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Organization and Structure in the Service of Systematicity

1. Systematicity, Productivity, and Structure

• Representation requires systematicity.
  – Magnetotactic bacteria systematically discriminate among ambient levels of oxygen (v. carbon) to navigate toward optimal oxygenation levels.
  – Vervets systematically discriminate among predators, producing calls that are systematically correlated with appropriate actions: {*eagle, snake, leopard*}, {*look up, look down, climb*}.
    - The structure of this representational system is *pointwise* and *parallel*: $P_x \rightarrow R_x \rightarrow C_x \rightarrow A_x$; hence finite.
 — *Productivity* requires that systematicity to be structural (Fodor and Pylyshyn).
  – Languages impose systematic combinatorial structure on a finite, pointwise base, thereby generating indefinitely many representations in a rule-governed way.
  – This systematic structure also connects and distinguishes those representations' meanings, harnessing formal structure for inferential use.

 — *Pro-propositionalism*: How else?
  – Propositional format is maximally expressive (Devitt, Rey); and only propositional format is general enough to support modular integration (Pylyshyn, Carruthers).
  – Other compositional systems are ultimately notational variants on predicate calculi (Sober, Szabo); so alternative formats are either impractical or theoretically irrelevant.

• *But*: systems distribute representational burden differently between vehicles and processes (Anderson).
 — Different ways of exploiting information-laden structure affect how that information is processed:
  – what information can be directly encoded and what must be derived;
  – what information can be accessed and altered in isolation;
  – what kinds of properties the implementing medium must support;
  – what kinds of representational effects are produced by which kinds of error. (Camp 2007, 2018)

→ Theoretically, how are systematicity and productivity related to structure?
Practically, how can we identify a system's operative structure?

2. Organization and Structure

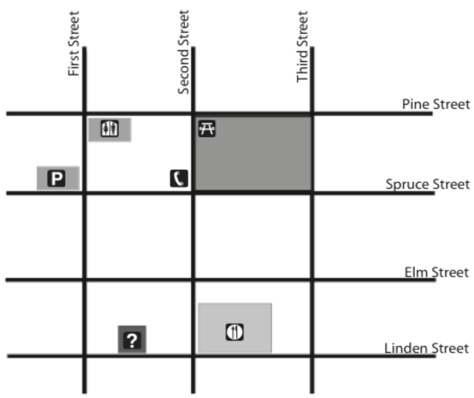
• Productivity is possible without a recombinable base.
 — Analog magnitude representations (AMRs) exploit a unidimensional structural correlation between the magnitudes of an internal register R and an external property P.
  – *Analog* structural principle entails that system generates indefinitely many vehicle-types ($R_a, R_b, R_c, \ldots$).
  – Analog *structural* principle entails that vehicle-types are ordered w.r.t. each other, enabling system to track changes to contents by altering vehicles in structure-relevant ways.
 — *But*: this structure is unidimensional and internally unstructured, so productivity is expressively thin.
 — Shea: such representational systems are "organized" (v. vervet calls) but not "structural" (v. languages), because their vehicle-types lack internal parts related in a systematic, significant way.

• When are a system's representations structural? If so, what structure?
 — Shea: rats' cognitive maps: neurons in rats' hippocampus function as 'place cells' denoting locations. Two challenges.

1) Having representational parts is neither necessary nor sufficient for having internal structure.
  a) Organized systems can have non-structural parts: e.g. waggle dances employ two parallel, co-instantiated AMRs: ($duration_m \rightarrow distance_m$), ($orientation_n \rightarrow direction_n$).
  b) 'Merely organizational' structural information can be exploited at a *systemic* level.
    - e.g. compare contents by comparing vehicles; aggregate contents by aggregating vehicles.
    - While the system as a whole represents these relational properties, the vehicles lack independently identifiable syntactic parts – only Kulvickian parts identifiable by abstraction.

2) Actually instantiating a topological configuration that mirrors denoted locations is neither necessary nor sufficient for instantiating cartographic structure. (Nor is it actual.)
  – *Functional* structure: relations of cellular co-activation systematically co-vary with relations of distance and direction among denoted locations, which rats exploit for efficient navigation.

• When does a system encode information in single representation with functionally significant parts, v. extracting information from "a series of different representations"?
  — A map in a road atlas is a *single* map because its parts (e.g. names, blue dots, red lines) actually stand in spatial relations that are themselves representationally significant.



  — Cartographic structure is *holistic*: its parts comprise a functionally integrated whole in a way that an informationally equivalent list of conjoined sentences does not (Camp 2007).
    – Because all of its marks actually stand in all of the spatial relations they represent, the map directly represents all of the spatial relations among all of the properties that it represents.
      - Implementationally, any change to the placement of a mark *M* representing property *P* thereby alters all of the spatial relations in which *P* is represented as standing, so that merely partial changes to those represented relations are not just inconsistent, but impossible (Camp 2018).
      - Interpretively, information about spatial relations among represented properties comes along as a "free ride," in virtue of representing those properties at their various locations (Shimojima 1996).

• Why treat co-activation of rats' place cells as exhibiting integrated cartographic structure?
  – Granting that rats exploit a structural correspondence between relations of cellular co-activation and the geometry of denoted locations, does this suffice for a single representation with structurally significant parts?
  – Contrast 3 implementations of how rats' navigation system might select a route from source location (denoted by L_1) to goal location (denoted by L_{12}), all built on a common base of place cells:
    • *System 1:* scans list *A* of recorded pairwise transitions between cells:

$L_1 \rightarrow L_2$; $L_3 \rightarrow L_4$; $L_5 \rightarrow L_9$; $L_7 \rightarrow L_8$; $L_9 \rightarrow L_{10}$; $L_8 \rightarrow L_{12}$; $L_2 \rightarrow L_3$; $L_3 \rightarrow L_7$; $L_1 \rightarrow L_5$; $L_5 \rightarrow L_2$;

- compiles list *B* of sequences of pairs sharing at least one cell, beginning with L_1; labels sequences with numerals denoting the number of pairs they contain;

  $L_1 \rightarrow L_2$; $L_2 \rightarrow L_3$; $L_3 \rightarrow L_4$ **(3)**
  $L_1 \rightarrow L_2$; $L_2 \rightarrow L_3$; $L_3 \rightarrow L_7$; $L_7 \rightarrow L_8$; $L_8 \rightarrow L_{12}$ **(5)**
  $L_1 \rightarrow L_5$; $L_5 \rightarrow L_9$; $L_9 \rightarrow L_{10}$ **(3)**
- scans *B* for sequences containing L_1 and L_{12}; if multiple, selects sequence with smallest number.

• *System 2:* "re-plays" sequences of recorded cellular activation (separately, but possibly in parallel), segmenting where an attempted movement was blocked or stopped:

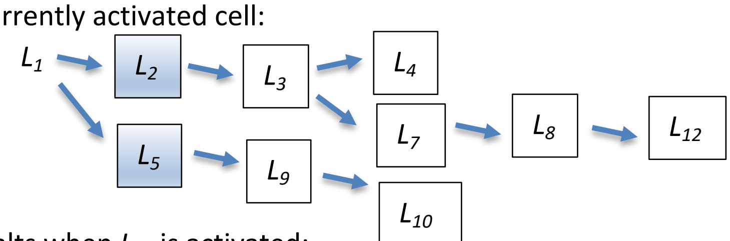
$L_1 \rightarrow L_2 \rightarrow L_3 \rightarrow L_4 \mathbf{S}$
$L_1 \rightarrow L_5 \ddagger L_6$
$L_2 \rightarrow L_3 \rightarrow L_7 \ddagger L_{11}$
$L_{10} \rightarrow L_9 \rightarrow L_5 \ddagger L_6$
$L_9 \rightarrow L_{10} \ddagger L_{11}$
$L_{12} \rightarrow \ddagger L_{11}$
$L_7 \rightarrow L_8 \rightarrow L_{12} \mathbf{S}$

- compiles segments with common endpoints:

  $L_1 \rightarrow L_2 \rightarrow L_3 \rightarrow L_4 \mathbf{S}$
  $L_1 \rightarrow L_5 \rightarrow L_9 \rightarrow L_{10} \ddagger L_{11}$
  $L_2 \rightarrow L_3 \rightarrow L_7 \rightarrow L_8 \rightarrow L_{12} \mathbf{S}$
- if no sequence beginning with L_1 and ending with L_{12} has been compiled, scans for sequences containing common transitions, and splices and compiles until such a sequence is compiled:

  $L_1 \rightarrow L_2 \rightarrow L_3 L_7 \rightarrow L_8 \rightarrow L_{12} \mathbf{S}$
- tracks sequence lengths via 'duration' AMR; if multiple, selects least magnitude.

• *System 3:* beginning with L_1, simultaneously activates every cell previously co-activated with each currently activated cell:



- halts when L_{12} is activated;
- progressively de-activates every cell $\neq L_{12}$ and not connected to at least two active cells;
- initiates action to the location denoted by the L_1-neighboring cell that remains activated after pruning; if multiple, selects at random).

— All 3 systems are functional maps in a weak sense: at a systemic level, they exploit structural correspondences between external world and inner states/processes, without directly instantiating topological structure.

– But they exhibit more fine-grained functional differences.

- Systems 1 and 2, but not 3, require memory and "little chains of reasoning" to record, compile and extract routes from separate representations. So they can fail to perform a comprehensive search of possibilities, and introduce transcription errors, in different ways from System 3.
- Systems 1 and 2, but not 3, produce stable representations of possible transitions, which are then available for rapid recall and exploitation.
- Some empirical evidence for 3: parallel diffusion over entire array of place cells (Shea 2018, 115).

3. Systemic Structure and Productivity

• Both a fixed pointwise base (vervet calls) and parallel structure (e.g. vervet calls, AMRs) limit productivity; systemic organization can scaffold productivity (e.g. AMRs). How?

— E.g. seating charts and System 3 deploy a holistic structure on a pointwise base.

– Their structural systematicity supports fairly robust productivity: property-denoting marks can be permuted (although location-denoters can't).

– By contrast, AMRs' organizational structure doesn't support permutation, only generation/update.

— A system with a pointwise base can also support productivity by deploying a mechanism for expanding that base – especially by exploiting systemic organization.

– Contrast three ways rats' navigation system might add new place cells:

a) unorganized and parallel: random selection of neurons, assigned reference piecemeal, *a la* names (*George, Betty*…).

b) internally organized and parallel: sequential selection of neurons, assigned reference on first activation, *a la* idealized indexicals ('here$_1$', 'here$_2$'…).

c) structurally organized selection and interpretation, *a la* a physical map.

– Here too, alternatives make a practical difference.

- e.g. System 1 + a $\Rightarrow$ establish each new co-activation relation piecemeal;
System 3 + c $\Rightarrow$ co-activation relations inherited from assignment structure.

• What about an analogue base?

— AMRs for location: egocentric direction and distance; AMRs for properties: e.g. risk, effort, reward.

— Higher-order relational contents (e.g. relative route lengths, risk, reward) represented directly but without explicit local coding and inferential extraction.

– Highly distributed, functionally abstract.

– But strongly systematic and productive; indeed, compositional and computational.

L_1	L_2	L_3	L_4 $\downarrow$?
L_5	L_6	L_7	L_8
L_9	L_{10}	L_{11}	**L_{12}**

References

Anderson, John (1978): "Arguments Concerning Representations for Mental Imagery," *Psychological Review*, 85: 249–77.
Camp, Elisabeth (2007): "Thinking with maps," *Philosophical Perspectives,* 21:1, 145-182.
——— (2009): "Putting thoughts to work: concepts, systematicity, and stimulus-independence," *Philosophy and Phenomenological Research* 78:2, 275-311.
——— (2018): "Why maps are not propositional," in *Non-Propositional Intentionality*, ed. A.
Carruthers, Peter (2003), "On Fodor's problem," *Mind & Language* 18(5), 502-523.
Devitt, Michael (2006): *Ignorance of Language* (Oxford: Clarendon Press).
Fodor, Jerry, and Zenon Pylyshyn (1988): "Connectionism and the Cognitive Architecture of Mind," *Cognition,* 28: 3–71.
Kulvicki, John (2015) Analog Representation and the Parts Principle Review of Philosophy and Psychology 6:165–180.
Pylyshyn, Zenon (2003) *Seeing and Visualizing: It's Not What you Think* (Cambridge, MA: MIT Press).
Rey, Georges (1995) A Not 'Merely Empirical' Argument for the Language of Thought. *Philosophical Perspectives,* 9: 201–22.
Shea, Nicholas (2018): *Representation in cognitive science*. Oxford: Oxford University Press.
Shimojima, Atsushi (1996): "Operational constraints in diagrammatic reasoning," in *Logical Reasoning with Diagrams*, ed. J. Barwise & G. Allwein (Oxford: Oxford University Press), 27-48.
Sober, Eliot (1976): "Mental Representations," *Synthese* 33: 101–48.
Szabo, Zoltan (2012): "The Case for Compositionality," *The Oxford Handbook of Compositionality* (Oxford: Oxford University Press), 64–80.