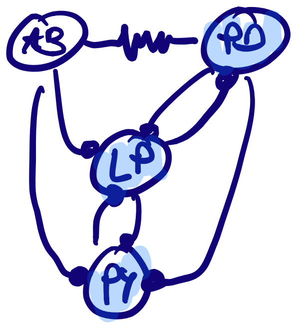
Eve Marder: Cellular Mechanisms → Tile Time

(Bernstein 19') ⊕ Differential Resilience to Perturbations

Fixed time constants → Function across range of conditions → HOW?

→ REDUCTIONISM PoV → Abstract complexity → HYPOTHESIS: BUT Many Channels Crucial!

Motor Pyloric Rhythm



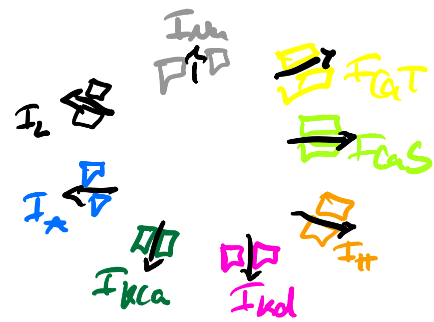
"1,2,3"

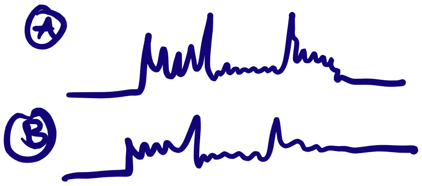
→ Circuit diagram abstracts away too much

↓

ION CHANNEL DYNAMICS

DIFFERENT VOLTAGE/TIME DEP. ION CHANNELS





Net A "≈" Net B

Dynamics vs. Params → "Good model" → WHAT Q to ask next?!

Inter-animal variability

↓

2-6 Volt Potassium Ch.

Perturbation (Global → Temperature) Q10 coefficient

↓

breakdown > 23°C

⇒ NON-ROBUST PATTERNS

↳ individual

↓

Temperature Compensation is very rare in param space → But all crabs do it!!!

↓

Alonso & Marder 19'

⇒ TIME TILING

↳ Continuous shift in currents as temperature (↑)

Summary

- Heterogeneity in crab mechanisms (given same initial circuit)

↓

DISEASE

- Multiple membrane & synaptic currents

↓

ALLOW SMOOTH SLIDING → MAINTAIN FUNCTION ACROSS CONDITIONS

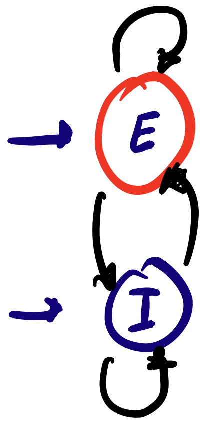
↓

Different Mechanisms

↓

DON'T MODEL EVERYTHING BUT ENOUGH

Nicolas Brunel: How strongly coupled are cortical circuits?



STRENGTH

I: $w \ll 1$ → Weak → Non-Linear

II: $w \sim 1$ → SSN → Non-Linear

III: $w \gg 1$ → Balanced → Linear

? E/I Balance ?
? Inhibition ? (ISN)
? Sync vs Async ?

Inhibition Stabilized Nets

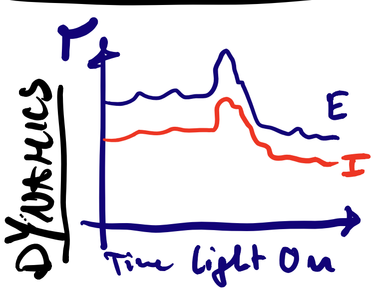
E-E strong enough (LIF)
↓
Freezing I activity would result in runaway activity!
↓
Tsodyks et al., 97'

ISN → Paradoxical behavior

Experimental evidence mixed (pharmacological id E/I cells)
⇒ BLOCKING (V1)
⇓

$\boxed{\text{V1} \Leftrightarrow \text{ISN at Rest}}$

High In / High Rate



Van Miller

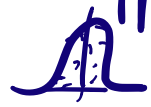
Simple ReLU E-I Rate Model fits well!

$1 < w_{EE} < [2, 6]$

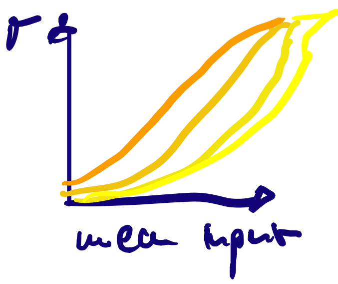
Characterising Non-Linearities

⊙ Experiments: Visual ⊕ Optogenetic Stim → Sum?
→ Mouse: Linear
→ Monkey: Sub-Linear

⊙ Modelling: Diffusion approx.
→ Input: White noise



→ Firing rates ⇔ self-cons. eq.



→ Vary K (fixed E-I connect.)
↳ Strong vs. weak coupling

→ Params ⇒ diverse behaviors

→ Low In / Low Rate: Less impact of variance!
↳ BI-STABILITY

— Conductance-Based Inputs?
— Structured connectivity?; Synchrony?

Claudia Clopath : Rapid compressible & Reversible Learning in Hippocampus

(Bernstein 19')

⇄ Replay → TIME COMPRESSED

→ 1 Rapid
→ 2 compressed
→ 3 ⇄

Goals

CA3

1 2 3

"TEMPORAL BACKBONE"

CA1

Theta Freq.

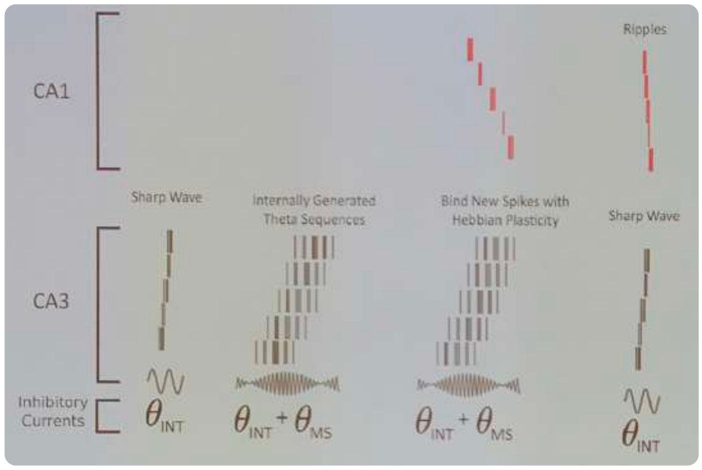
COMPRESSION

⊙ Replay ⇄

θ_{INT} ↕ θ_{MS}

SWR – Replay
Slow – Behavior
] DILATE → COMPRESS

→ EXPERIMENTAL DATA → Pastalkova Lab



FORCE TRAIN → CA3 Model

↓

Interference Theory

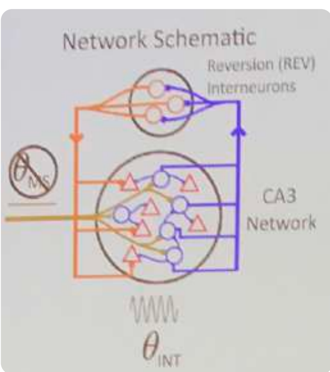
→ PHASE PRECESSION

Carrier vs. MS frequency
(MS = Medial Septal Input)
⇒ Remove after time → Compressed

⊙ Rapid Hebbian Learning

CA3 "Backbone" → pre/post → CA1 "Behavior"

↳ One-Slot Learning of Seq.



→ Activate Reversion Neurons
⇓
backward Replay

⊙ Predictions θ_{INT} / θ_{MS}

→ Optogenetic Manip. Freq. Driving of Medial Septum

→ Manipulate learnable seq. length

BEFORE : Learn Time → Outlook : Space

IDEA: Somatic / Dendritic disinhibition have different effects on place cell emergence!

⇒ Importance: Acetylcholine in hippocampal learning

Matthias Bethge: Neural Decision Making from Pixels to Percepts

$\boxed{\text{Life = Decision Making; Brain = Machine}}$

Here: Vision ⇒ Underlying Mechanisms

Past Data → Internal Models ← Continual updating

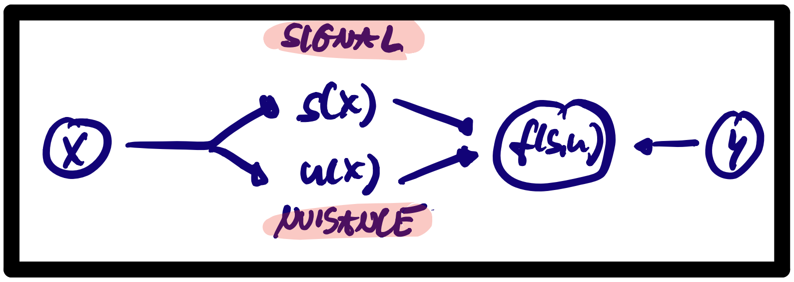
Internal Models ↓

Future Data → Decision Making → Action

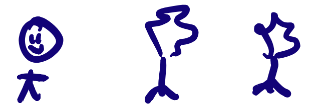
- Performance only single measure
⇒ Many DISCREPANCIES

(NON-) TARGETED ADVERSARIAL ATTACKS → Ilyas et al. 19' ⇒ Feature not bug
↳ LEARNING Dynamics!

ADVERSIAL
↓
Net decision boundary



INVERTIBILITY
↳ Generate METAMER



SIGNAL GEN. NUISANCE

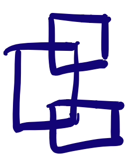
METAMERIC
↓
Human decision boundary

⊙ Solution / Robust for MNIST! (ICLR, 19')

$\boxed{\max I[f(s,n), y]}$ vs $\boxed{\max I(s,y) \oplus \min I(n,y)}$ More human like!

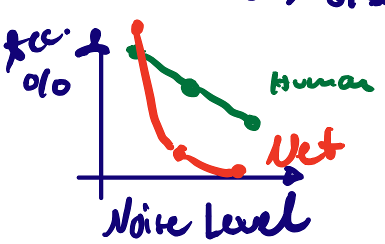
⇒ Resulting 'ambiguity' plausible →

⊙ Bag-of-Patches ImageNet

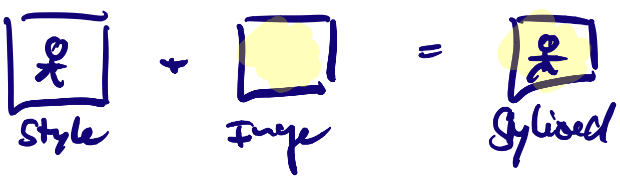


→ Interpretability!

→ Bias towards texture!
↳ Noise Non-Robustness



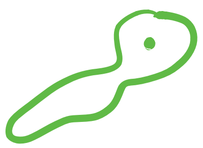
⊙ Style Invariance



→ Robustify via Augmentation
↳ REASON FOR ART

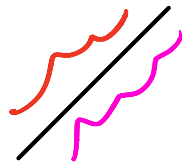
⊙ Transfer Learning → DeepGaze / DeepLabCut
↳ Predict energy / gaze / keypoints

Haim Sompolinsky: Neural Representations – Geometry & Computation

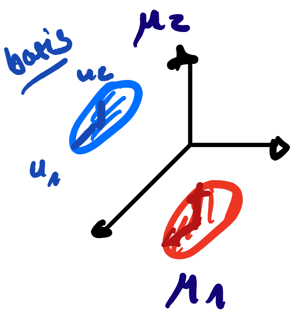


PERCEPTUAL MANIFOLDS → Untangling through hierarchy

GOALS:
- Quantify untanglement
- Geometric measures



LINEAR SEPARATION (e.g. as in CNNs)



CAPACITY = Max. # M Separable w. (w. high probability)

$\boxed{\alpha_c}$ → NORMALIZED BY # NEURONS

≈ Object/Category Info per Neuron

① $\alpha_c = 2$

⇒ PERFECT STRUCTURE

② $\alpha_c = 2/m$ (random sel.) points per M

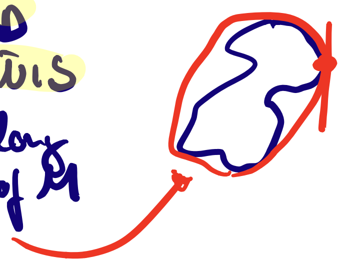
⇒ NO STRUCTURE

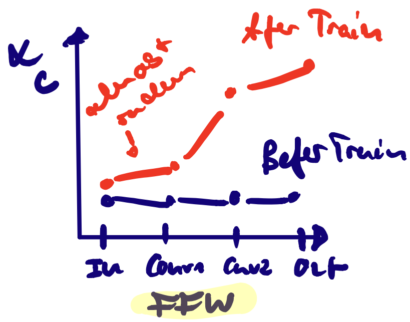
③ $\alpha_c = \frac{2}{2D+1}$ dim. M

⇒ STRUCTURE INV. PROP. TO DIM.

UNTANGLED! → SAMPLING MEASURE/GEOMETRY CRUCIAL

MANIFOLD ANCHOR POINTS
Travelling along Convex Hull of M

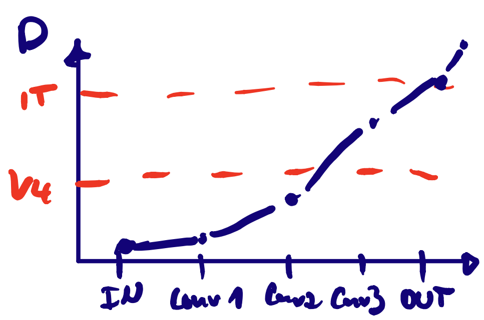




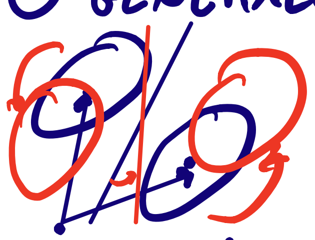
- Dim of M ↓ (D)
- Radius of M ↓ (R)

→ MOST HEAVY LIFTING DONE BY FINAL LAYERS

MACAQUE FACE PROCESSING (DiCarlo Data)



⊙ GENERALIZATION – FEW-SHOT



Takeaway: For fixed R
↳ Performance better as D↑
→ Theory of Ellipsoids

→ Hold-out data vs. Hold-out manifold

NOT YET IT CORTEX ☺

Hopi Hoekstra: From Mice to Molecules – The GENETICS OF BEHAVIORAL EVOLUTION

BEHAVIORAL ECOLOGISTS ⇄ NEUROBIOLOGISTS & GENETICISTS

THE EXTENDED PHENOTYPE
↓
→ animal artefact
↳ variation from genes

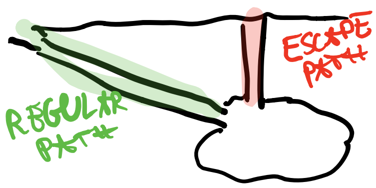
SPIDER WEB SHAPE, ETC.

Genes → Circuits → Behavior
↳ Heritage Measurement ↑

BURROWS ⇔ FITNESS

Mouse model (genus Peromyscus)
→ Diverse Habitats ⇒ Gene Variety
→ Transgenics ⇒ Sequencing

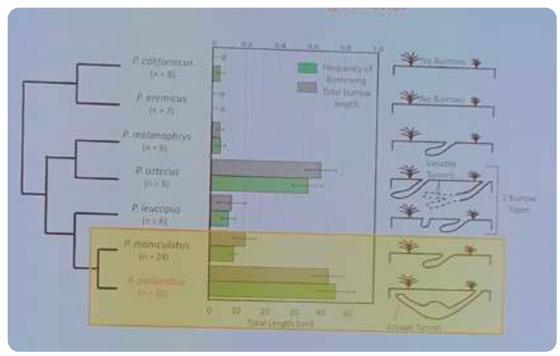
↳ DESIGN? ⇒ CATCH MOUSE



PLACE IN BOX ⇒ BUILD NEW BURROWS

→ Pull Out
↳ 3D Model!
↳ COMPARE ACROSS SPECIES!

WHAT IS THE GENETIC BASIS?



↳ No impact of how mom raised

⊙ F1-Hybrid crossing ⇒ Kids, Grandkids, etc.
↳ ~3-5 genes appear to influence length
↳ Architecture (escape tunnel, entrance length)

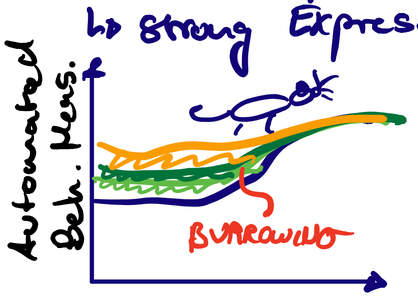
⇒ 4 "Causal" Chromosomes

① STRONG GENETIC COMPONENT INFLUENCES BEHAVIOR

② SIMPLE UNDERLYING GENETICS

③ COMPLEXITY VIA SERIES OF MODULAR CHANGES

⊙ Chrom 5 Expression Level
↳ Strong Expression Difference

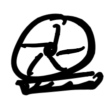


↳ Compare
⇒ MOTIVATION DIFFERENCE

↳ Dopamine! ⇒ Entry to addiction, ADHS, etc.

⇒ HOW DOES GENE WORK ON NEURAL CIRCUIT LEVEL?

↳ Chrom 5 does not affect wheel running behavior



Gašpar Tkačik : Optimality Theories $\xrightarrow{\text{ARC}}$ Data

NORMATIVE MODELS → BIOLOGICAL COMPLEXITY → Info / Comm. → Transport → Evolution

Predict Optimal Behavior ↕ Inform / Compare with data

Shannon Mutual Info

SOURCE $p(x)$ → CHANNEL $p(y|x)$ → RECEIVER
EFFICIENT CODING!

CHALLENGES

1. Hypo Test Optimality
2. Measure Closeness
3. How to set constraints to break degeneracy
4. Can optimality help to infer parameters

$\boxed{1.}$ NORMATIVE ∞ STATISTICAL

$\theta^* = \arg\max U(\theta)$
↓
No data
⇓
Theoretical Predictions

Inference via ML / Bayes
↓
+ lots of data
⇓
No fit. constraints

Data Constraints / Regularization

PRIOR: $\exp(\beta U(\theta))$

LIKELIHOOD: $\prod_t p(x_t|\theta)$

↳ Controls Amount Regularizer!

⇒ Test $\beta \neq 0$ using LR Test

↳ HYPOTHESIS TESTING FOR OPTIMALITY

$\boxed{2.}$ Population Optimality

β → θ_1 … Indiv θ_N → D_1 … Data D_N

⇒ Compare 'degrees' of opt.!

$\boxed{3.}$ Optimization Regularized Inference

↳ Highly structured priors can yield powerful insights

$\boxed{4.}$ Positional Info

↳ Gap gene expression levels
↓
embryo position of all

High Dim: Go the other way around ←
↳ Use data as regularizer!

SETS OF SOLUTIONS

→ Perturbations around solutions
↳ Not unique but metabolic-efficient!

Matt Botvinick: A Distributional Code for Dopamine-Based Reinforcement Learning

(Bernstein 19')

Deep RL

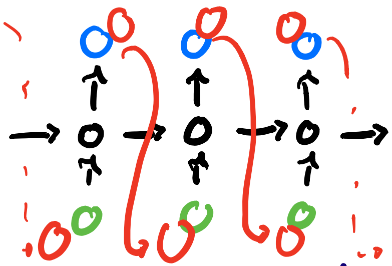
DL + RL → ATARI, Go, Chess, StarCraft, CTF

[] → ⋮ → ⋮ |t|

REPRESENTATION ⊕ REWARD-DRIVEN BEHAVIOR

Learning to Learn
- Originally Supervised
- Meta RL ⟺ PFC

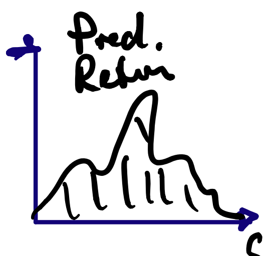
⊕ Deep Learning + Reinforcement L. = NEW THINGS HAPPEN!



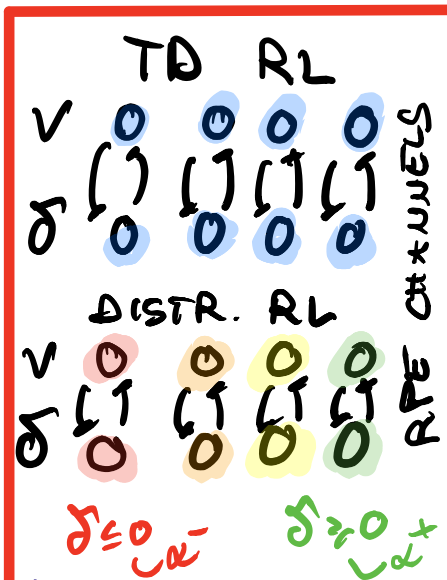
Wang et al. 18'
↳ Meta RL
↳ Net learns to Explore!

Distributional RL + Dopamine

$V_i(t+1) \leftarrow V_i(t) + \alpha_i \delta_i(t)$ → SCALARS



↳ INTUITIVE PROBLEM: $E[R(s)] = E[R(s')]$
→ Backpropagation yields similar representation
⇒ But R Distr. might be very different!
↳ Use full distr. objective to learn!

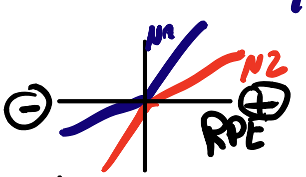


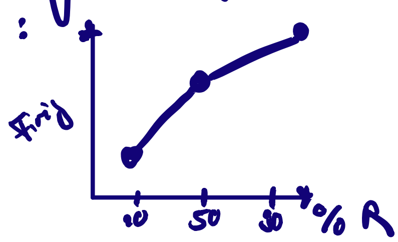
↳ Different Levels In Optimism

DOPAMINE DATA: Nao Uchida (Harvard)

→ R Magnitude: Reversal Points for different juice levels $\delta > 0 \rightarrow \delta < 0$

→ R Probability:

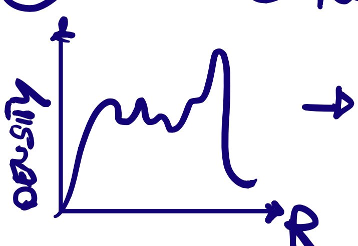




Step function Firing
↳ Different Behavior to RPE ≷ 0!

↳ Results in different optimism levels!

⊙ Quantile Regression



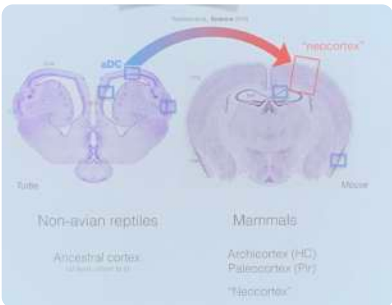
→ EXTRACT RANGE OF CONSIDERED REWARDS

⊙ What uncertainty encoded?
↳ Here: Epistemic → Un-Red.
↳ Different from EXPLORATION!

Gilles Laurent: A Reptilian Model for Sleep Control & Evo

Cortex Development → Compare across species → Filtrate Cortical Comp.
↓
MAPPING

Reptiles: 3 Layers (only 1 cell layer)
⇓
COMMON ANCESTOR



FUNCTIONS OF SLEEP

① BEHAVIORAL → Muscle tone, consciousness, etc.
② ELECTROGRAPHIC → REM & NON-REM

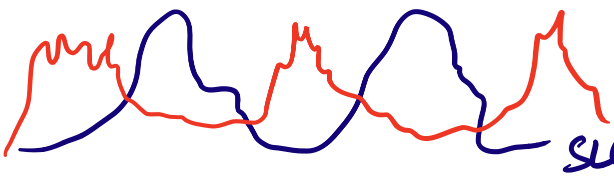
Wake → Non-REM → REM
90Min Cycle
4-5 Total

↳ VERY DIFFERENT IN OTHER MAMMALS!
[E.g. Mouse is fragmented / aperiodic]

DIFFERENT CIRCUITS
→ Sleep - Wake
→ REM - Non-REM
⇒ NESTED OSCILLATORS
↳ Coupling with world!

3rd TYPE?

⊙ REM exists in both mammals & birds ⇒ homeotherms [Body Temp. Regulation]



non-REM ⇔ SWS ?
↳ Fast cycling (~300 Total)
↳ Not caused externally

⊙ SWS = Composition Sharp Waves & High-Freq. Ripples

IMPORTANCE OF SWR
→ CA1: Compressed Replay / Consolidation
→ Complex Mechanism triggered by PCs

CLAUSTRUM AS CENTRAL SLEEP CONTROL HUB!

DVR AREA ORIGIN: SWR
→ AP delays
→ E/I converge
↳ Network drives!

RNA Sequencing Reptile Pallium
→ amDVR: Generates Ripples!
↳ CLAUSTRUM HOMOLOG
→ Sleep Control Circuits: ACh, NA, DA, 5HT

Highly Connected to entire forebrain!
BROAD-CAST!
↳ Turning off shuts down SWRs in DVR!

Turtle vs. Lizard
⇒ Different place
⊕ Different Arch.