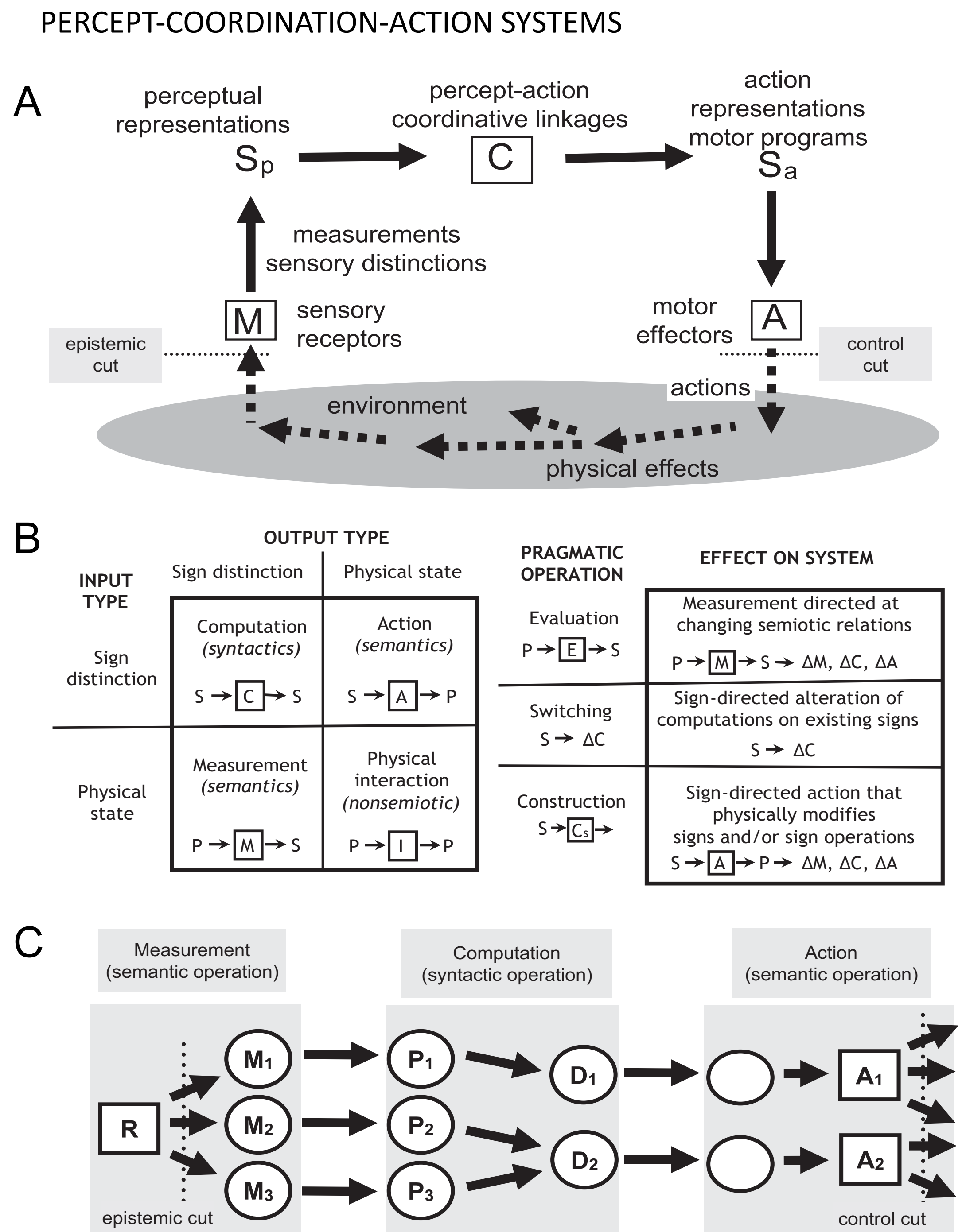


ALTERNATE COMPLEMENTARY DESCRIPTIONS

FUNCTIONAL ORGANIZATION
Description in terms of organization of sign-mediated operations

SIGN-MEDIATED OPERATIONS

OBSERVED STATE-TRANSITION PATTERNS CHARACTERISTIC OF SIGN-MEDIATED OPERATIONS



PRIMITIVE SIGN-MEDIATED OPERATIONS

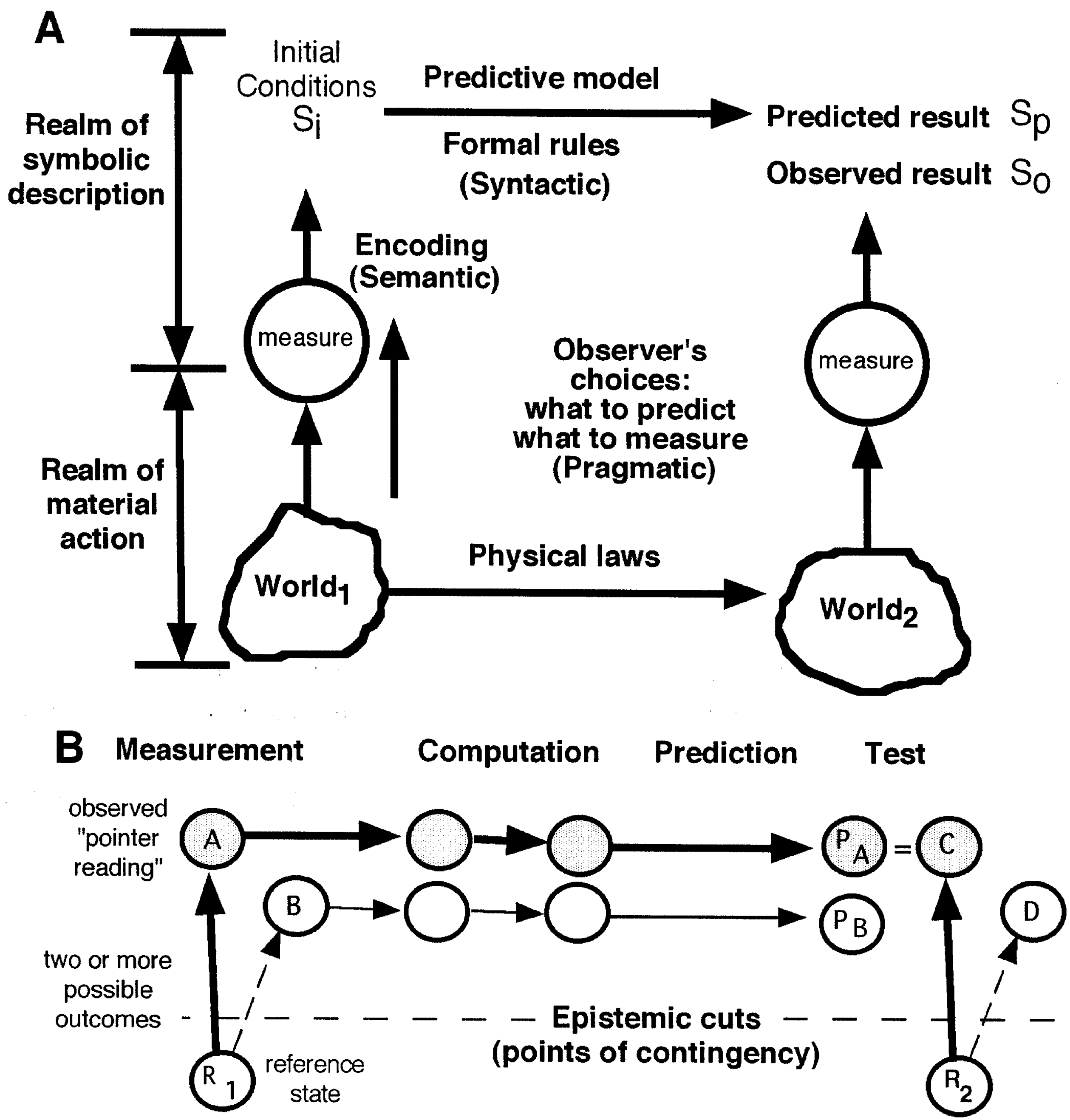
General types of operations

Sign operations that modify internal structure/ organization of the system

OUTPUT TYPE

INPUT TYPE	Sign distinction	Physical state
Sign distinction	Computation *(syntactics)* $S \rightarrow \boxed{C} \rightarrow S$	Action *(semantics)* $S \rightarrow \boxed{A} \rightarrow P$
Physical state	Measurement *(semantics)* $P \rightarrow \boxed{M} \rightarrow S$	Physical interaction *(nonsemiotic)* $P \rightarrow \boxed{I} \rightarrow P$

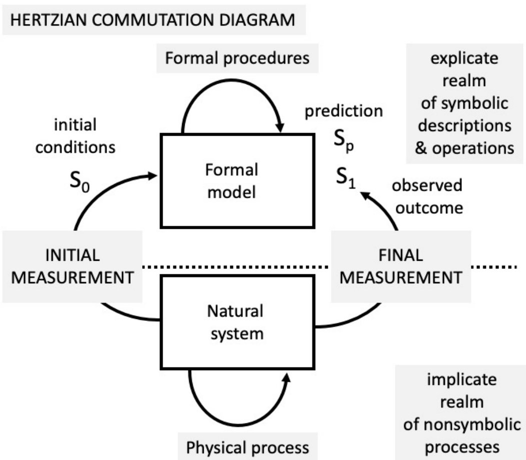
PRAGMATIC OPERATION	EFFECT ON SYSTEM
Evaluation $P \rightarrow \boxed{E} \rightarrow S$	Measurement directed at changing semiotic relations $P \rightarrow \boxed{M} \rightarrow S \rightarrow \Delta M, \Delta C, \Delta A$
Switching $S \rightarrow \Delta C$	Sign-directed alteration of computations on existing signs $S \rightarrow \Delta C$
Construction $S \rightarrow \boxed{C_s} \rightarrow$	Sign-directed action that physically modifies signs and/or sign operations $S \rightarrow \boxed{A} \rightarrow P \rightarrow \Delta M, \Delta C, \Delta A$

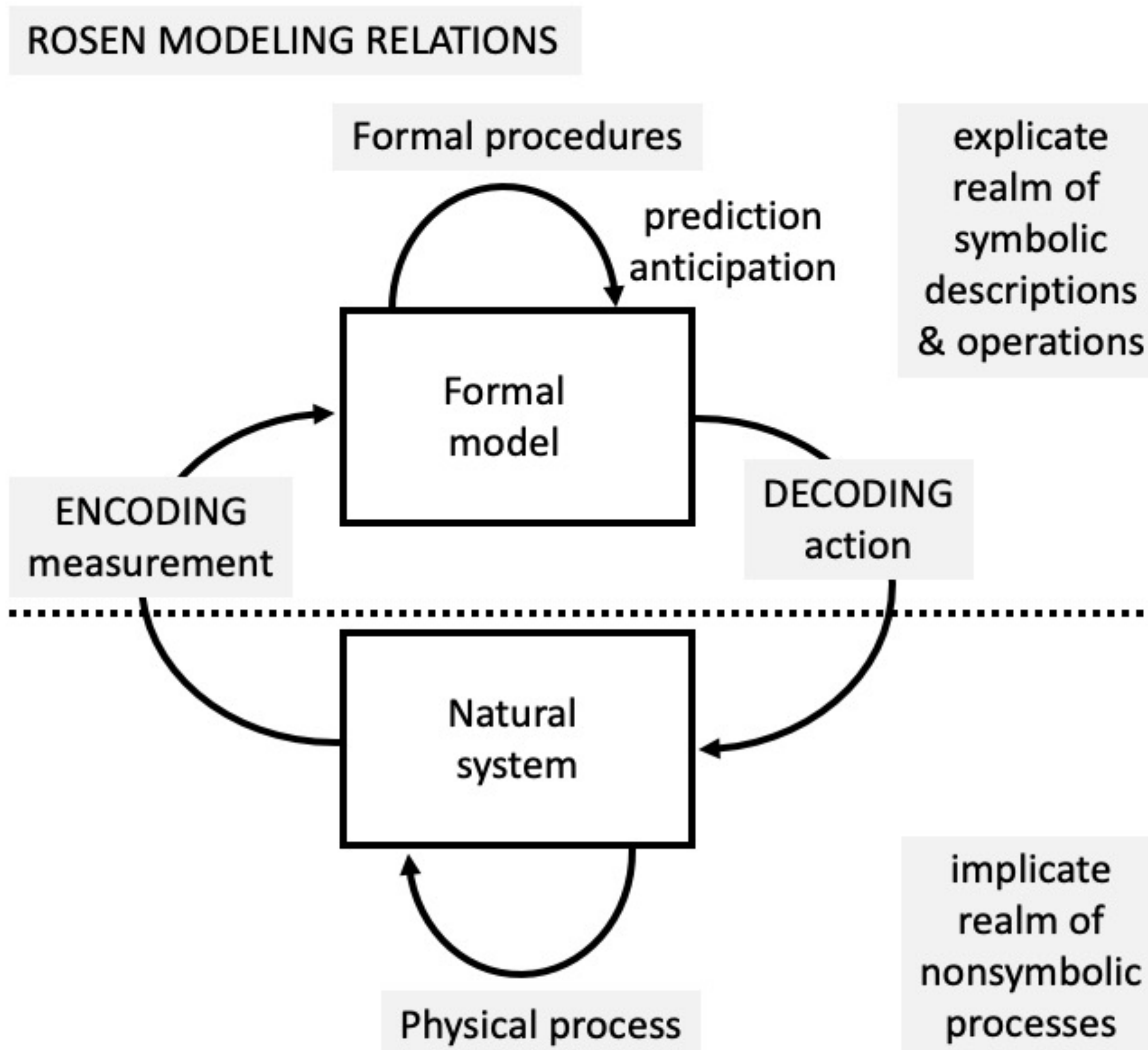


Semiotics of Hertzian commutation diagram
(observer mechanics of empirical prediction)

"Follow the symbols"

State-transitions amongst sign-states

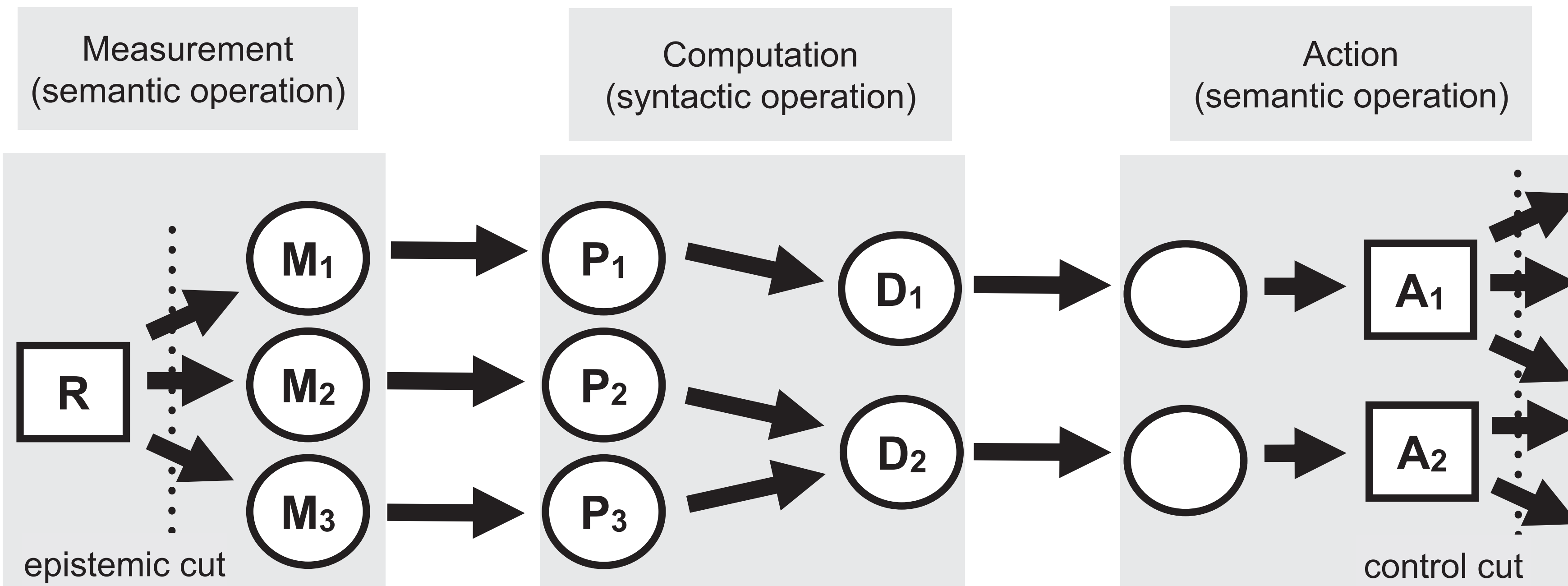

HERTZIAN COMMUTATION DIAGRAM
Formal procedures
initial conditions
S_0
Formal model
prediction
S_p
S_1
observed outcome
explicate realm of symbolic descriptions & operations
INITIAL MEASUREMENT
FINAL MEASUREMENT
Natural system
implicate realm of nonsymbolic processes
Physical process

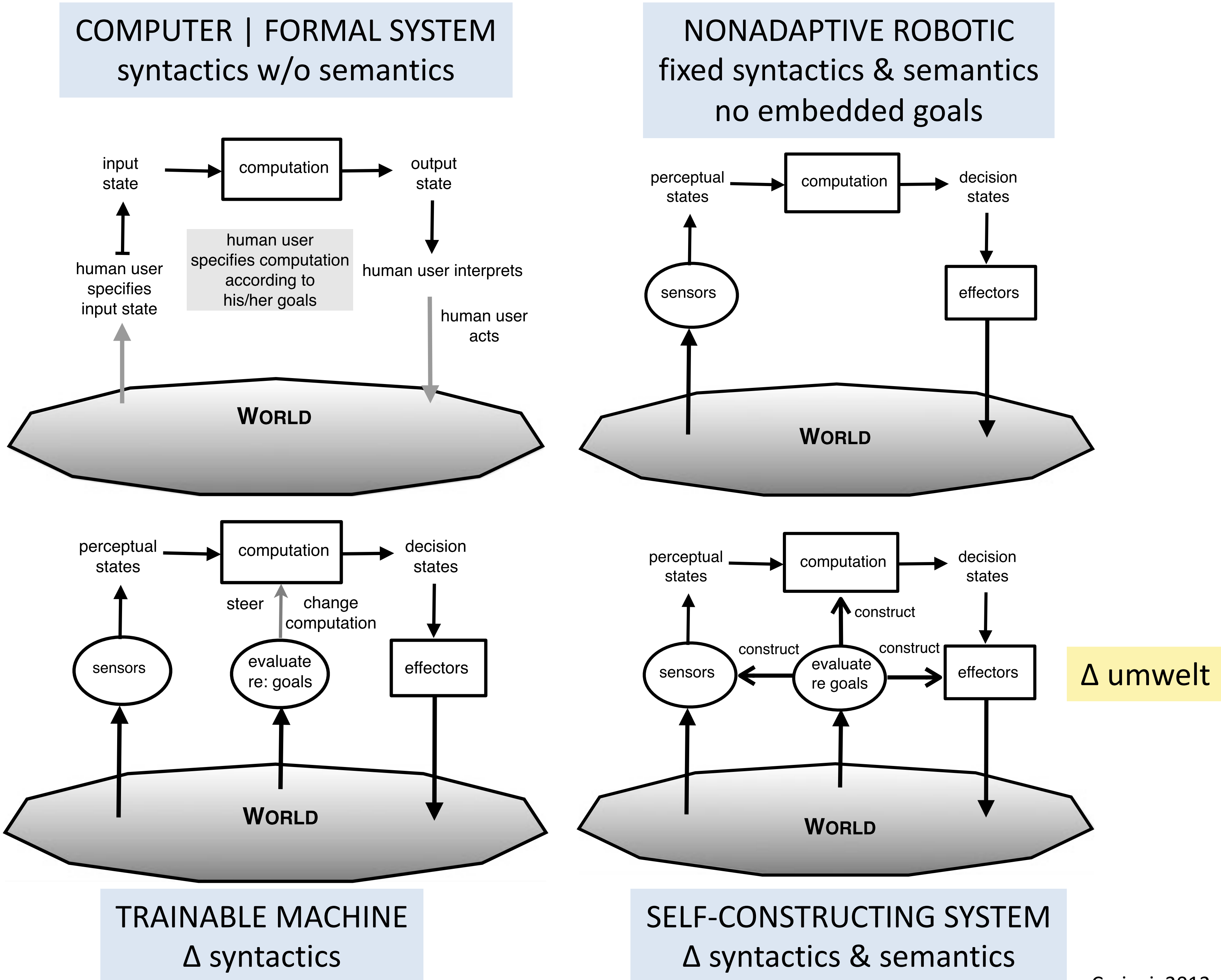

ROSEN MODELING RELATIONS
Formal procedures
prediction anticipation
explicate realm of symbolic descriptions & operations
Formal model
ENCODING measurement
DECODING action
Natural system
implicate realm of nonsymbolic processes
Physical process

State-transition structure of sign-mediated operations

What distinguishes a "measurement" operation from a "computation"? Contingent vs. Determinate STs

How would we recognize such operations in natural and unknown artificial systems?





Cariani, 2012

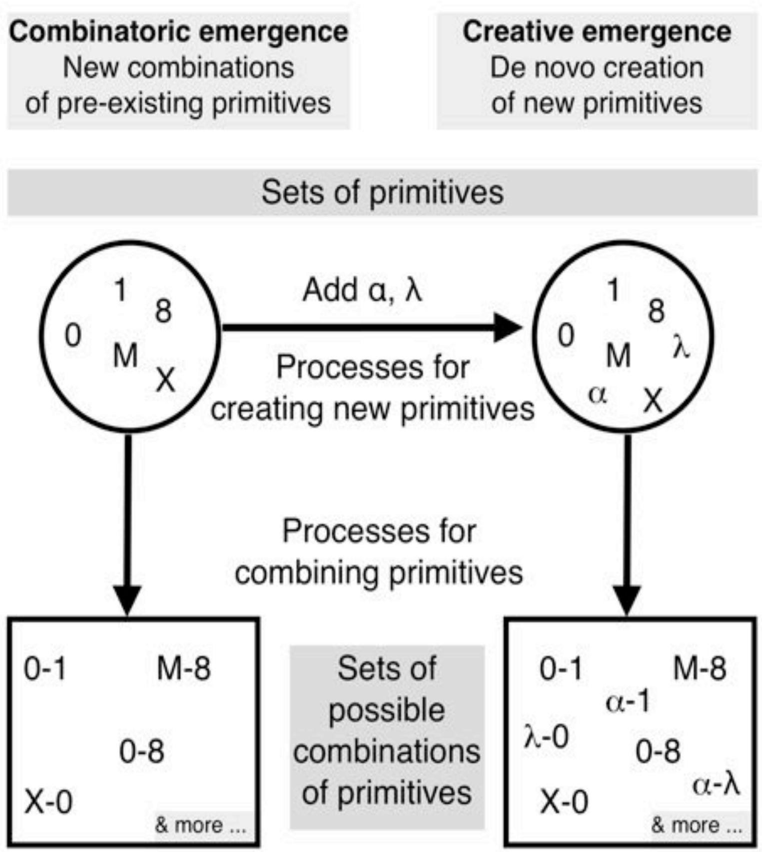
Types of semiotic creativity (semiogenesis)

Combinatoric creativity
(new combinations of existing primitive distinctions)
new syntactic, semantic, pragmatic linkages

Emergent creativity
(*de novo* construction of new primitive distinctions)
formation of new categories, dimensional increase

Piaget's types of adaptivity:
Assimilation (Δ within schemas)
Accommodation (new schemas)

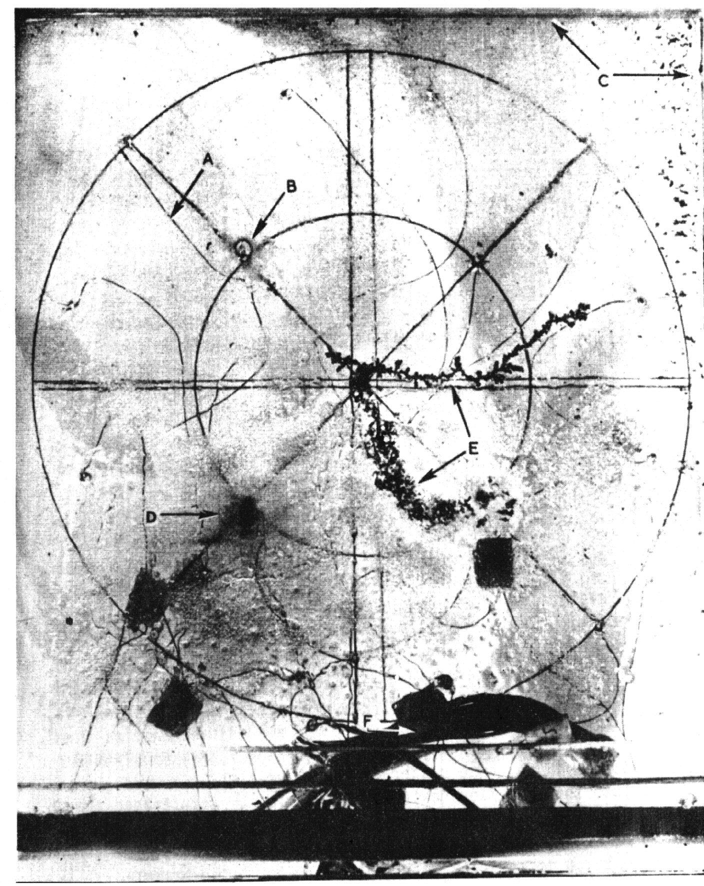
COMBINATORIC CREATIVITY
New combinations of existing primitives
VS.
EMERGENT CREATIVITY
Creation of new primitives



Closed
possibility-space

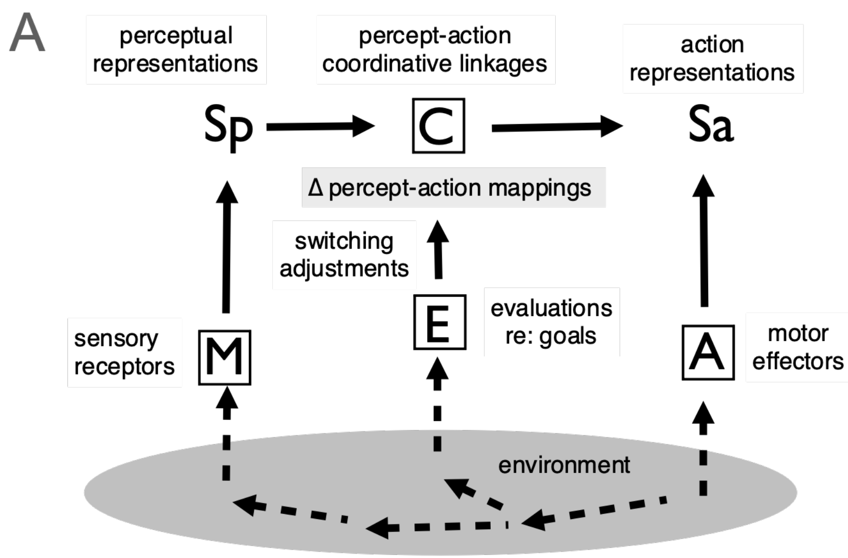
Open
possibility-space

PASK'S ELECTROCHEMICAL DEVICE (1959)
"Organic analogues to the growth of a concept"
Open-ended evolution of new sensing capabilities

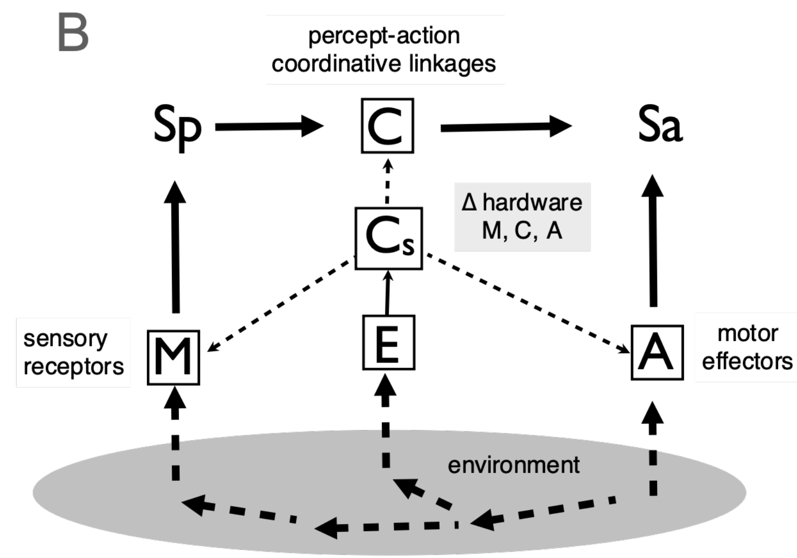


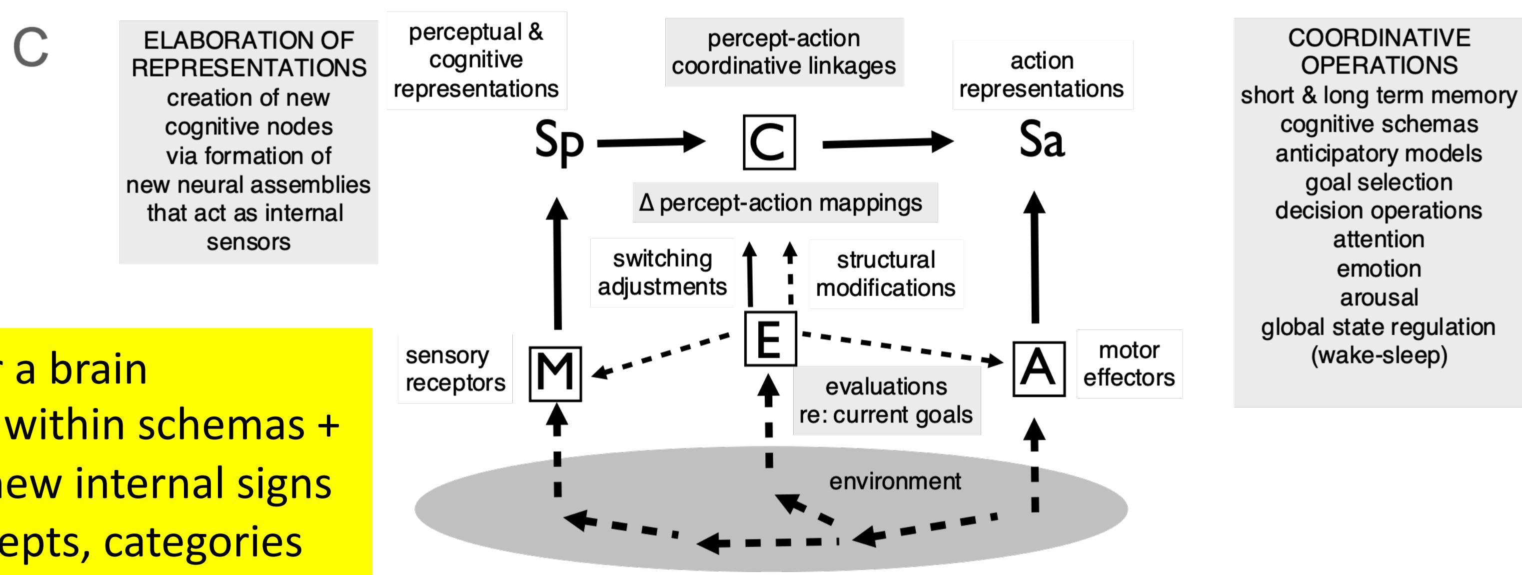
ADAPTIVE & SELF-CONSTRUCTING SYSTEMS

Trainable machines (adaptive percept → action)



Self-constructing hardware



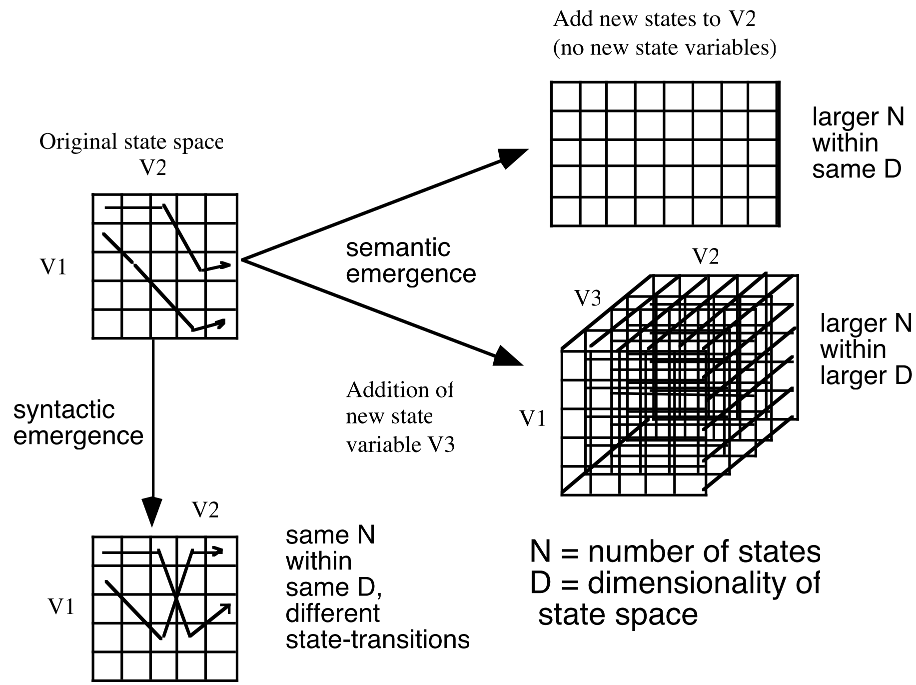


Design for a brain
Switching within schemas +
Creating new internal signs
New concepts, categories

Operational, epistemological definition of functional emergence

Emergence-relative-to-a-model (Rosen, Cariani)

How do we recognize when a system has evolved a new distinction?



An empirical, systems theoretic approach. Observer must first have a model that fully predicts the ST behavior of the observed material system in its initial state. The system then runs, changes its internal structure, and hence its ST behavior.
Combinatorial emergence: behavior can still be predicted in terms of existing phase-space, albeit with different trajectories.
Creative emergence: prediction of behavior requires the observer to employ new observables in order to recover predictability.

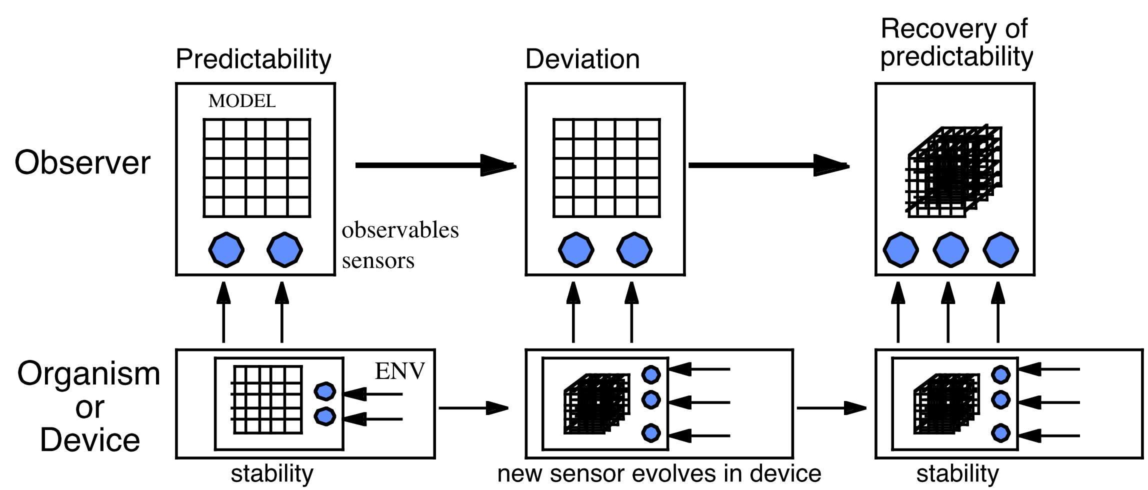
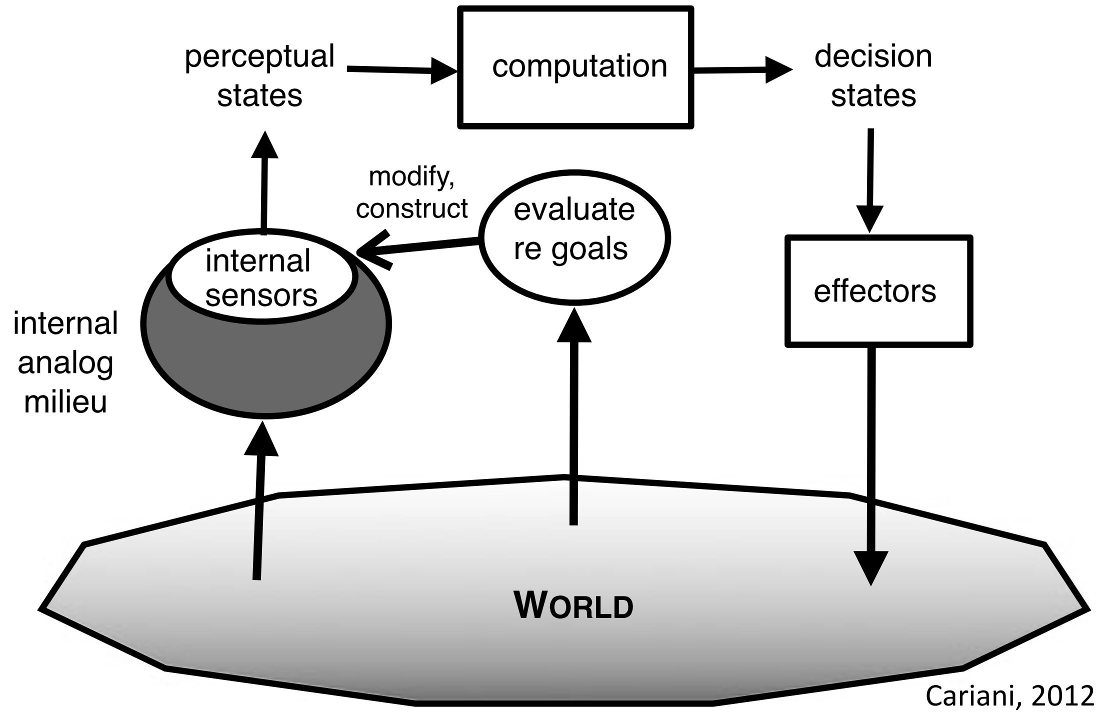


Fig. 15.5 Emergence relative-to-a-model. What changes need to be adopted by an observer in order to continue to predictively track the behaviour of an evolving, complexifying system?

Fig. 15.6 Creation of new semantic primitives by means of internal sensors. Neural assemblies play the role of sensors on an internal milieu of neural activity patterns



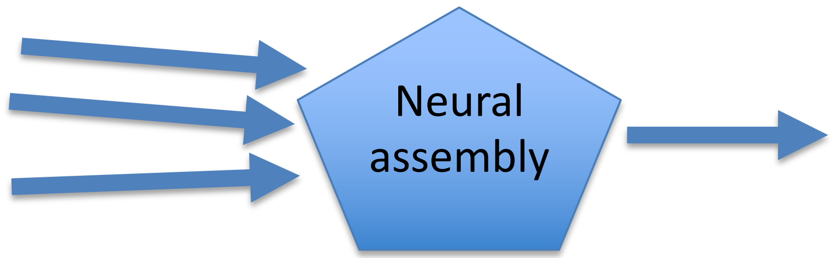
[Convolutional neural networks can be regarded as networks that adaptively choose their input representations, filters.]

Semantic pointers (for concepts, categories)
Semiogenesis: formation of a new semantic pointer by training a neural assembly

concept tags (Cariani)
perceptual symbols (Barsalou)
semantic pointers (Eliasmith)

BOTTOM-UP ACTIVATION PRODUCES CONCEPT TAGS

Signals for low-level features

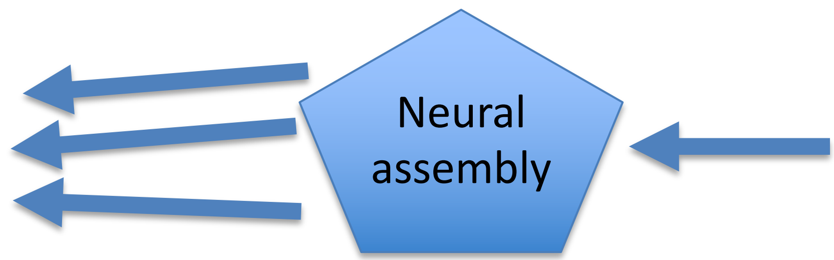


[convolution]

Signals indicating higher-level “tag”

TOP-DOWN ACTIVATION PRODUCES CONSTITUENT FEATURES

Signals for low-level features



[deconvolution]

Higher-level “tag” pattern

Recover lower-level attributes

CONTENT-ADDRESSABLE MEMORY

Quick, what does an apple have in common with fire truck?

NEUROSEMIOTICS

How patterns of neural activity realize distinctions that subserve mental functions

(sensing, perception, cognition, emotion, motivation, memory, action, attention)

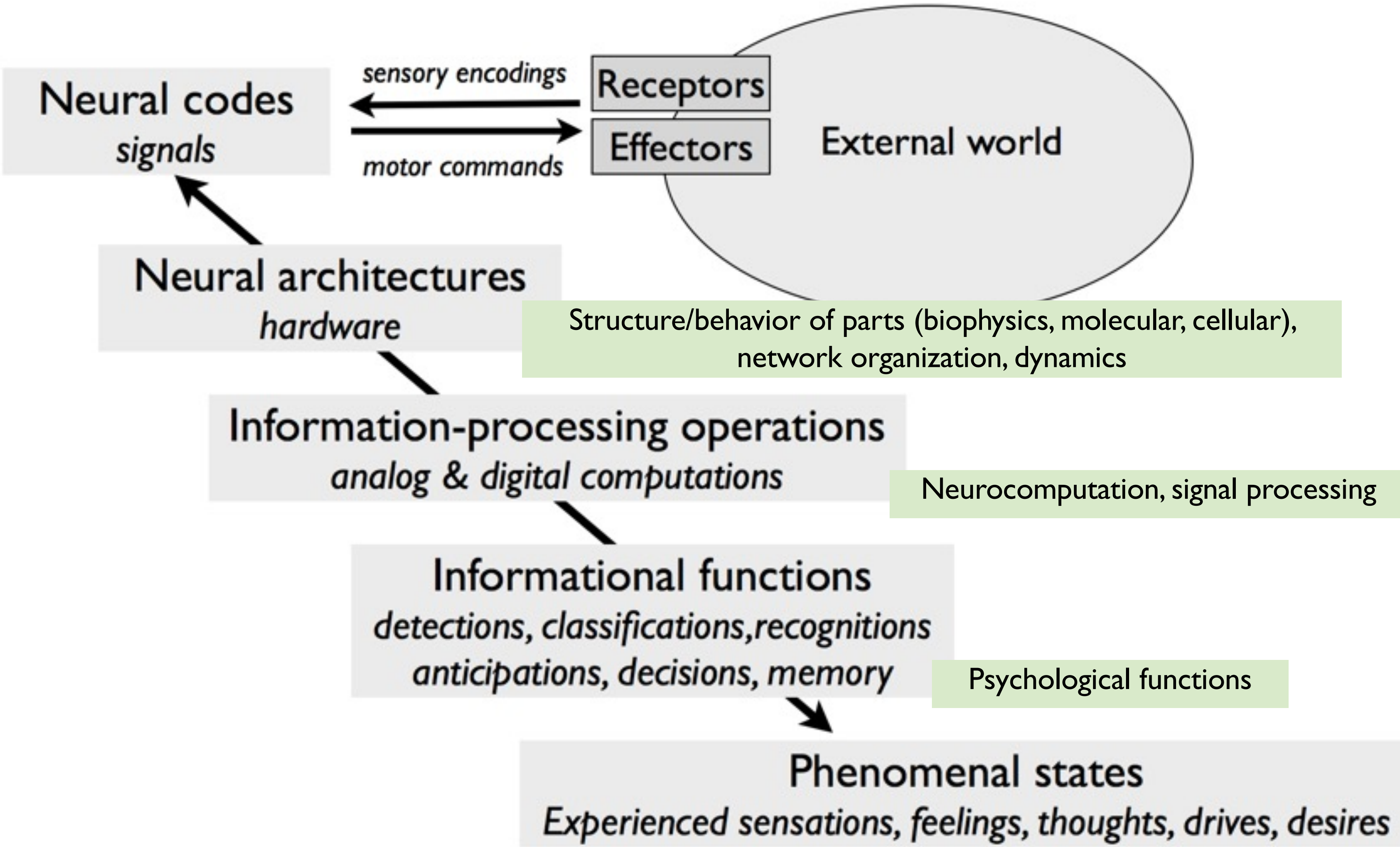
NEUROSEMIOTICS

Sign-mediated processes in nervous systems

<u>The neural coding problem</u>:
what are the "signals of the system" in the brain?

What neural differences produce differences in function? experience?

Reverse-engineering brains: What do we need to know to understand how the brain works as an informational system?



Neural coding

How are distinctions encoded in spike trains?

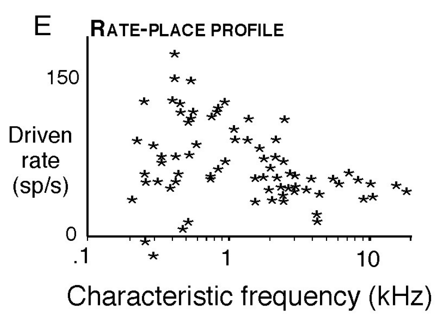
Major types of codes:

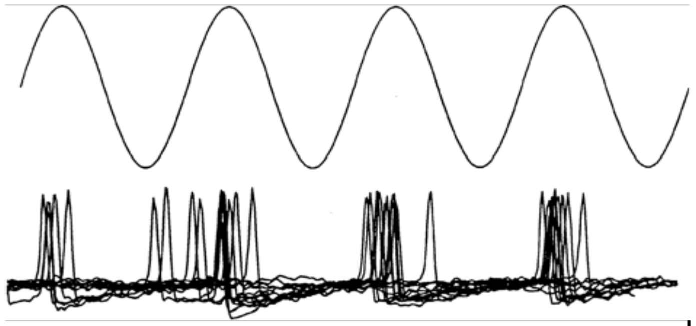
Channel codes -- which neurons respond

Rate-channel codes -- which neurons fire most

vs.

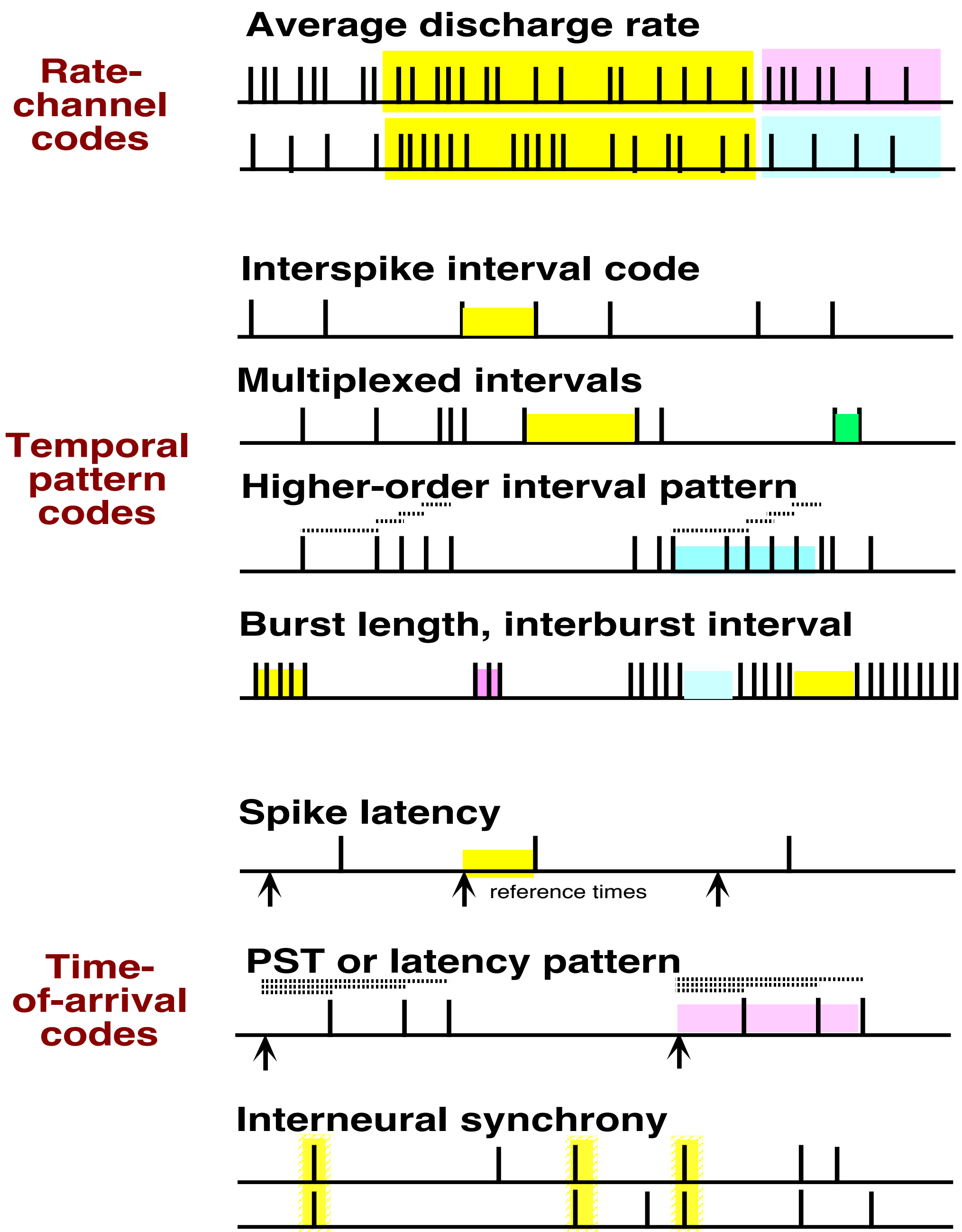
Temporal codes – temporal patterns of firing





Javel

Neural pulse codes



Neurons are cells specialized for sending & receiving signals

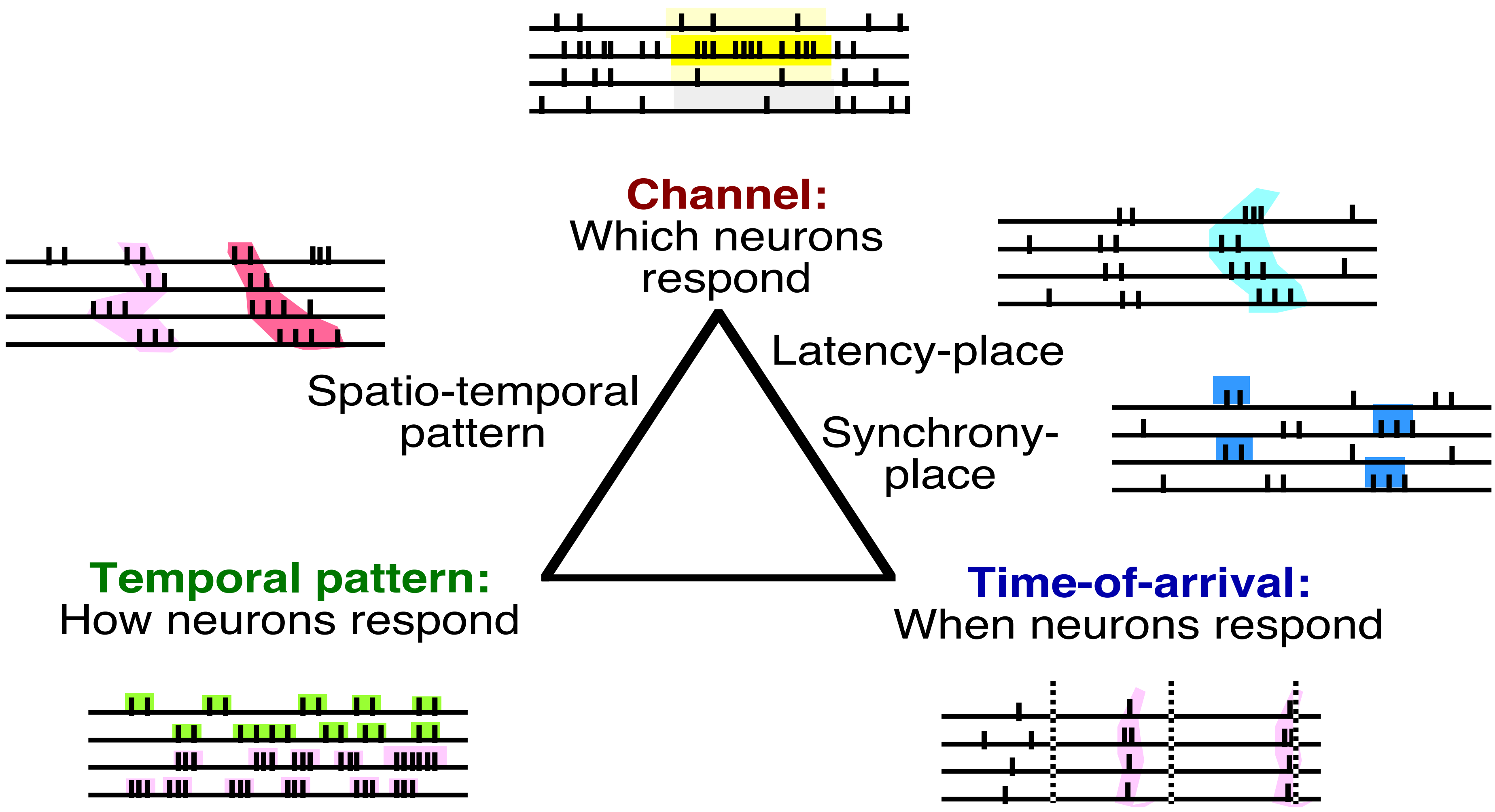
Codes are defined in terms of their functional roles

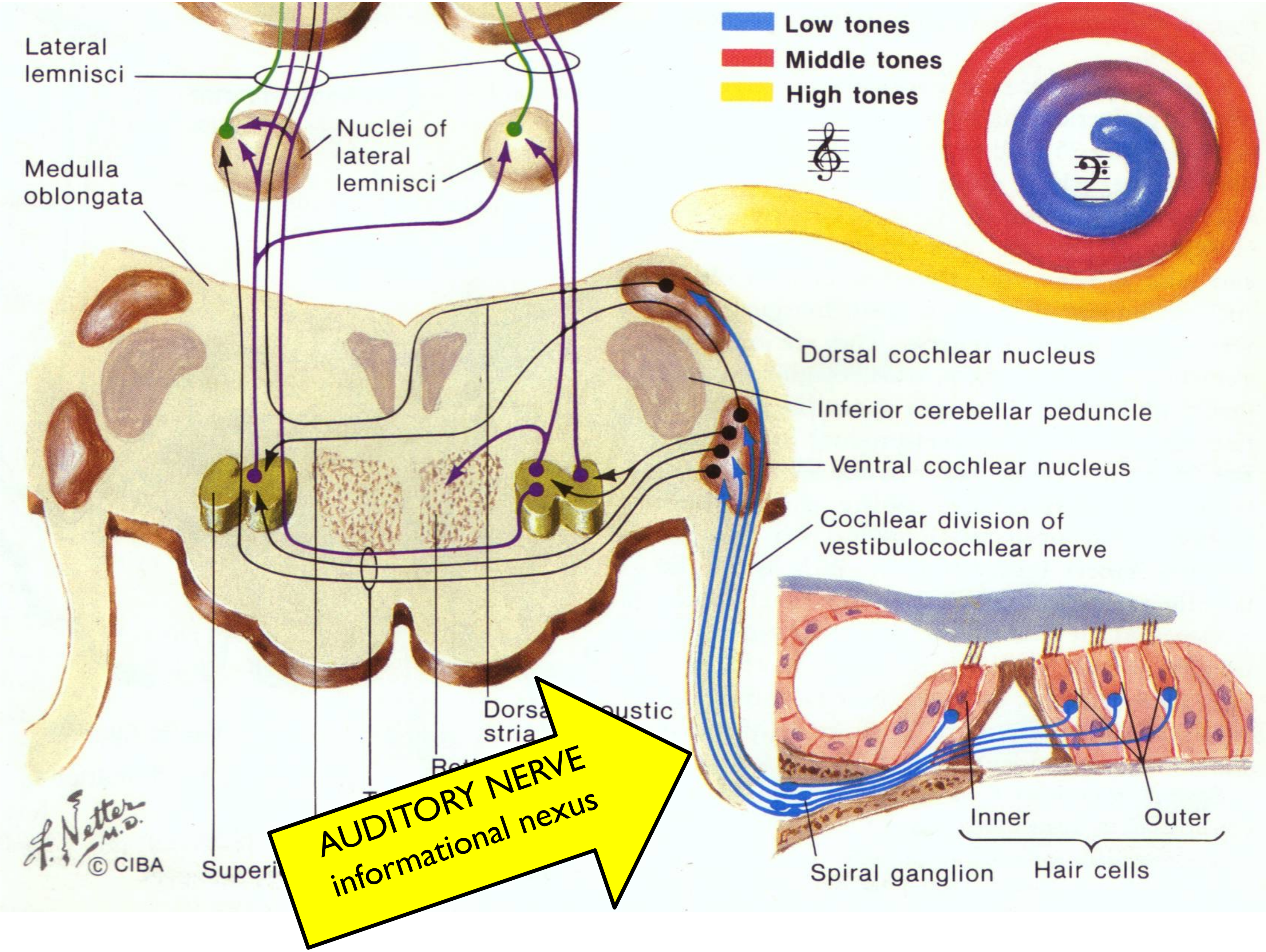
What spike train messages have the same meanings?
(functional equivalence classes)

What constitutes "a difference that makes a difference"?

Temporal codes are neural codes in which timings of spikes relative to each other are essential to their interpretation.

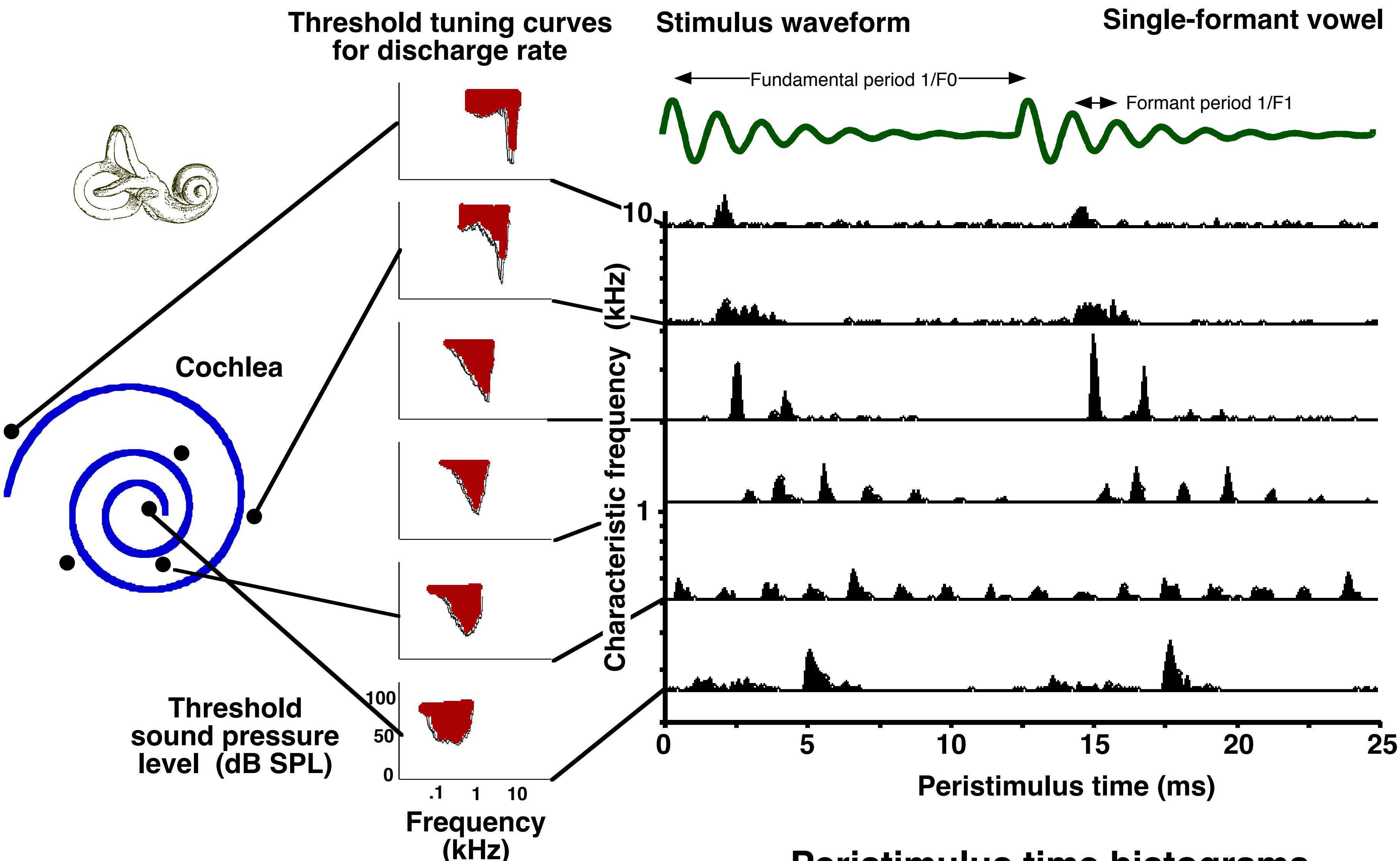
Three complementary types of neural codes





Frank H. Netter, Medical illustrator

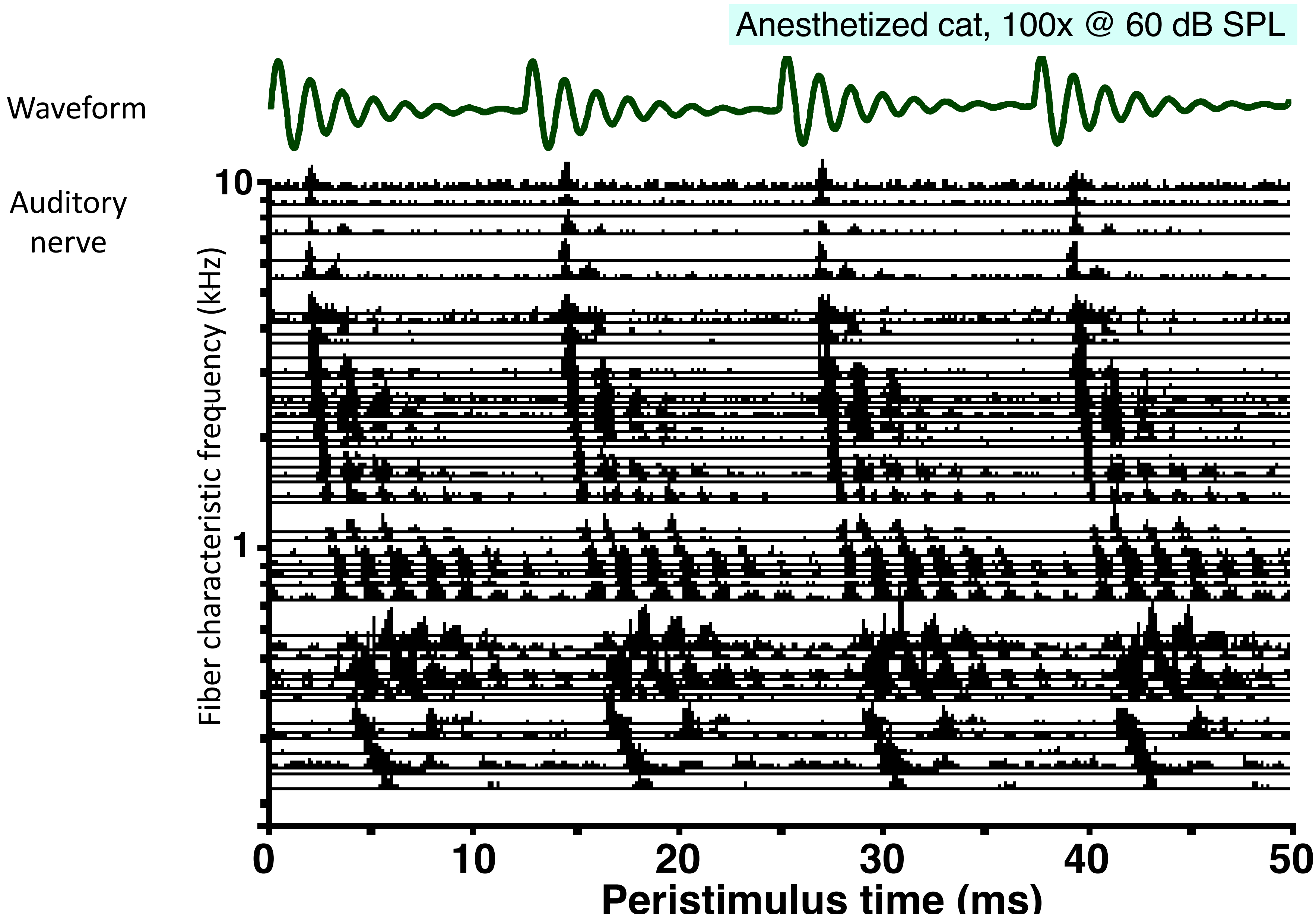
Frequency and time in the auditory nerve



Peristimulus time histograms

(100 presentations at 60 dB SPL)

Temporal coding of sound in the auditory nerve
Spike timings are correlated with stimulus waveforms

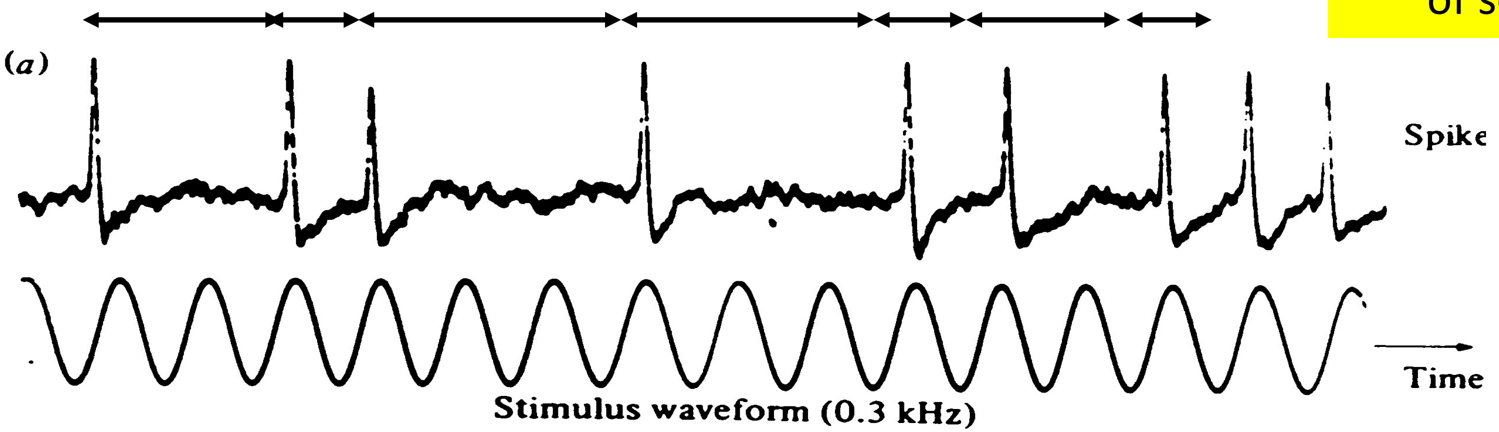


Sounds impress their temporal structure on neural firing patterns
Interspike intervals in the auditory nerve encode stimulus periodicities

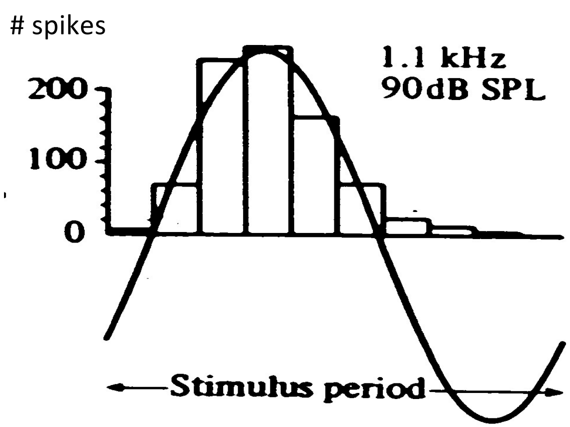
Iconic, temporal representation of sound

Phase-locking of auditory nerve fibers to a 300 Hz pure tone

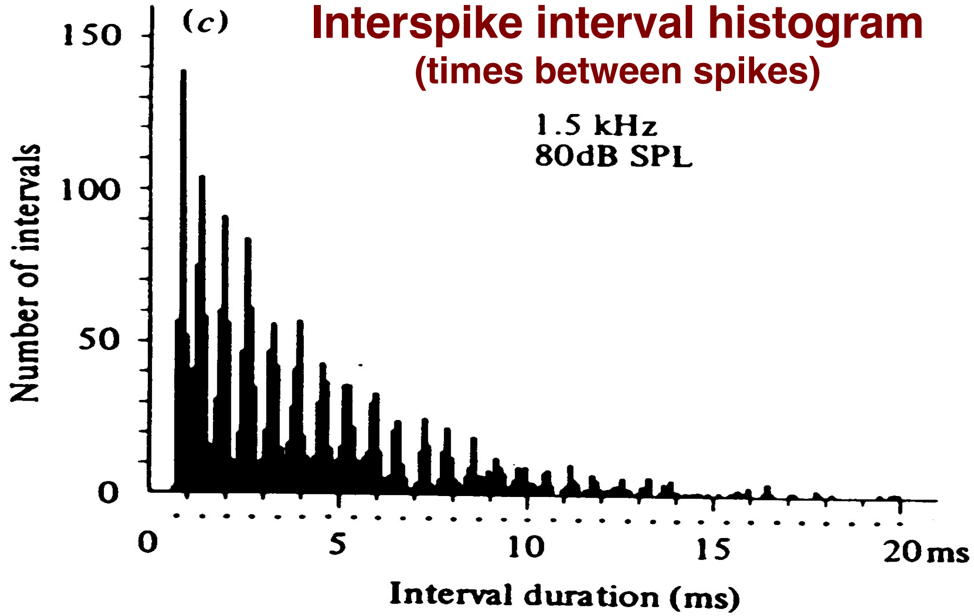
Spike train



Period histogram

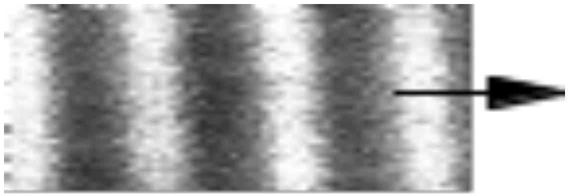


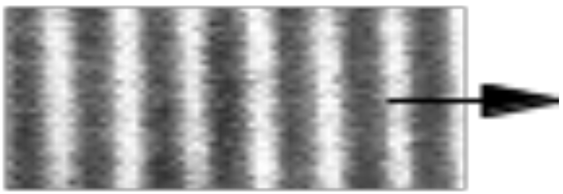
Interspike interval histogram
(times between spikes)

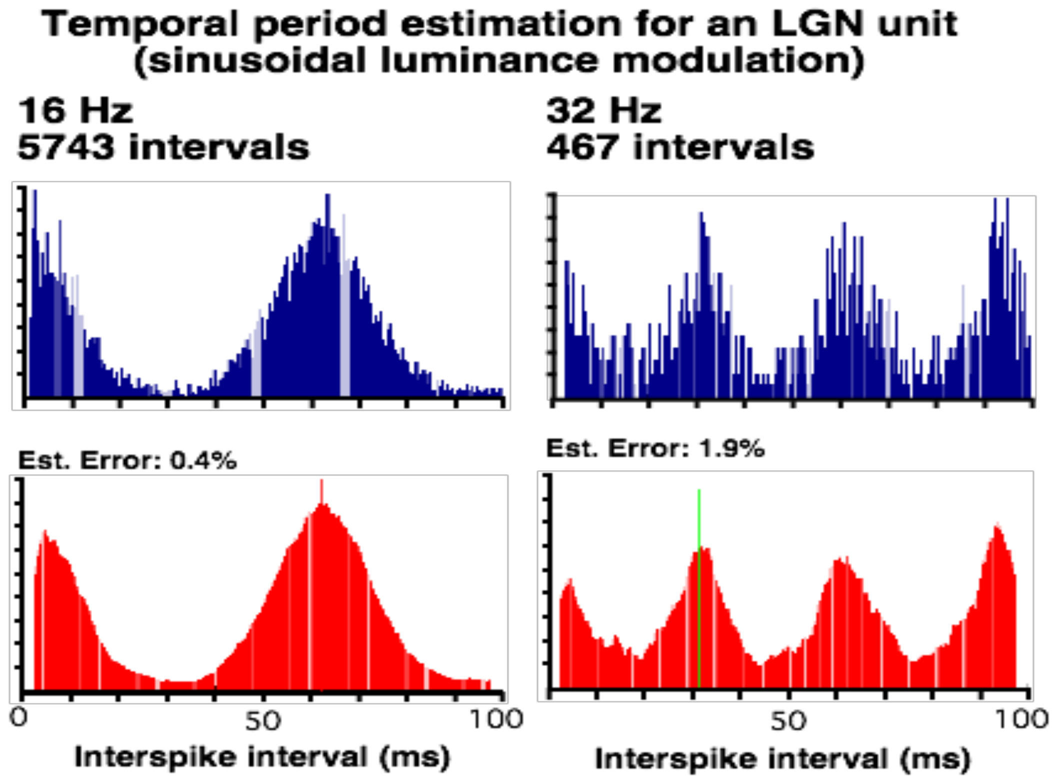


Evans, 1982

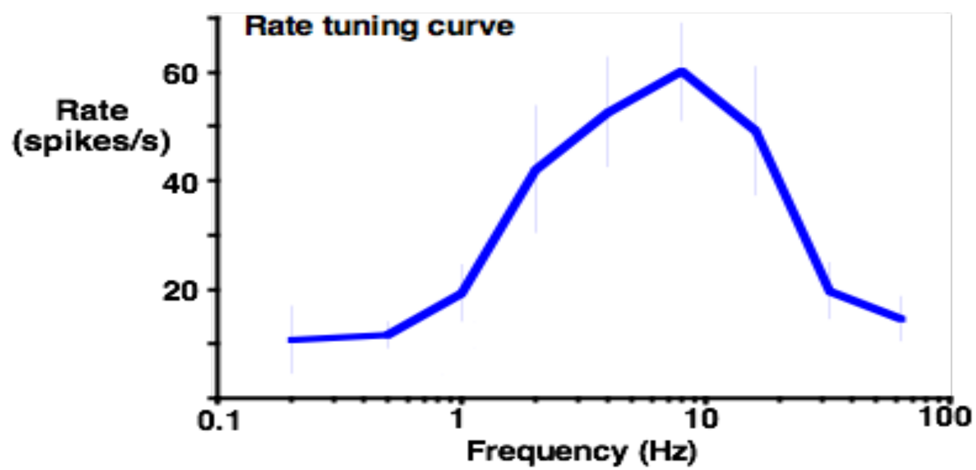
Phase-locking in visual thalamus (LGN)







Stimuli: Drifting sinusoidal gratings

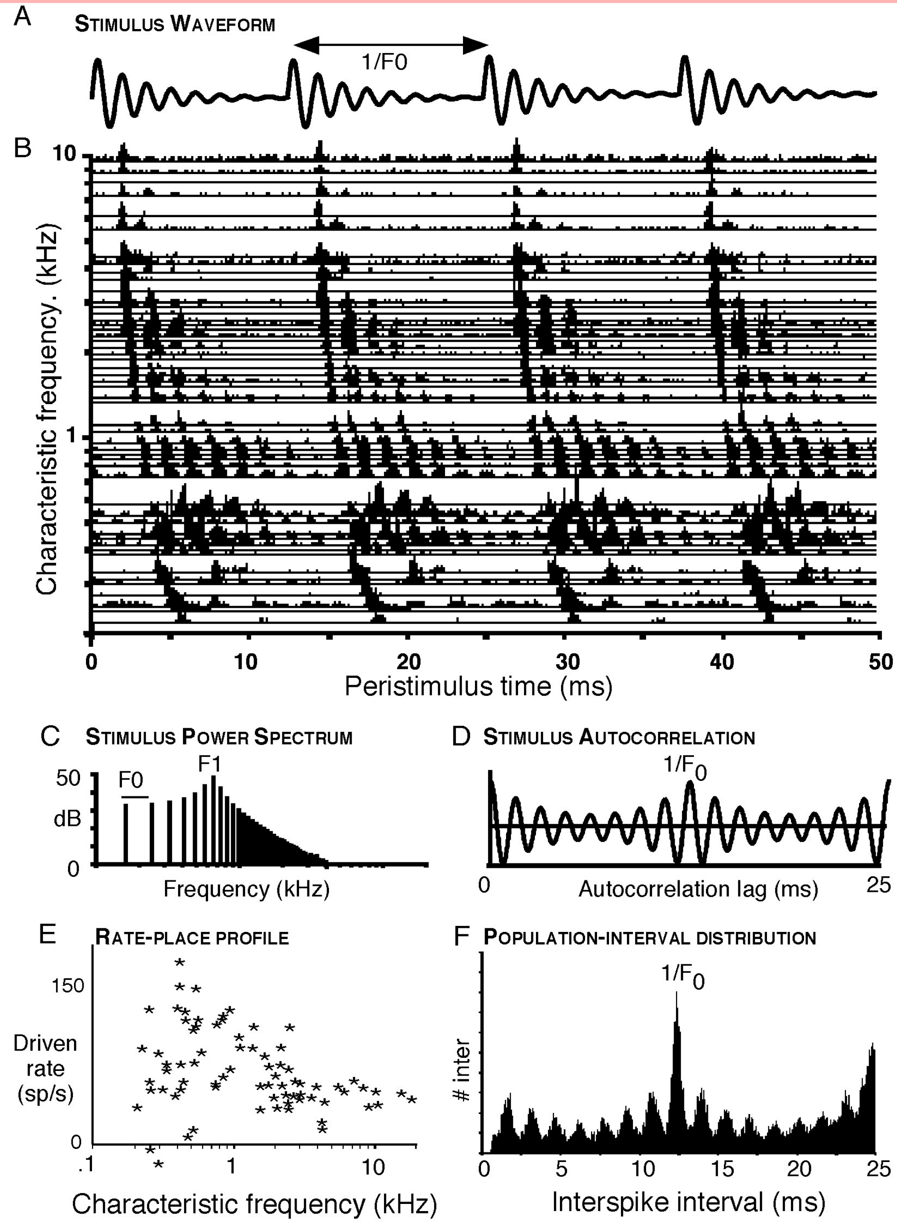


Raw spike train data courtesy of Andrzej Przybyszewski & Dan Pollen

Neural code for musical pitch: Global interspike interval representation

Based on distribution of all-order interspike intervals across all fibers in the auditory nerve

- Pitch = the predominant interval, interval pattern
- Pitch strength (salience) =
- % pitch-related intervals



Explains most pitch perception:

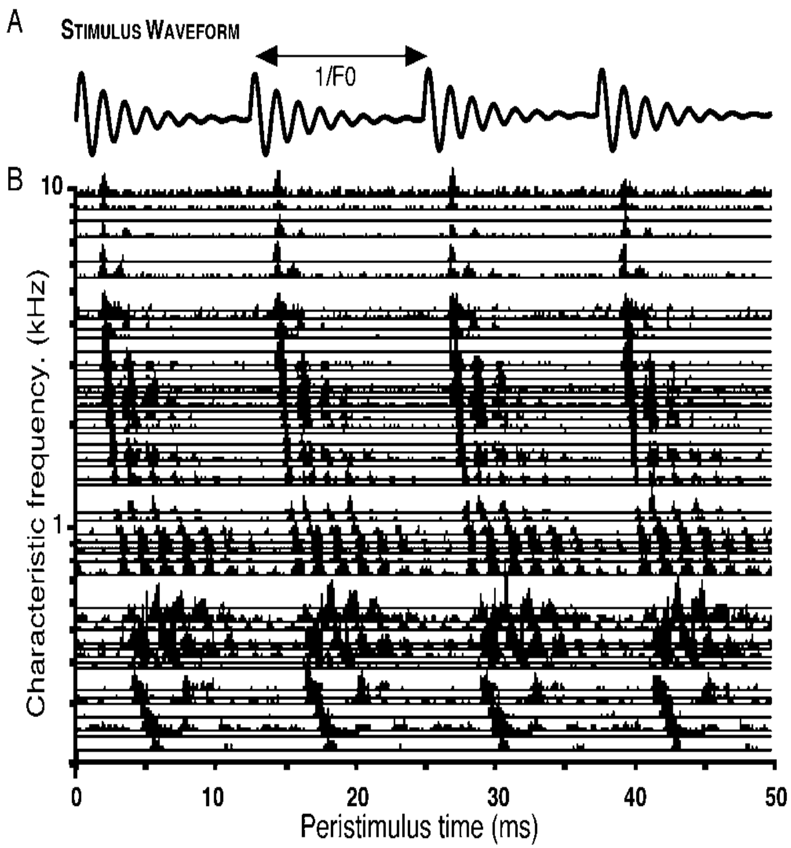
- ◎ pure tones < 5kHz
- ◎ harmonic complexes
- ◎ missing fundamentals, F0 pitch
- ◎ pitch equivalences
- ◎ level & phase invariances
- ◎ dominance region, repetition pitch
- ◎ pitches of inharmonic complexes

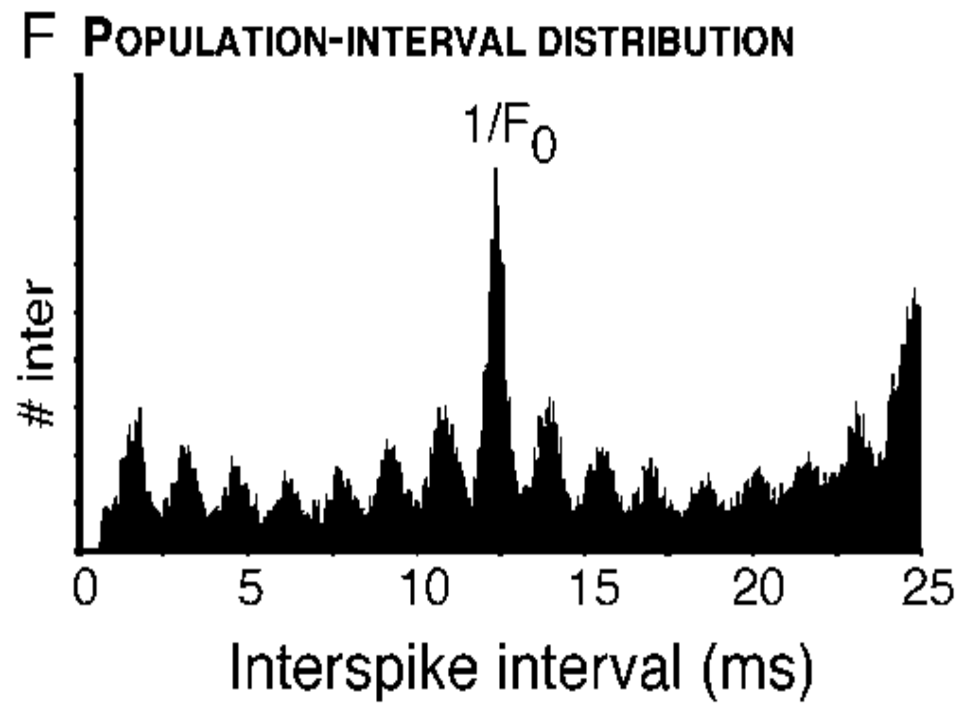
General autocorrelation-like representation:

encodes spectral aspects of timbre (e.g. vowels)

PREDOMINANT INTERSPIKE INTERVALS ACCURATELY PREDICT PITCHES HEARD

- Pitch = the predominant interval or interval pattern
- Pitch strength (salience) = % pitch-related intervals





Emergence of a pitch at the missing fundamental (F0)

HARMONICS 3-12 OF 200 HZ
ADDED SEQUENTIALLY

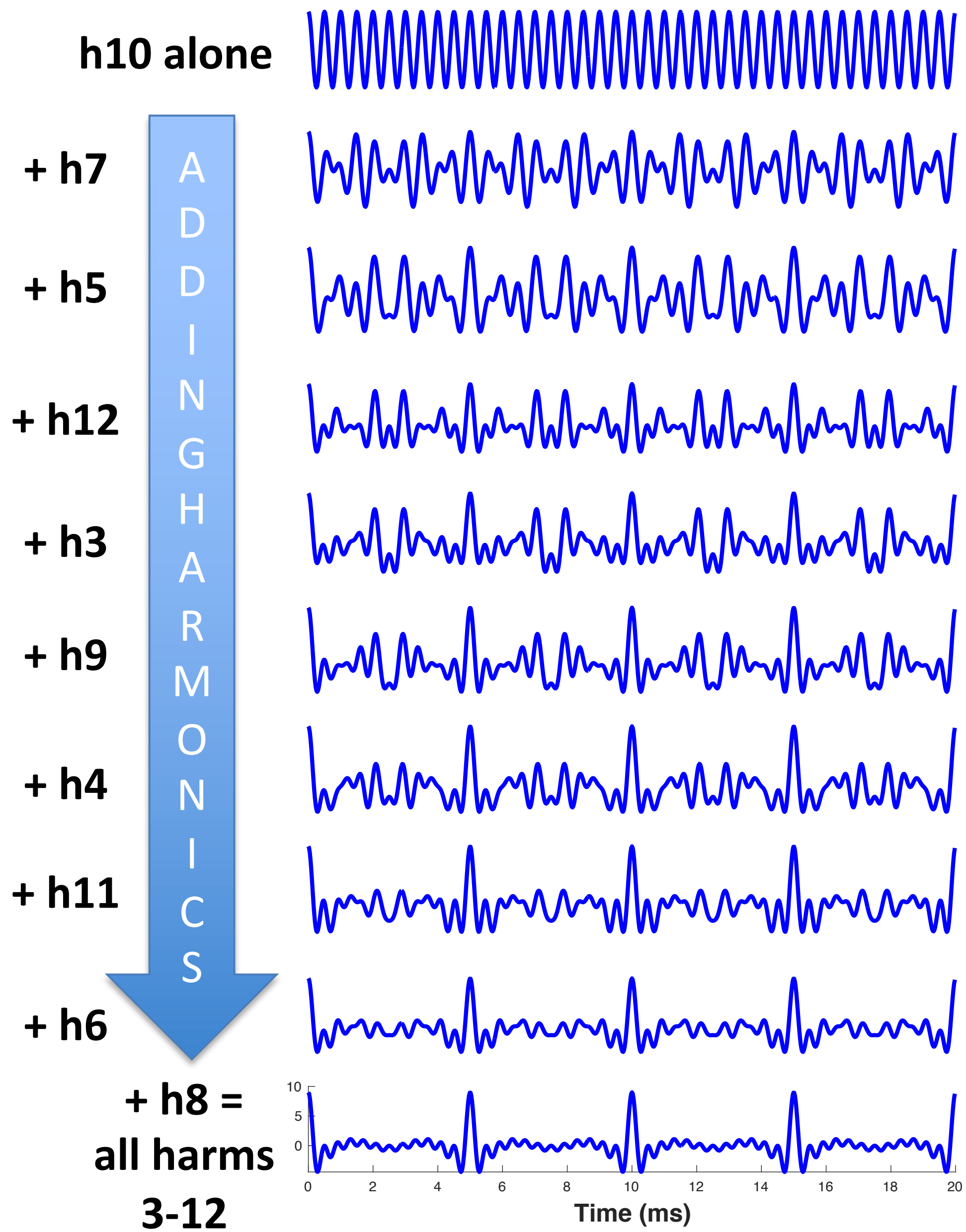
First, an arbitrary sequence of individual harmonics, played by themselves
10-7-5-12-3-9-4-11-6-8

Then harmonics added into a complex and all played.

The pitch at F0, the fundamental and first harmonic emerges as harmonics are added into the complex.

F0 = 200;
harms = [10 7 5 12 3 9 4 11 6 8];

Waveforms and Autocorrelation functions



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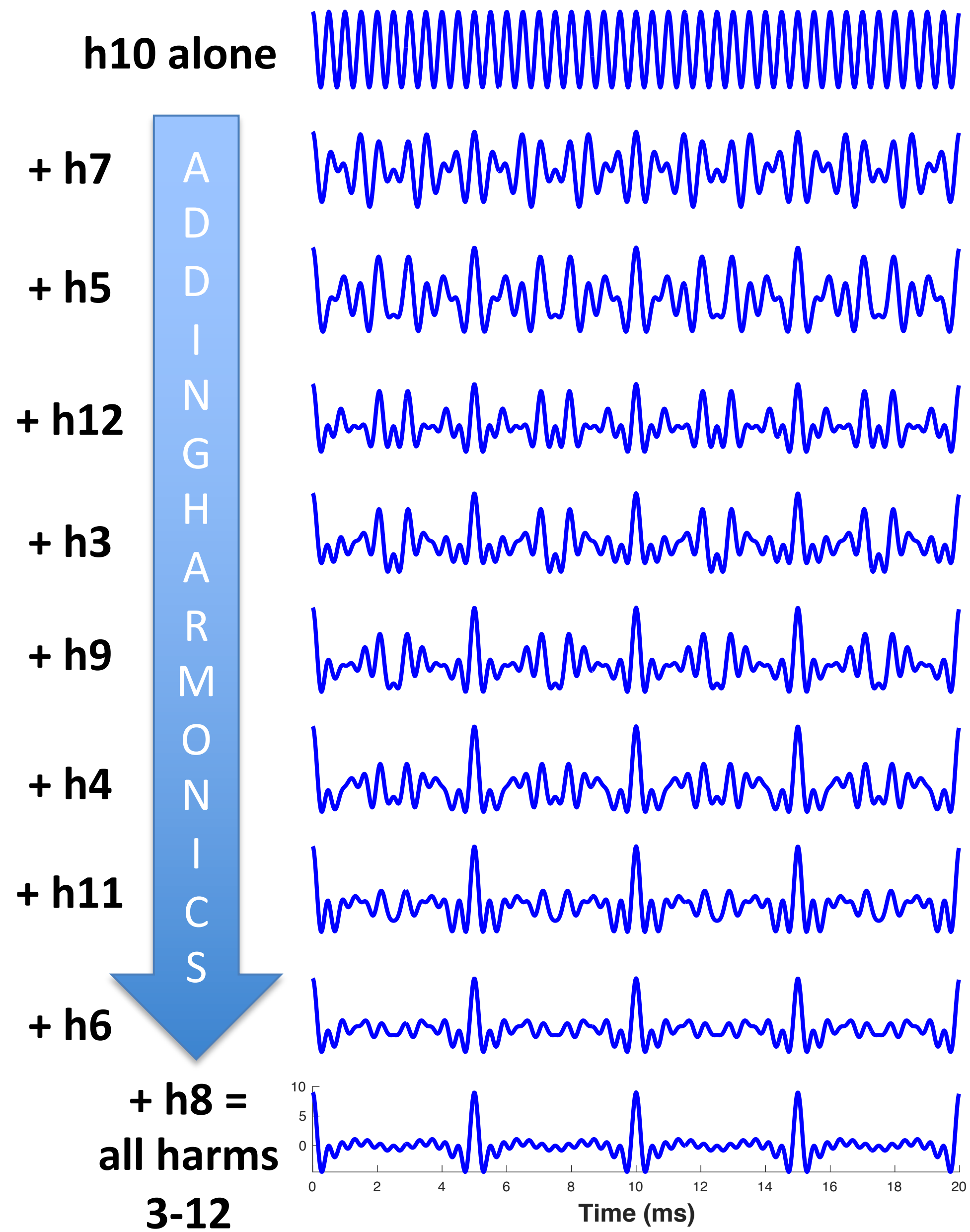


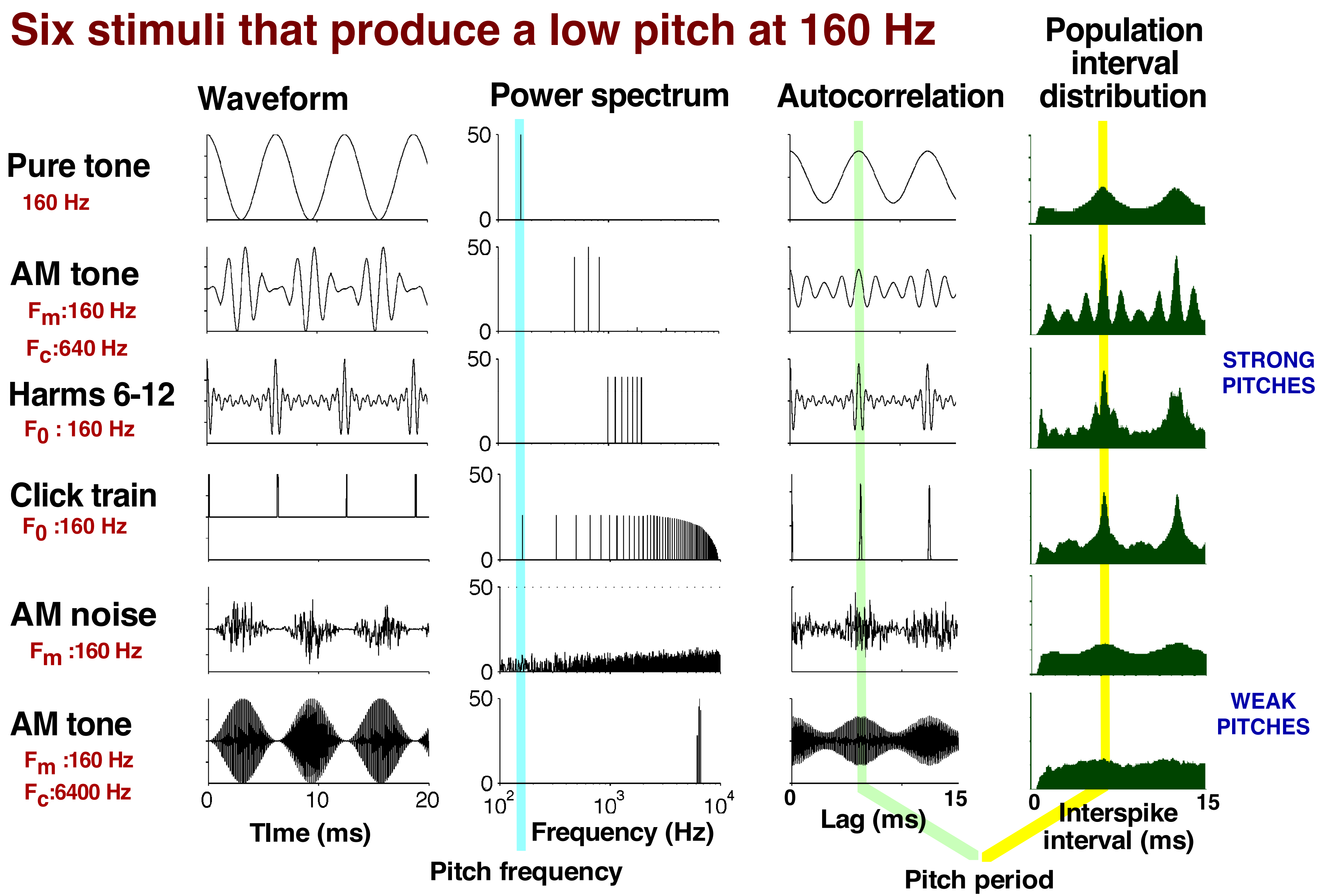
Population-based interspike interval models explain almost all pitch perception, for *f*, F0 < 4kHz

◎pure tones < 5kHz
◎harmonic complexes
◎missing fundamentals, F0 pitch
◎pitch equivalences
◎level & phase invariances
◎dominance region, repetition pitch
◎pitches of inharmonic complexes
◎pitches of repetition noise and AM noise
◎Spectral edge pitches

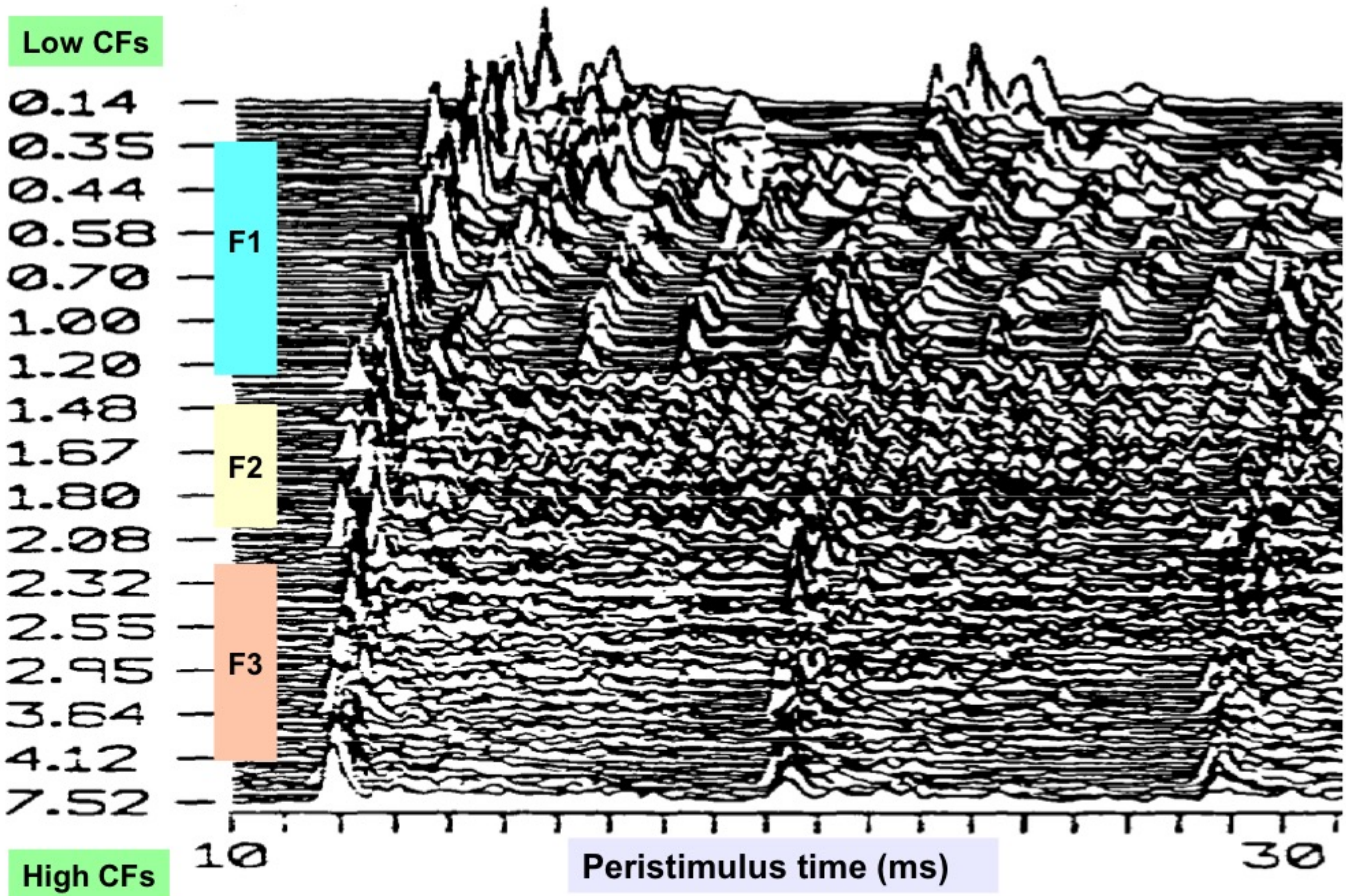
Only 3 clear exceptions

1. Pitches of high-frequency (> 5 kHz) pure tones
2. Click-rate pitch @ 2*F0 (for alternating polarity, near miss)
3. Zwicker tone afterimages (probable central origin)

Pitch equivalence classes
(keep the percept constant, identify neural response invariances)



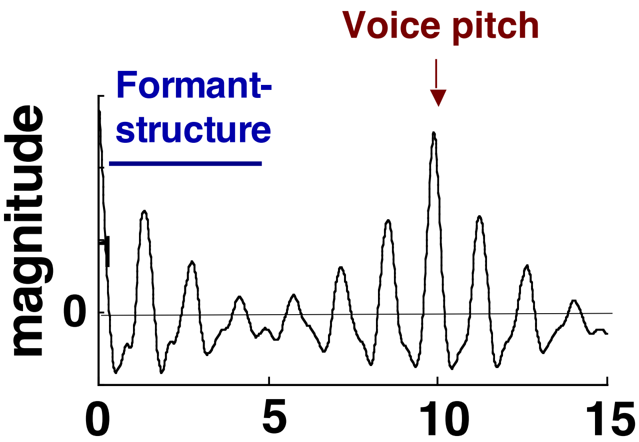
Temporal coding of /da/ (Seeker-Walker & Searle; Sachs & Young data)



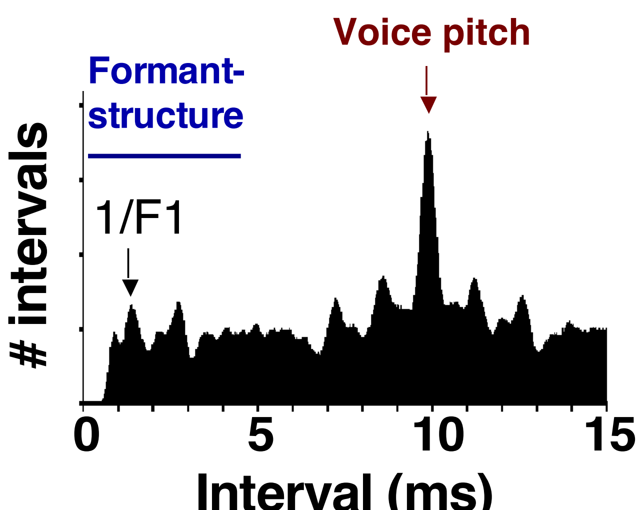
Vowels

Population-interval coding of timbre (vowel formant structure)

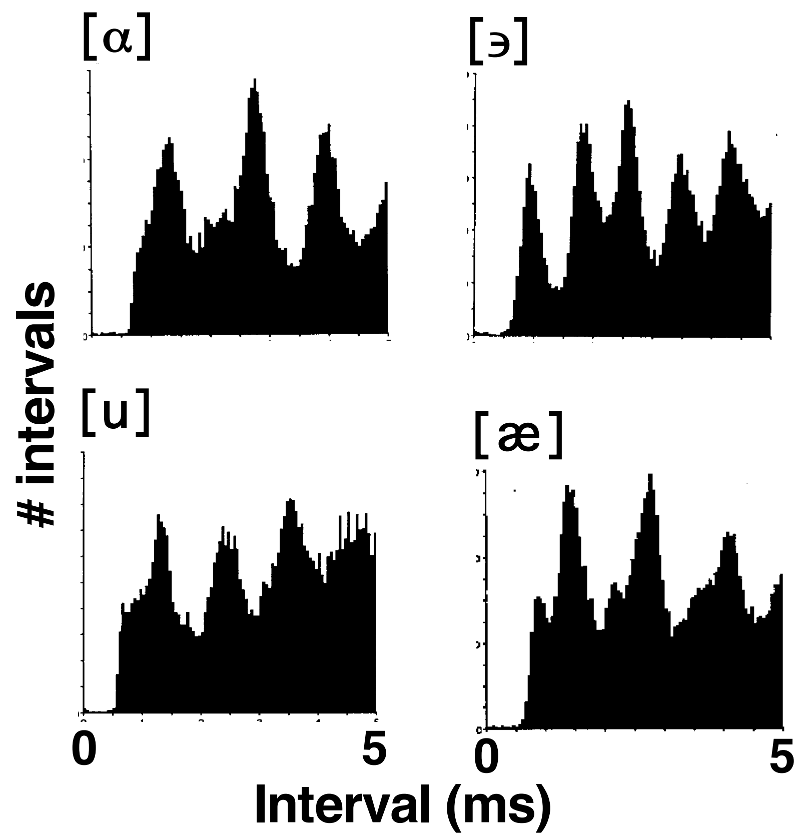
Signal autocorrelation [ae]



Population interval histogram

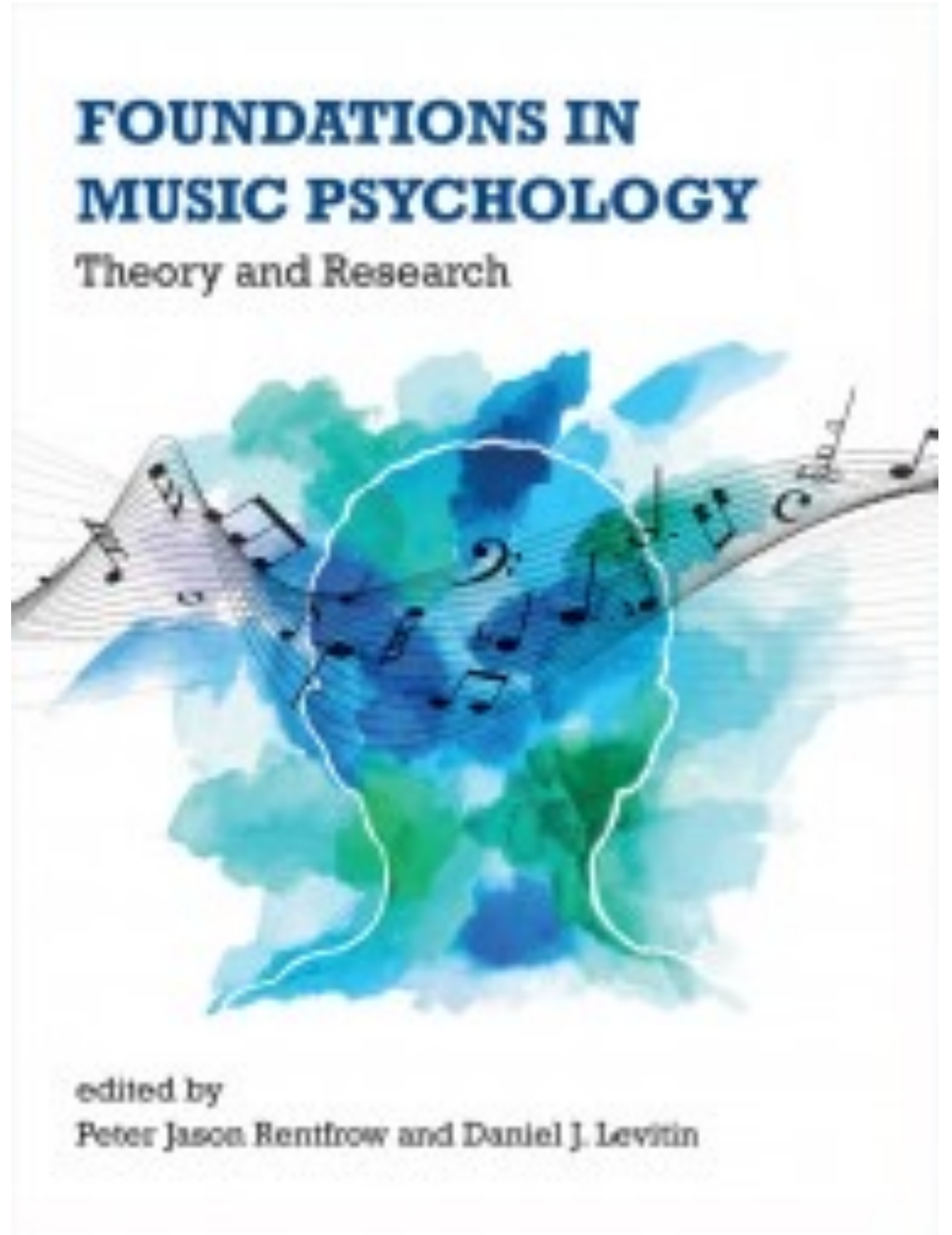


Population-wide distributions of short intervals for 4 vowels



Implications of temporal coding for music perception (musical tonality)

Peter Cariani (2019)
CHAPTER 5
Musical Intervals, Scales, and Tunings: Auditory Representations and Neural Codes
(pp. 149-220)



MIT Press, 2019

Psychological uses of music (some categories)

- **Drive motor systems** (dance, work, march)
- **Modulate moods, induce emotions** (emo music)
- **Facilitate motivation** (inspirational music)
- **Cognitive interest** (complexity, novelty, fascinating music)
- **Arousal control** (lullaby, relaxation, EZ listening, pump-up)
- **Memory** (nostalgia music, musical mnemonics)
- **Masking/distraction** (unwanted thoughts, feelings, pain)
- **Excitement** (virtuosity, awe-inspiration)
- **Entertainment/diversion/immersion**
- **Aesthetic interest** (beauty)
- **Identity assertion**
- **Gamut of social uses** (bonding, group identity/solidarity, anthems, ritual, courtship, rebellion)

The upper categories have more obvious neural correlates than the lower ones, being closer to sensory & motor surfaces.

Music, brain and time

Each musical genre is designed for only one or two primary psychological (ψ) purposes – to induce different ψ effects.

[One would not use heavy metal to calm a baby, nor a lullaby to get people dancing.]

Each musical genre uses different temporal & structural parameters to induce these effects.

[Tempo, sound levels, rhythms, melodies, tonal dynamics, orchestration/arrangement, complexity, predictability/surprise, etc.]

My working hypothesis: **Music speaks the languages of the brain, which are themselves temporal codes.** Different temporal parameters drive neural responses in manners similar to normal temporal patterns of brain activity so as to facilitate induction of desired ψ effects.

[Music intended for dancing will have tempos and rhythms similar to those of dance movements & their corresponding neural activity patterns in motor cortex]

Properties of this population-interval coding scheme in the auditory nerve

Temporal-pattern spike code

Iconic neural representation of sound

Population-based code (90k neurons)

Mass-statistical code

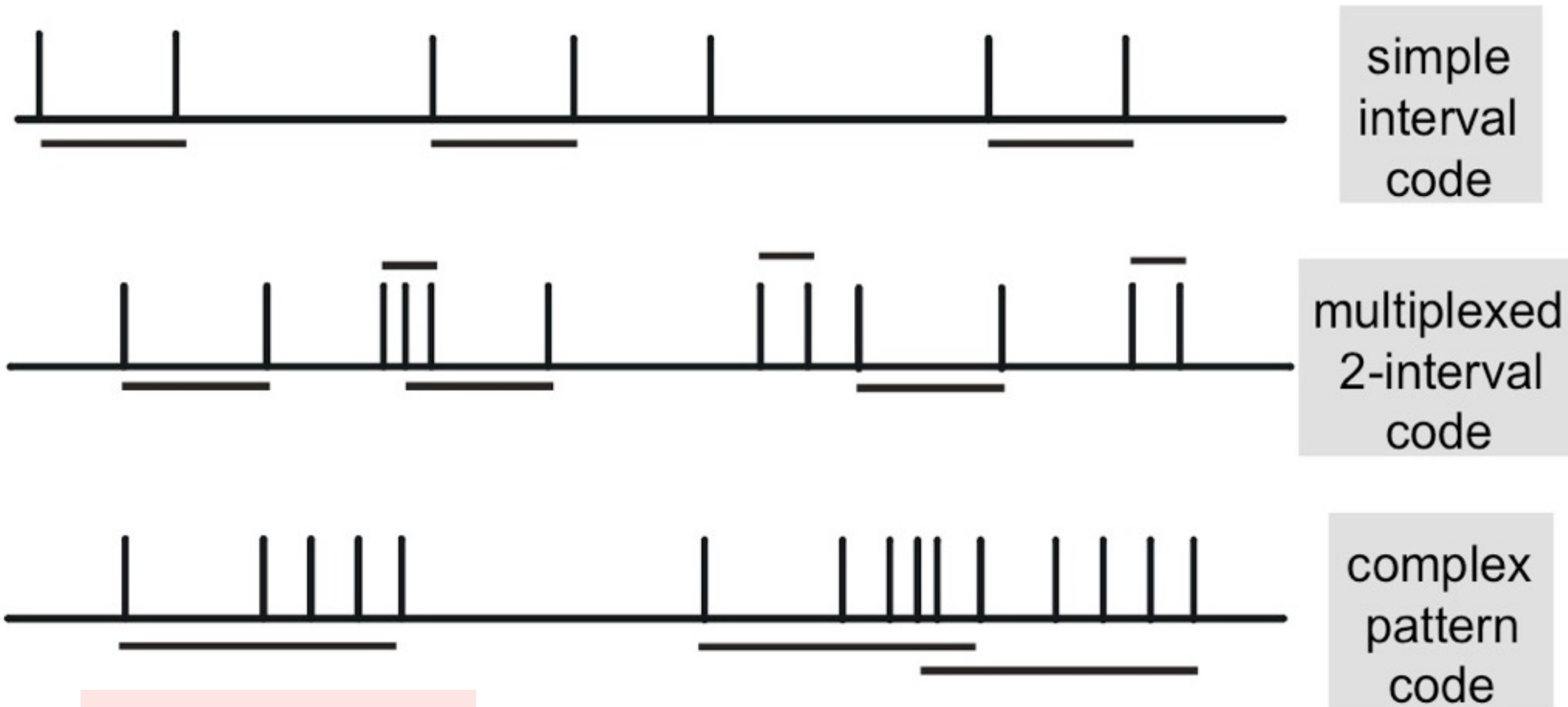
Autocorrelation-like

General-purpose, up to ~4kHz

Nonlocal: Not dependent on labelled lines

Multiplexing of multiple stimulus features (periodicity, spectrum, timbre, rhythm)

Simple and complex temporal pattern codes

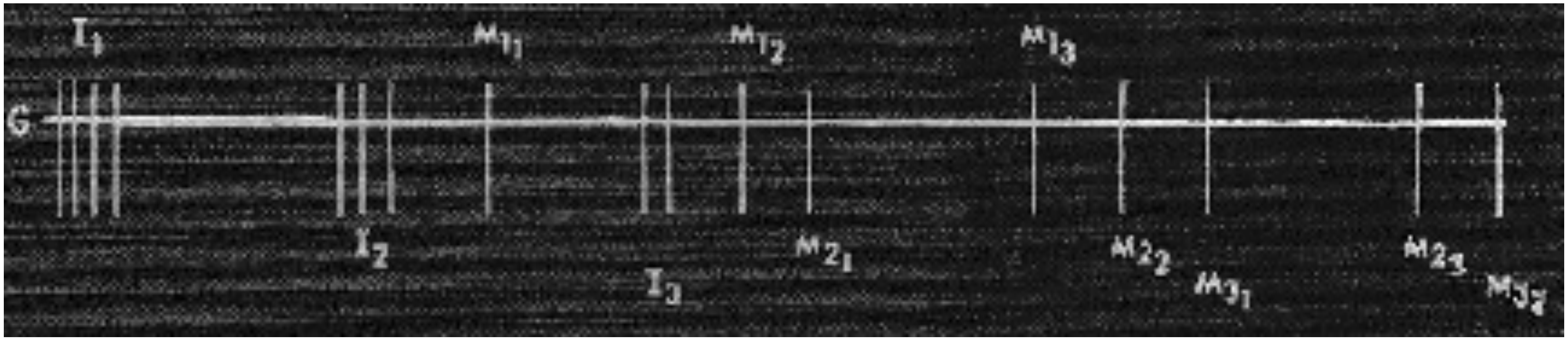


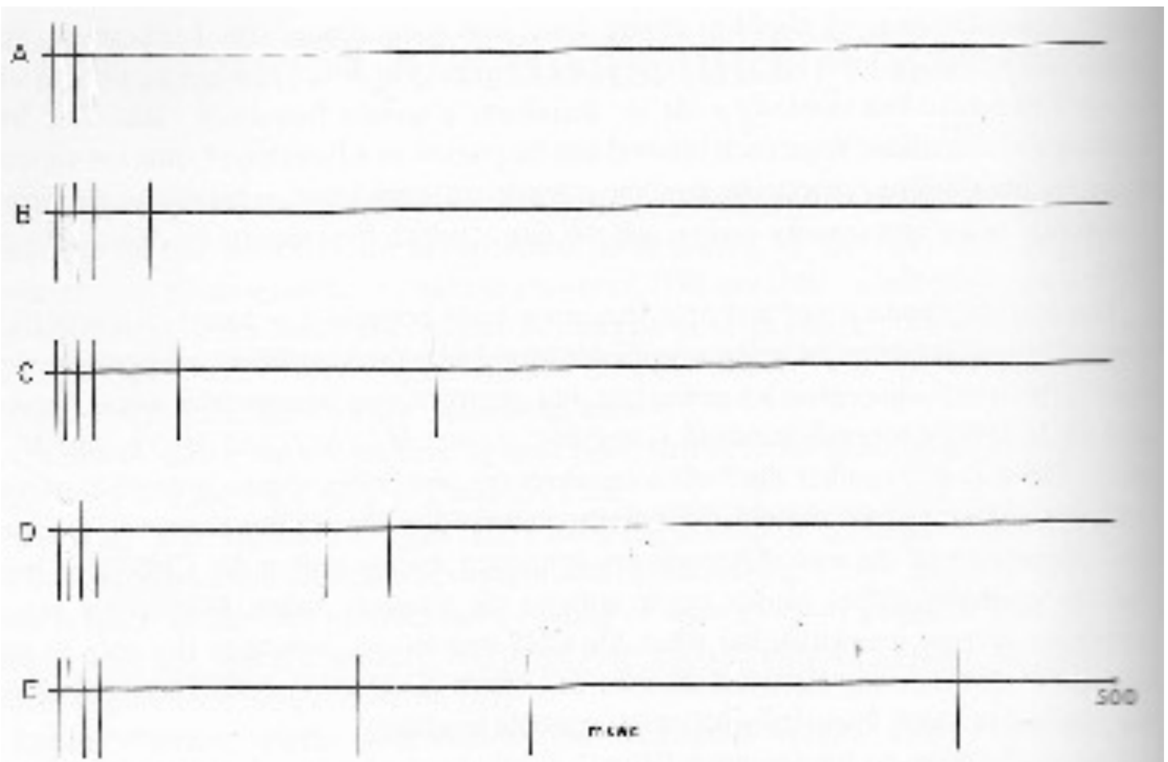
Complex temporal pulse pattern

Two multiplexed complex temporal pulse patterns

Asynchronous concurrent transmission of temporal patterns

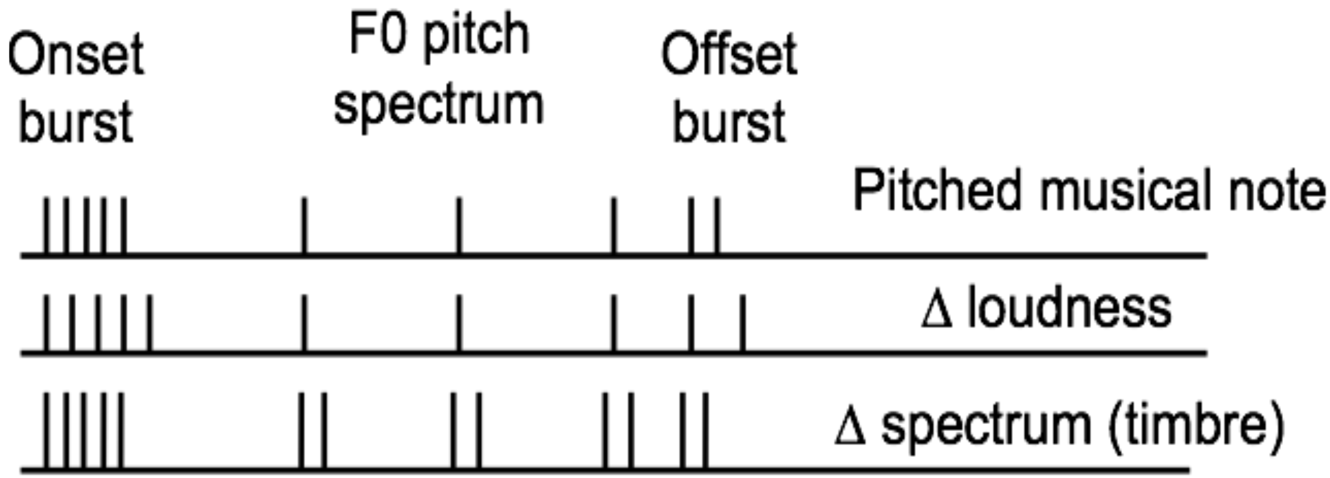
Emmer's proposed multimodal sensory code: multiplexed, interleaved multidimensional signals based on temporal pattern primitives





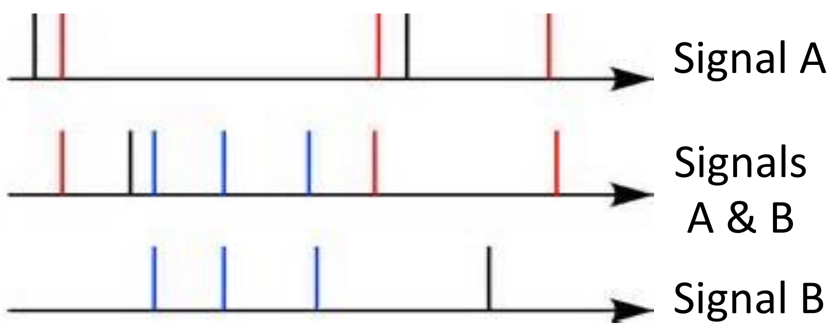
touch	D_1	pattern-vector
pressure	D_2	
thermal	D_3	
gustatory	D_4	
pain	D_5	

PUTATIVE CODING OF ATTRIBUTES OF A SINGLE MUSICAL NOTE



PUTATIVE CODING OF A RHYTHMIC PATTERN OF NOTES

COMPLEX TEMPORAL CODES
MULTIPLEXING OF NEURAL SIGNALS



liberates signals fr. particular elements & paths
enables temporal pattern-resonances
content-addressable (form indicates meaning)

mass action (robust)
broadcast communication, coordination
flexible vector-based time-domain processing

Iconic temporal codes: the signal's form indicates signal type (category) & value (distinction)
Rate-channel codes: channel identity/connectivity indicates type, rate indicates value

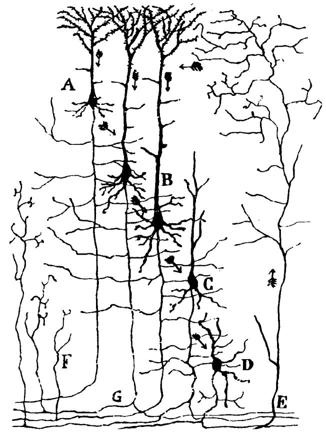
Multiplexing: Multiple independent signals in the same spike train.
Rate-codes are inherently scalar codes and cannot multiplex. Massive signal interference.
Multiplexing "liberates signals from wires" (radio network)
Rate-codes are tied down to particular transmission paths (telegraph network)
Multiplexing permits broadcast strategies of communication & coordination
(temporal pulse pattern signals do not interfere with each other)
Complex temporal codes make high-D vectoral population representations possible
(common temporal subpatterns indicate dimensions of similarity)

Neural codes require different type of neural network architectures

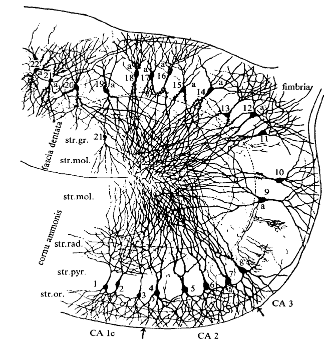
Channel codes	Mixed modes	Temporal codes
Fixed features Fixed filters Receptive fields STRFs	Time-to-place Jeffress model Licklider duplex Synchrony-channel Latency-channel	Stimulus-driven & stimulus triggered spike timing correlations Temporal pattern Latency pattern
Connectionist "switchboard" neural networks	Time-delay nets Synfire chains Oscillatory nets	Neural timing nets Interference nets Oscillatory nets

Rethinking the nature of neural architectures for signal processing

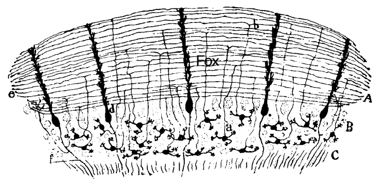
Cerebral cortex



Hippocampus



Cerebellar cortex



Cajal

CORTICAL STRUCTURES

RATE CODES

TIME CODES

NEURAL SPIKE-RATE INTEGRATORS

effective connectivity

NEURAL COINCIDENCE DETECTORS

effective connectivity
&
timing relations

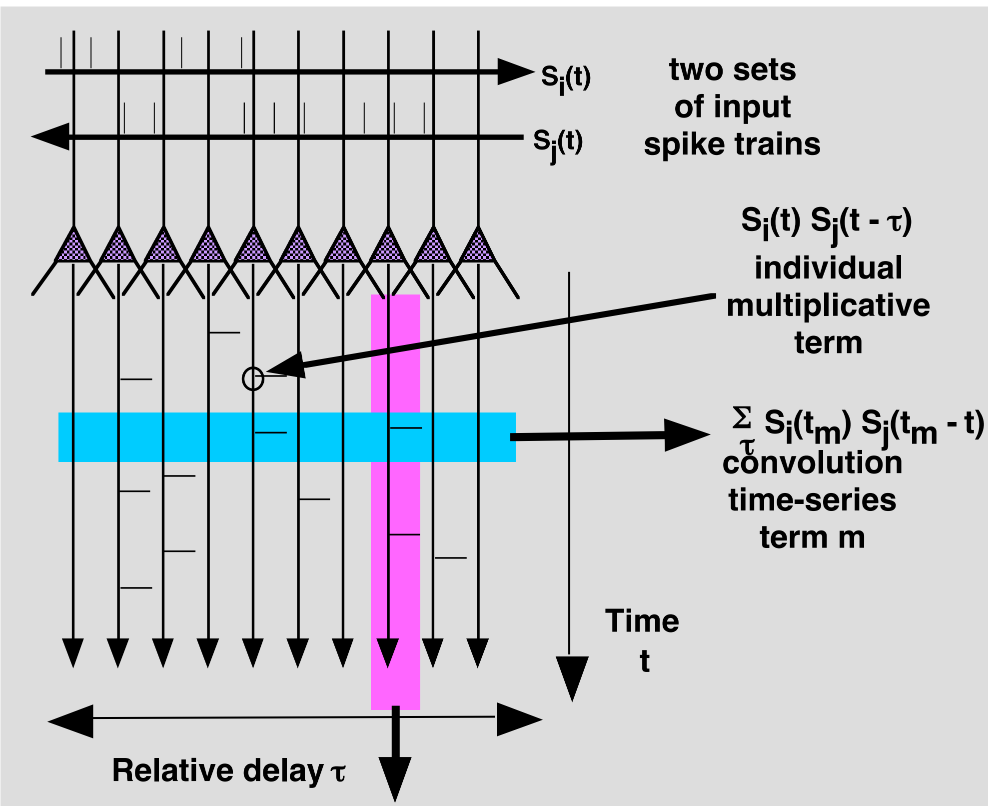
OUTPUT IS A SET OF ACTIVATED NEURONS

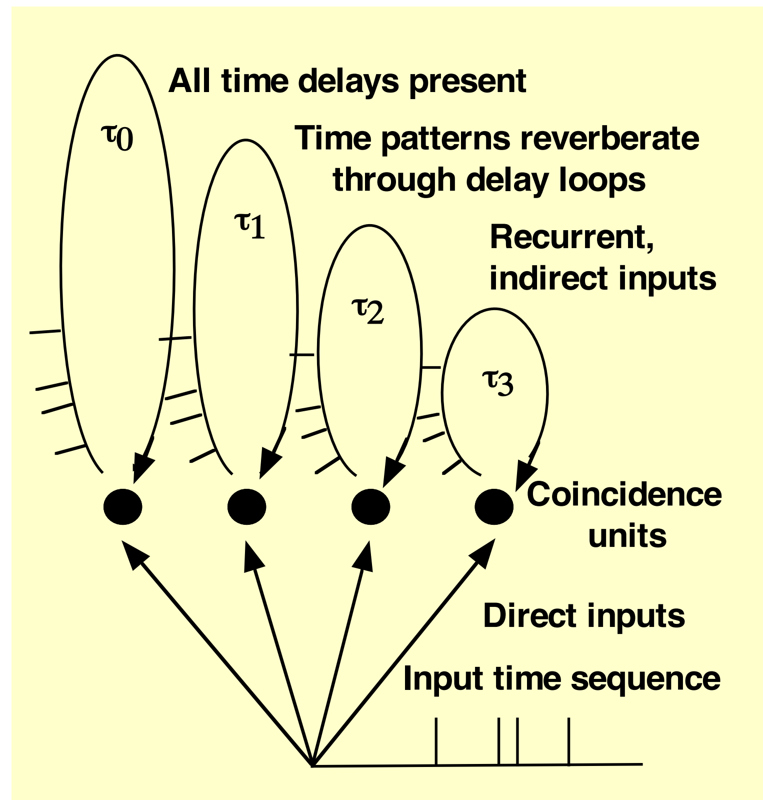
OUTPUT IS A SET OF TEMPORAL SPIKE PATTERNS

Neural timing nets (time-domain neurocomputations)

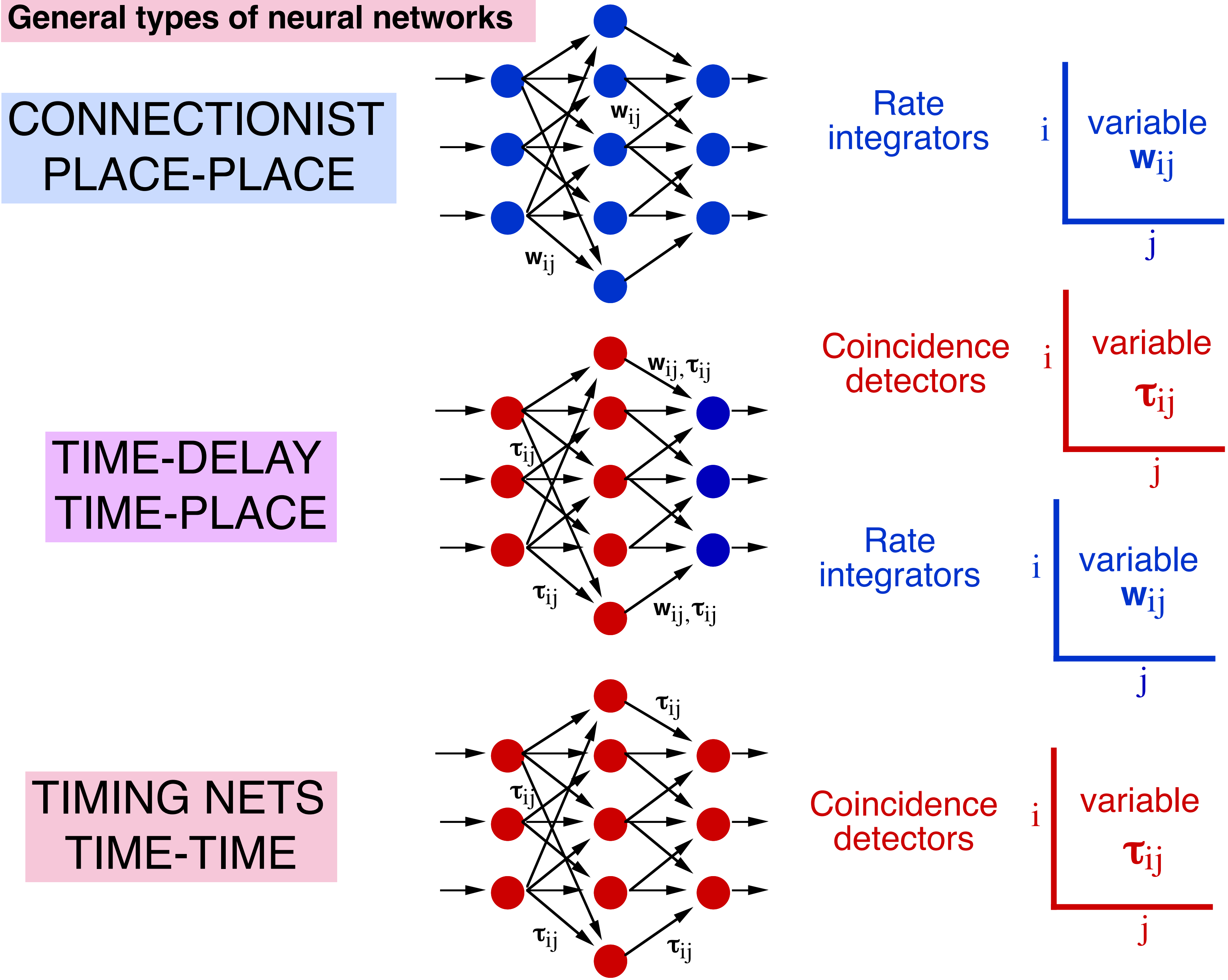
FEED-FORWARD TIMING NETS
- Temporal sieves, filtering operations
- Extract (embedded) similarities
- Multiply autocorrelations
- Cross-correlation & convolution
- Time scaling operations

RECURRENT TIMING NETS
- Build up pattern invariances
- Detect periodic patterns
- Separate auditory objects
- Create pattern expectancies
- Autocorrelation-like processing

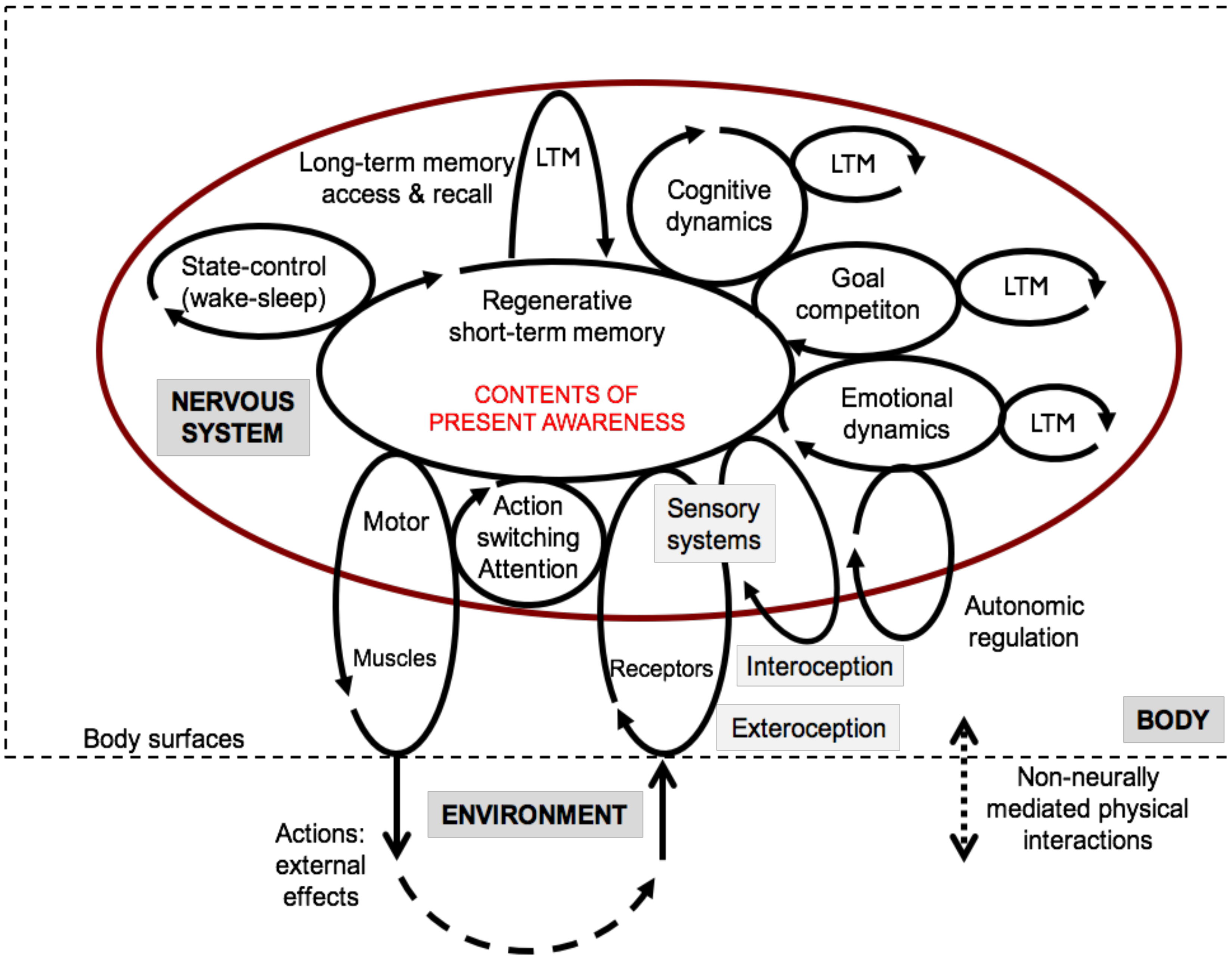


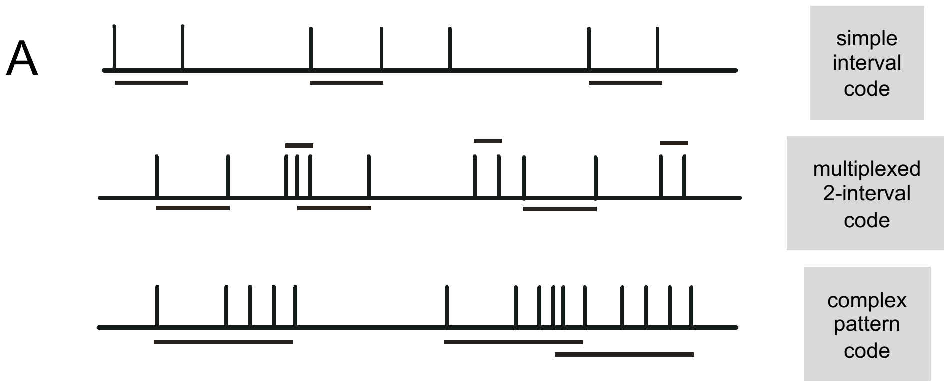


General types of neural networks



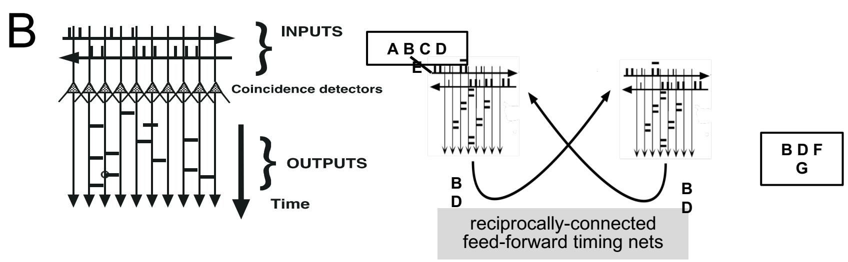
Map of basic types of mind-brain operations





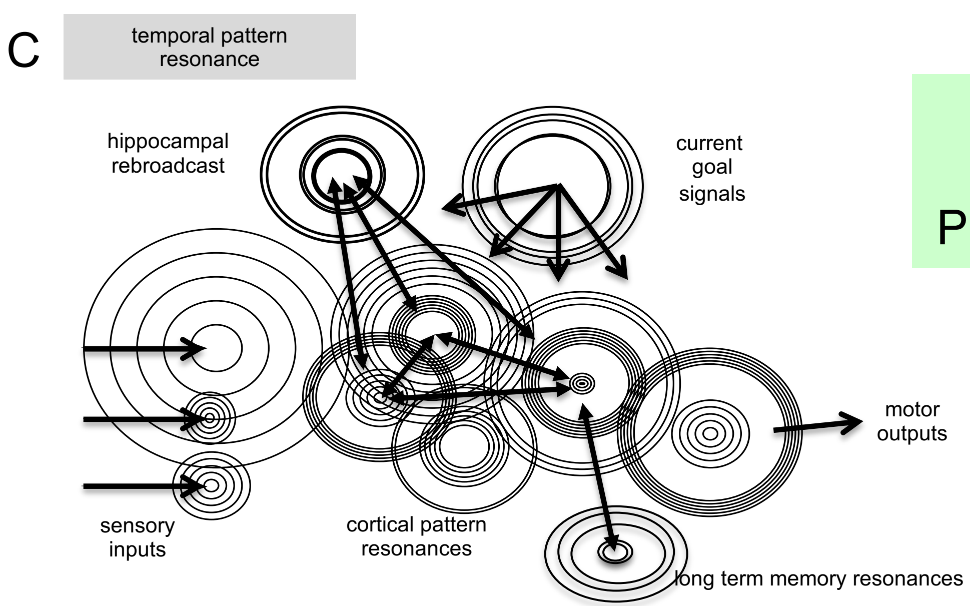
NEURAL CODING

COMPLEX
TEMPORAL SPIKE PATTERN
CODES



INFORMATIONAL BINDING

PATTERN-RESONANCE
AMPLIFICATION

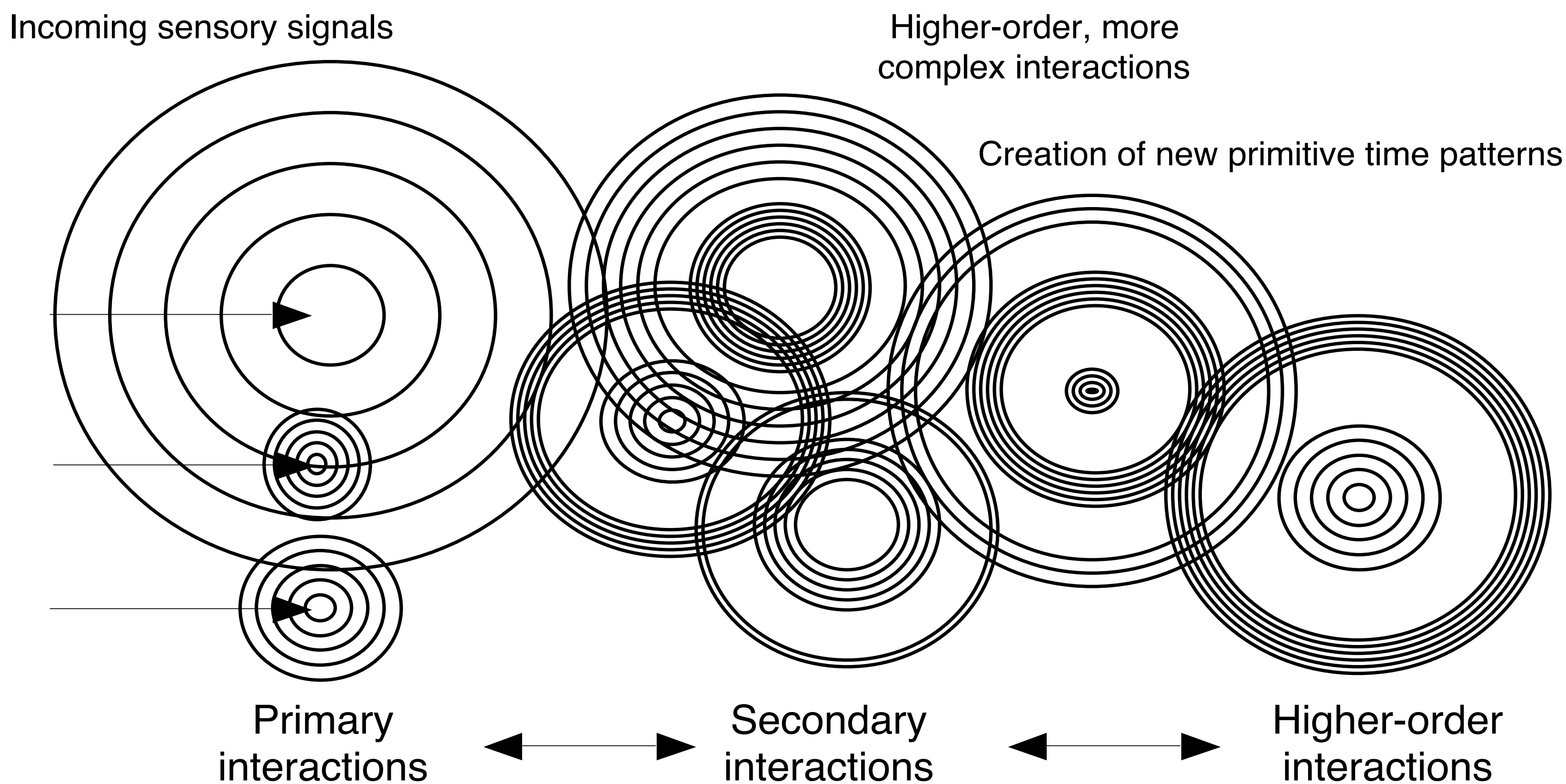


SPREADING ACTIVATION

SIGNAL DYNAMICS:
INTERACTING SIGNALS
PRODUCED BY NEURAL ASSEMBLIES

PATTERN RESONANCES
Sets of patterns compete
Mutually reinforcing patterns win out
Signal dynamics groups, interprets,
and chooses actions

Neuronal assemblies, groups
1) Recognize combinations of temporal spike patterns,
2) Add their own annotative “tag” pattern to circulating set of signals
3) Emergent, complexifying sets of signal productions
4) Tags of mutually resonant semantic nodes build up, regenerate each other and persist, while other non-resonant tags fade
5) New tags = new conceptual primitives (open-ended signal dimensionality)



Induction of two pattern-resonant states upon hearing the words “elephant” or “pangolin”

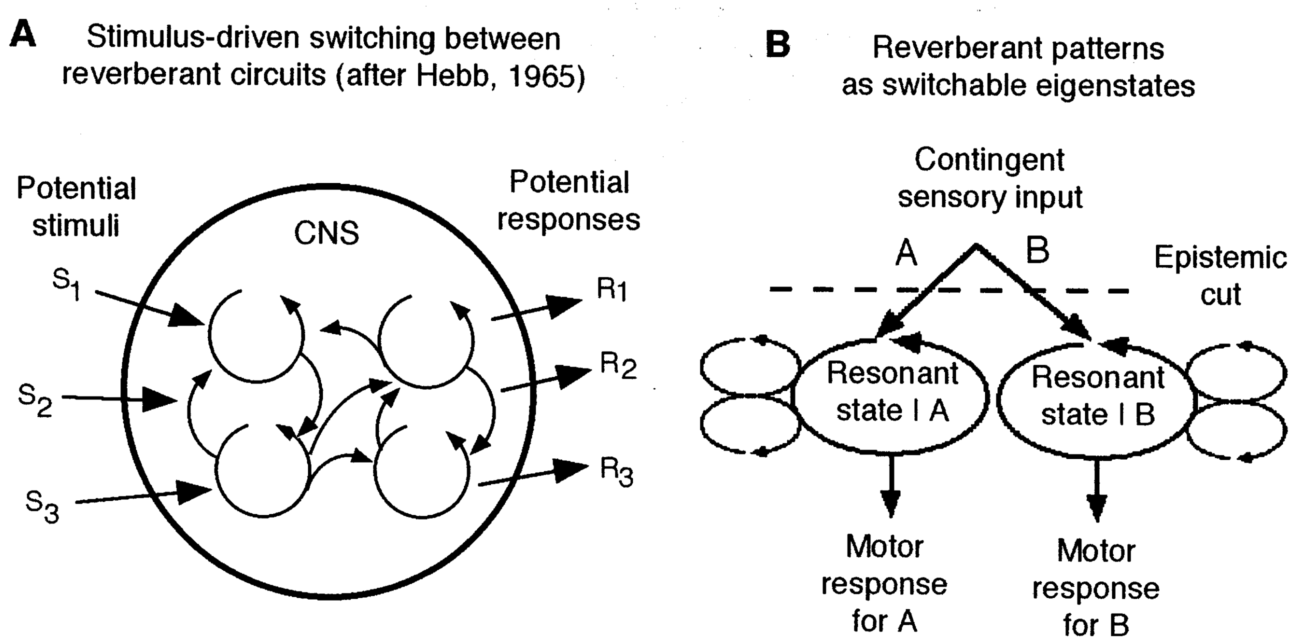


Fig. 2. Stimulus-contingent switching between reverberant states. (A) Hebb’s conception of percept-action mappings using reverberant loops. (B) Simplified state-transition diagram for this process. Depending upon the stimulus and the resulting neural activity pattern, the network enters one of two resonant states (pattern-resonances), which subsequently produce different motor responses. Resonant states at this level of description become the functional primitive (symbolic) states of higher-level descriptions. The epistemic cut for this system lies at the point of contingency, where stimuli A and B cause different system-trajectories.

NEUROPHENOMENOLOGY

The relation between
patterns of neural activity
and
subjective, conscious experience

NEUROPHENOMENOLOGY

What is the relationship between neuronal activity and our subjective, conscious experience?

NCCs: What are the neural requisites of waking consciousness?

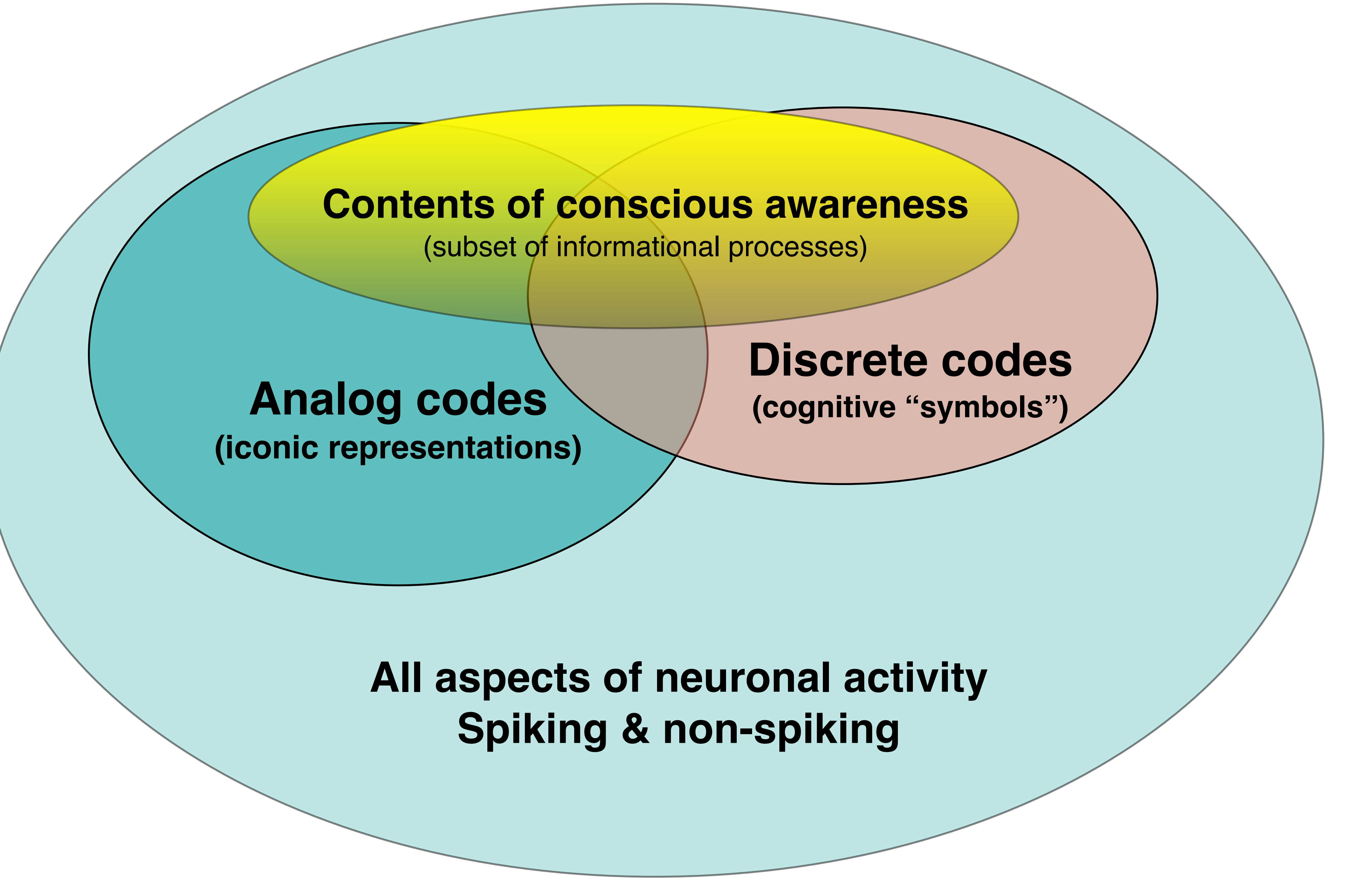
NCCCs: What are the neural activity patterns that produce specific experiential states (e.g. red vs blue, A440 vs C256, thinking of a dog vs. an elephant)?

Working hypothesis; neuropsychological isomorphism

organized matter → neural signs → awareness

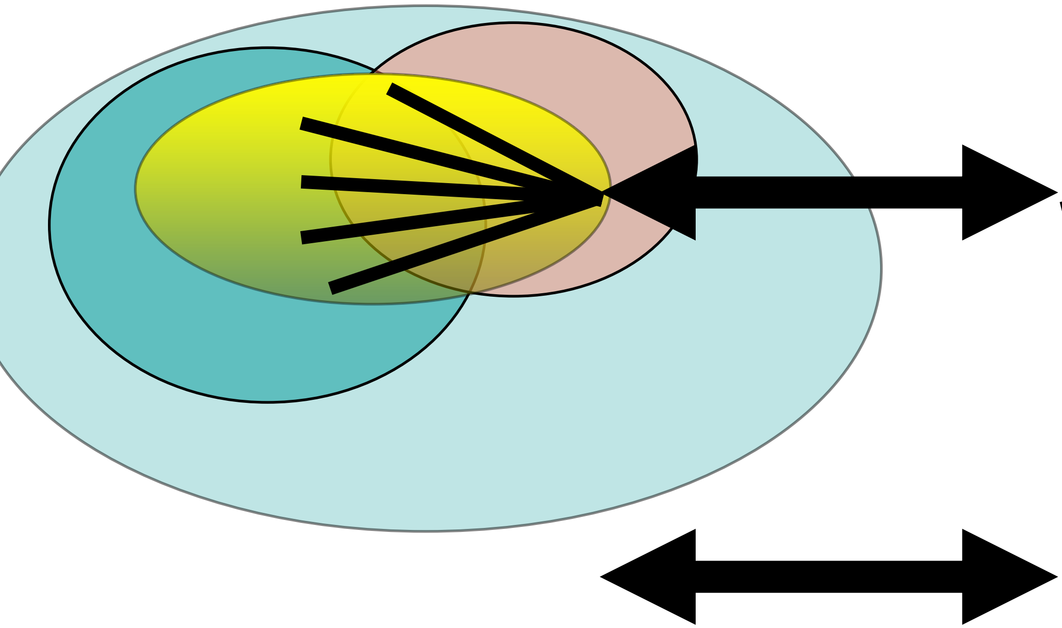
- All experiential states are due to coded patterns of neuronal spiking activity.
- Only a coded subset of neural activity causes changes in conscious awareness.
- Dimensional structure of experience reflects that of the neural codes

Neural code: aspects of neuronal activity that bear distinctions



Dimensional structure of experience reflects that of neural codes

Neural codes & computations subserving contents of awareness
(subset of informational processes)



Dimensions of experience
Distinctions within each dimension

<u>Vision</u>
Form
Texture
Color
Depth
Movement
Grouping
Position
<u>Audition</u>
Pitch, Timbre, Loudness
Duration, Location
Grouping
<u>Other senses</u>
Somatoception, balance
Pain, olfaction, gustation, intero

Affective, emotional state
Desires, drives
Thoughts
Memories

Isomorphic relations
Many equivalent neural activity states
for each phenomenal state
Structure of experience reflects
the structure of neural codes

EVENTUALLY WE WILL UNDERSTAND THE NECESSARY & SUFFICIENT NEURAL CONDITIONS FOR

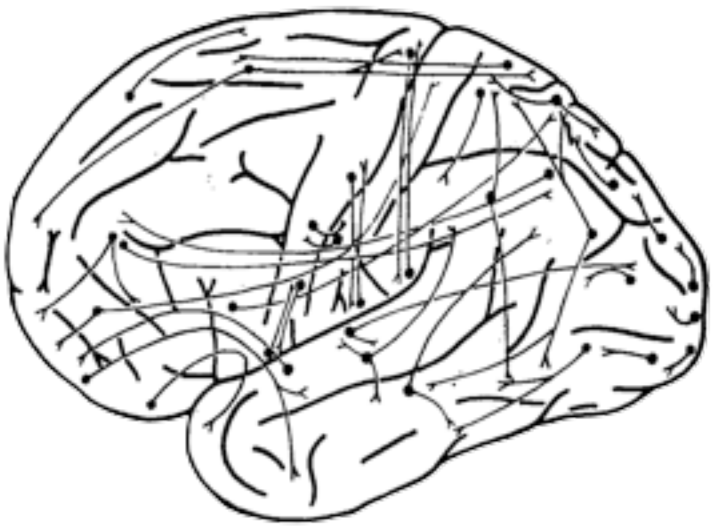
1) being aware (waking conscious state)

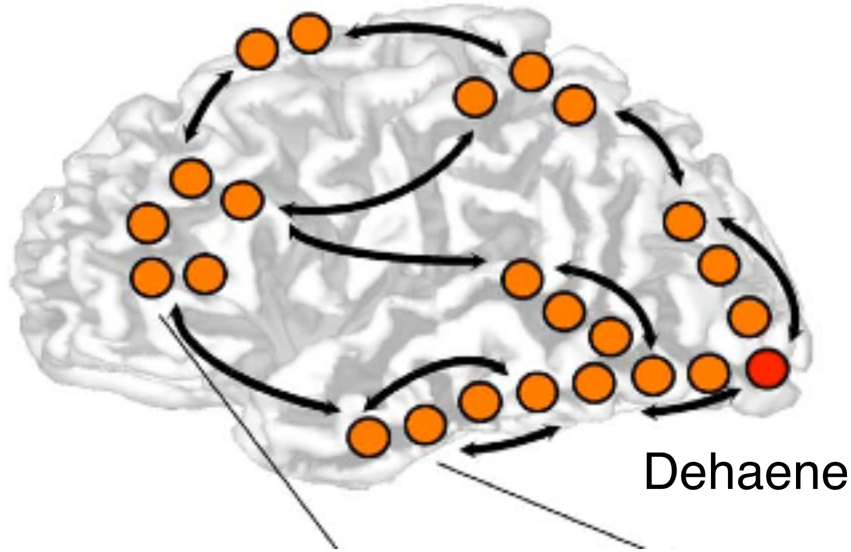
2) having specific experiences (hearing A440 or C523 Hz)

From the effects of general anesthetics, seizures, comas, sleep states, perceptual masking experiments, and normal brain functions, these depend on coherent organization of neuronal activity rather than its presence or absence.

IMHO, the strongest current theories are neuronal global workspace theories. These depend on recurrent activity in global (cortical) neural circuits. The presence of recurrent activity is an indication that global brain circuits are producing sustained regeneration of signals.

Many current theories rely on recurrent activation (RA), but what is special about recurrency per se?





Global workspace (Baars)

Recurrent activation (Edelman, Lamme, Dehaene, John)

Adaptive resonance (Grossberg)

Corticothalamic loops (Llinas)

Dynamic core (dynamic cortical & subcortical networks)

RA + anchoring to parietal body-space (Pollen)

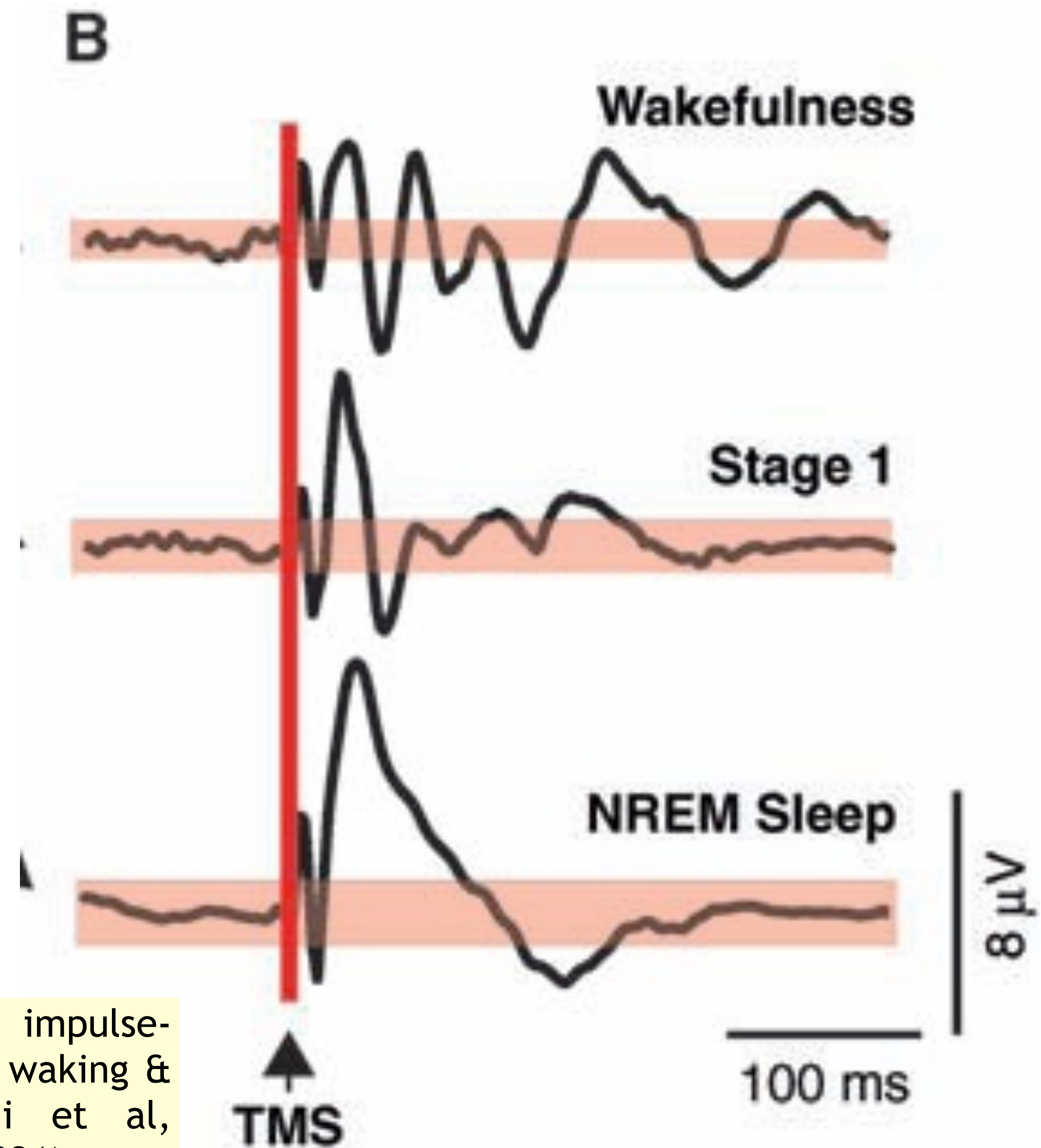
Threshold informational complexity (Tononi)

Differences between waking & sleep states

Impulses reverberate longer in global loops when we are awake

Workspace metaphor: global circuits not engaged during sleep

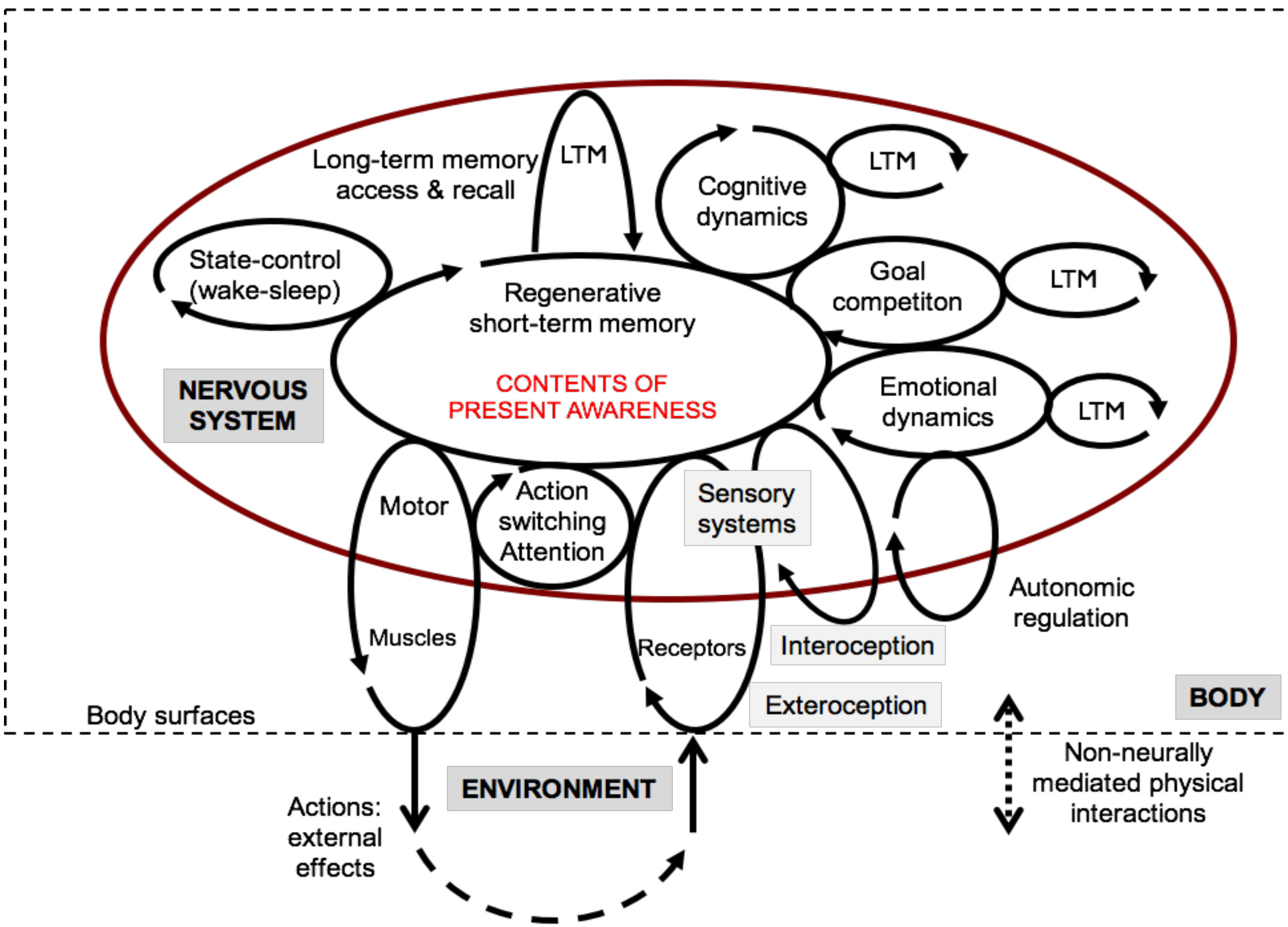
Drumming metaphor: drummers not listening to other local groups



Averaged TMS-evoked impulse-response of a subject in waking & sleep states (Massimini et al, Science 2005 309:2228-2231).

HYPOTHESIS: AWARENESS BASED ON REGENERATION OF NEURAL SIGNALS

1. Waking awareness depends on threshold levels of global circuit activity ("ignition") that integrate & sustain reverberating neural signals.
2. The contents of experience at any given time correspond with those sets of neuronal signals in the form of temporal pattern spike codes being actively regenerated in & by global circuits **(autopoiesis of neural signals)**.



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