

# Why It Hurts!



With freedom comes the biological need for pain

If **pain** is a signal meant to inform us of potential damage, then why does it have to be so **nasty**?

To answer this question, I will use a radically new concept, not only of how life works, but even of how **cause and effect** arise in the physical world at all.

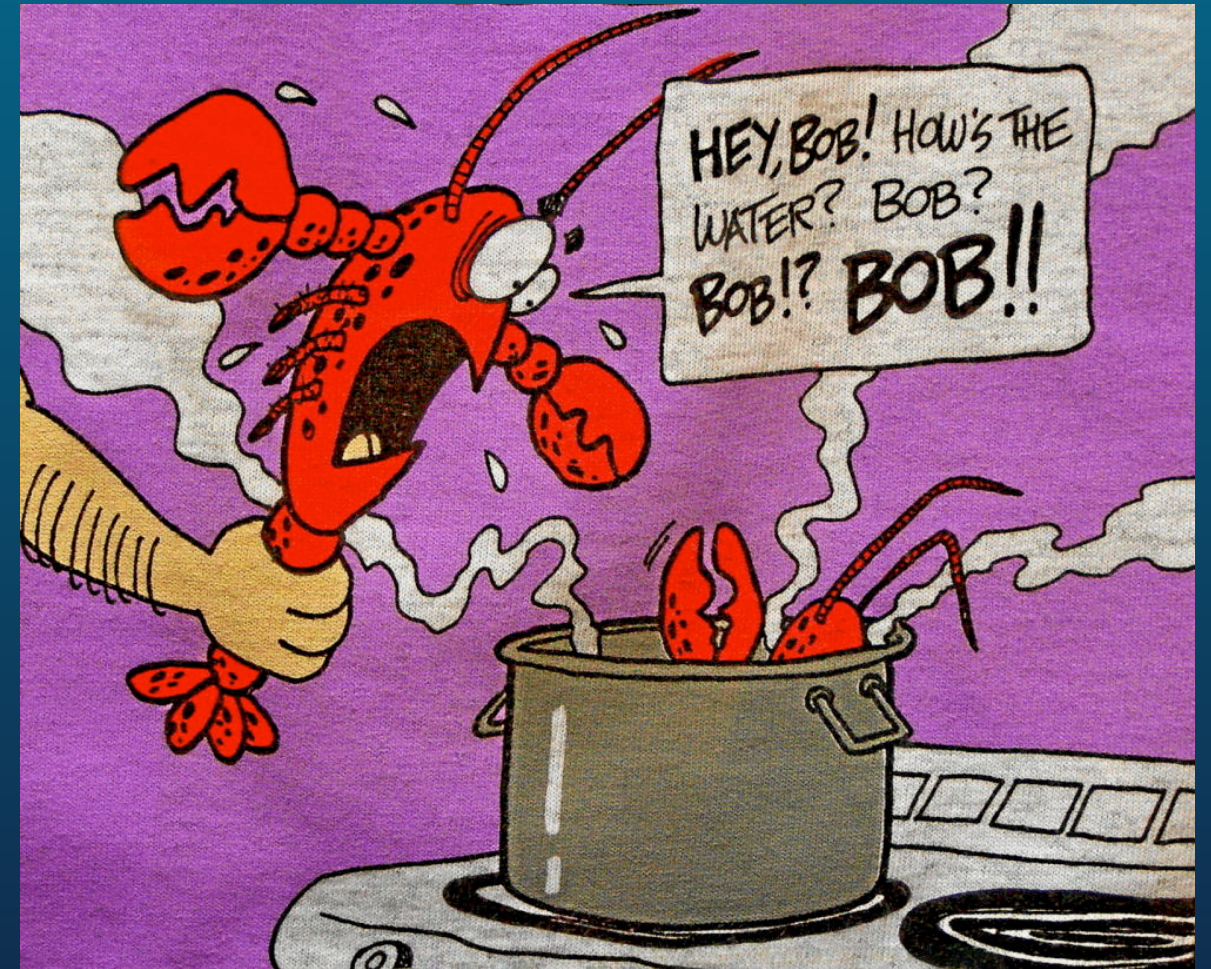
*Is this going to hurt?*







Bob Elwood



AP Biology Blog 2013

Famous for showing lobsters can **feel** pain.  
(as opposed to mere nociception)



My main premise is that pain is not just an informative signal.

It is a motivational command to attend to the cause of the pain.

Only needed if you can choose to ignore it.



*Wounded, still fighting.*



# The Pain question

Play on



Or not!

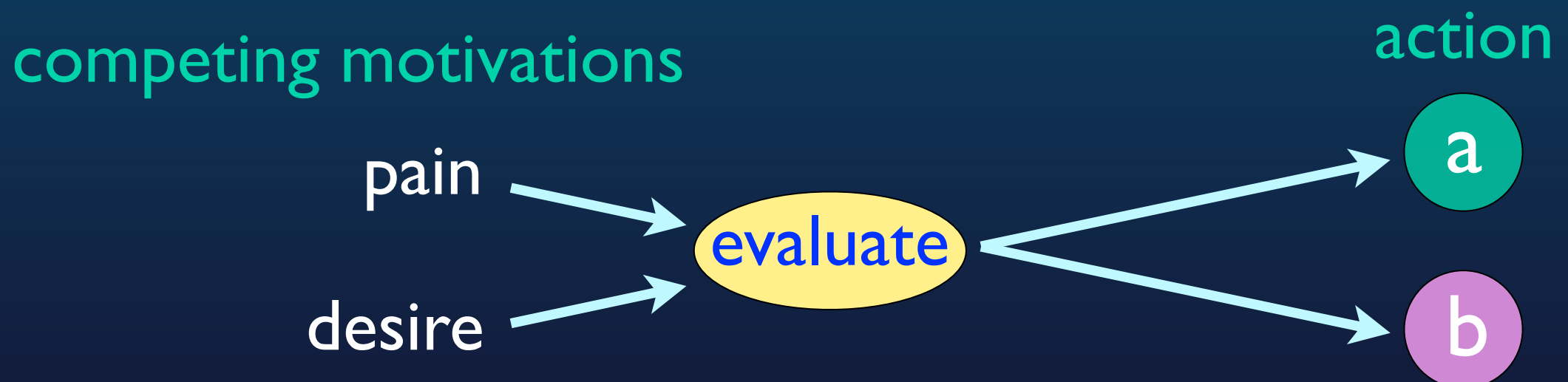
Danny Cipriani (Wasps) ankle subluxation (getty images)



We have a choice: attend to the source of **pain** or carry on regardless.

If we were **automatons**, pain would only need to be an **informative** signal.

If we are **free evaluative agents**, pain has to provide a **motivation** for behaviour change.



# Some Definitions

# What is Pain?



Gout: from Podiatry Coding. com

*“An unpleasant sensory and emotional experience associated with, or resembling that associated with, actual or potential tissue damage”*

The International Association for the Study of Pain (IASP)

A qualitative feeling, not just a (nociceptive) signal.



# What is Pain?



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*“An unpleasant **sensory and emotional experience** associated with, or resembling that associated with, actual or potential tissue damage”*

**Official**

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A qualitative feeling, not just a (nociceptive) signal.

# Qualitative subjective feelings

Exactly what it feels like  
to have the experience of  
sucking a strong mint.

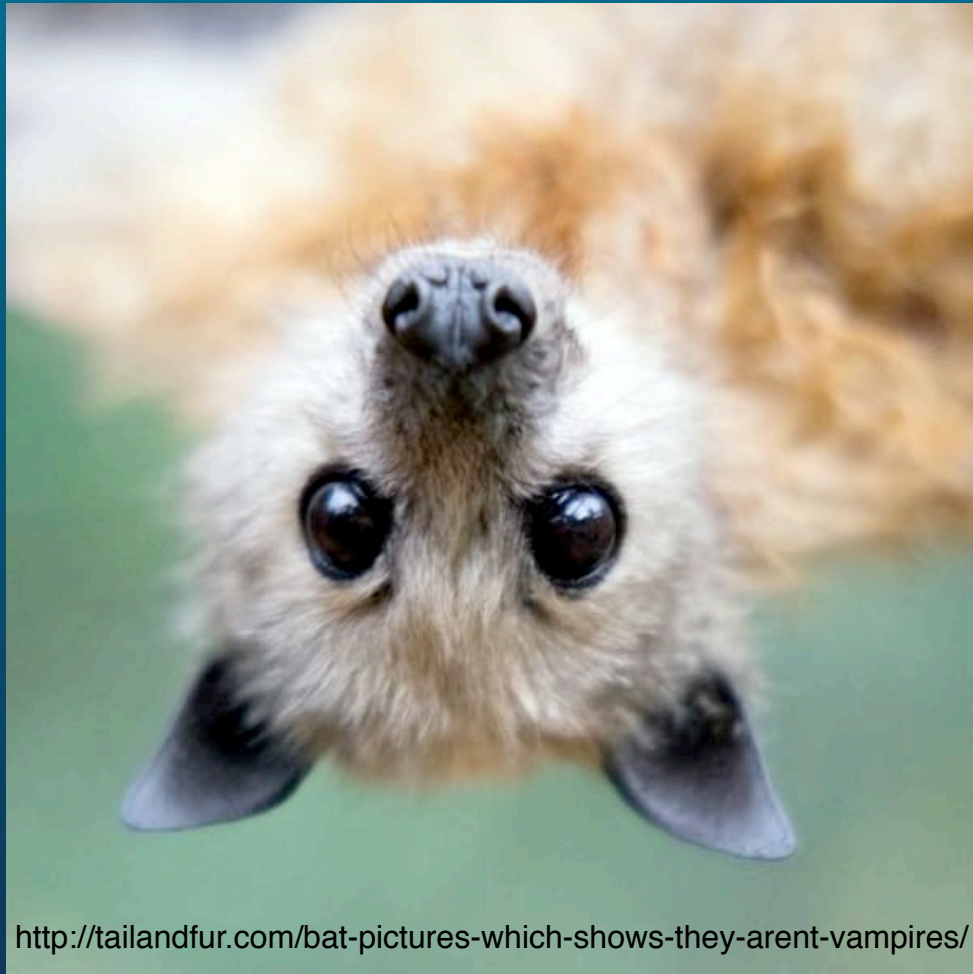


Philosophers call these ineffable internal experiences

## Qualia

*“What happens in my head stays in my head”.*

# What is it like to be a bat? (Thomas Nagel, 1974).



<http://tailandfur.com/bat-pictures-which-shows-they-arent-vampires/>

Thomas Nagel (Philosopher)



Flying fox *Pteropus poliocephalus*

...you can only know if you are a bat.



# Sentience

The capacity to feel, including sensory experiences (e.g. visual, auditory, tactile, olfactory) as well as feelings of warmth, comfort, fatigue, hunger, thirst, distress, anxiety, pain, pleasure and joy.

Andrew Crump et al. 2022. Anim. Sentience 32



vegan-supermarket.uk

It is one of the components of consciousness.

Sentience is self-evidently needed for pain, but consciousness might not be.

# Emotion (Affect)

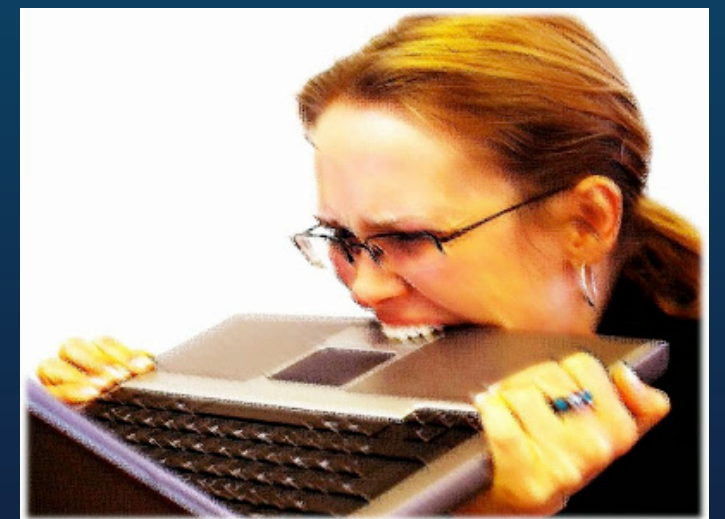
Sentience seems always to involve emotion.

Emotion is “*not mere phenomenal states but evaluative responses to one's situation*”. Helm, 2002. Am. Philos. Q. 39, 13–30.

Affect is a top-level phenomenon that sets the internal context for information processing and *action selection*:

It's an internal psychological milieu (literally, via neurohormones) modulating the parameters of judgement. To that extent emotions are *evaluative in function*.

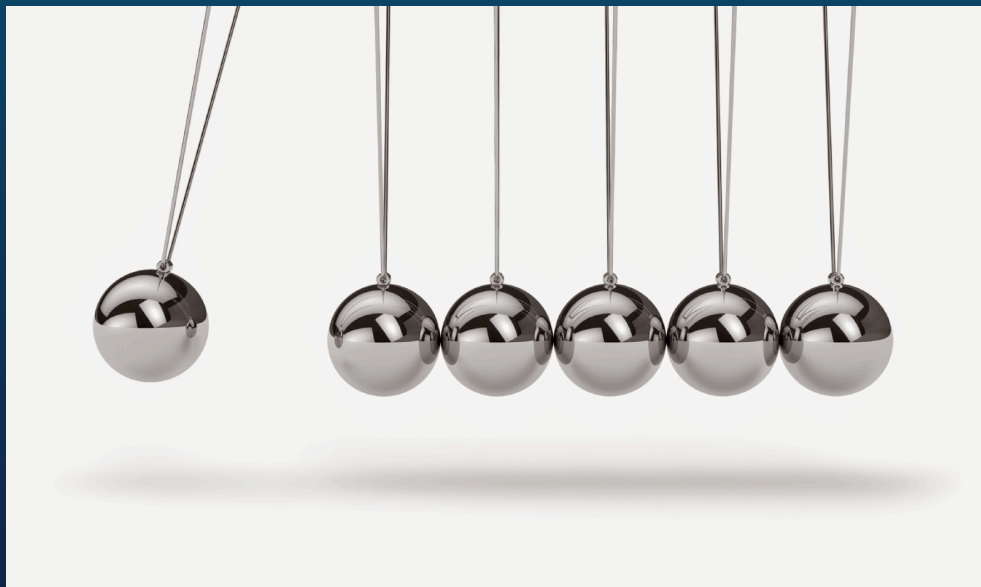
*We've all been there!*



# Biological Autonomy

Both **evaluation** and **action selection** imply autonomy: the ability to decide what to do, independent of exogenous control.

But autonomy is a violation of the laws of physics.



*For every cause there is an effect and for every effect there is a cause.*



*That is consistent with standard physics.*

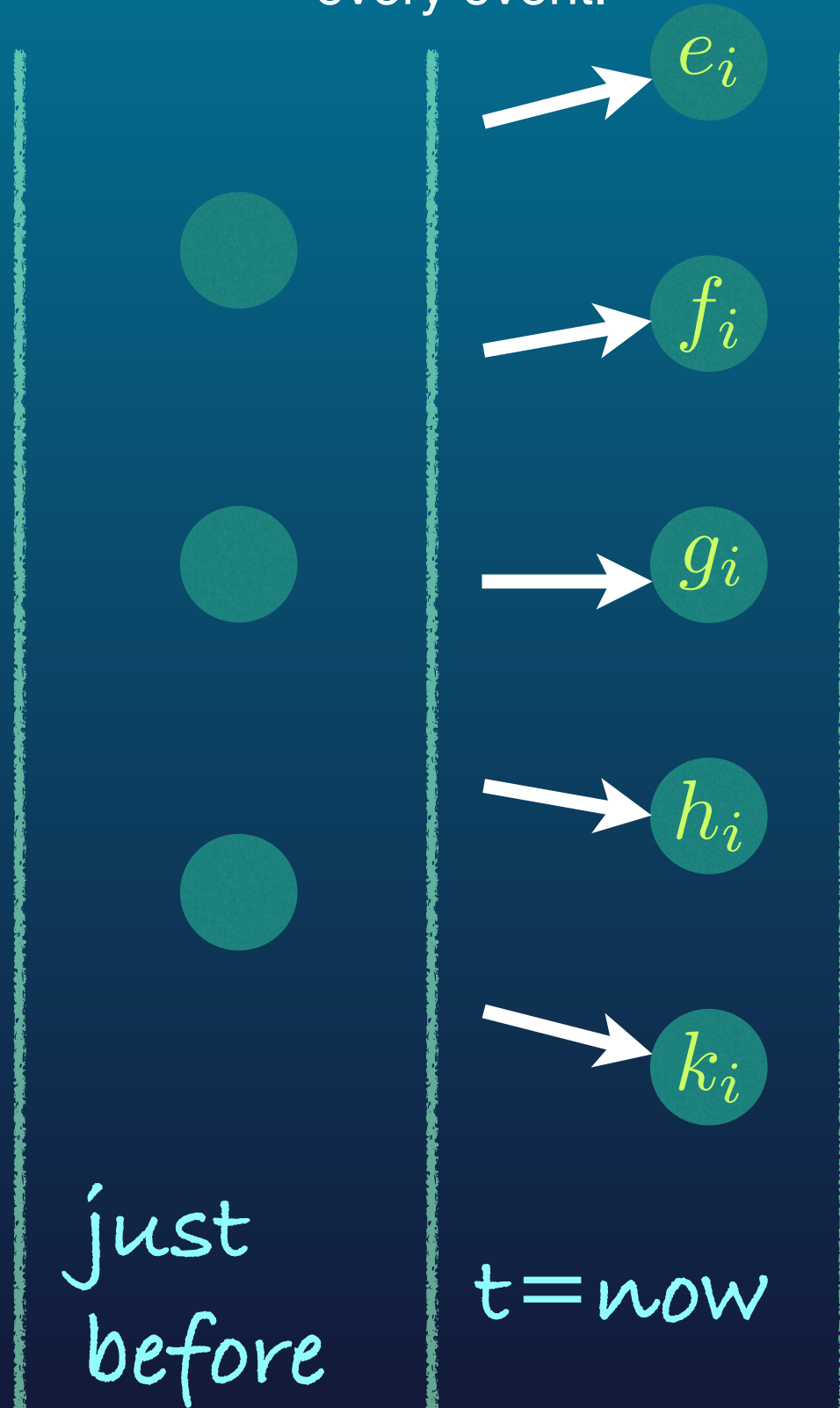
There is a prior cause for every event.



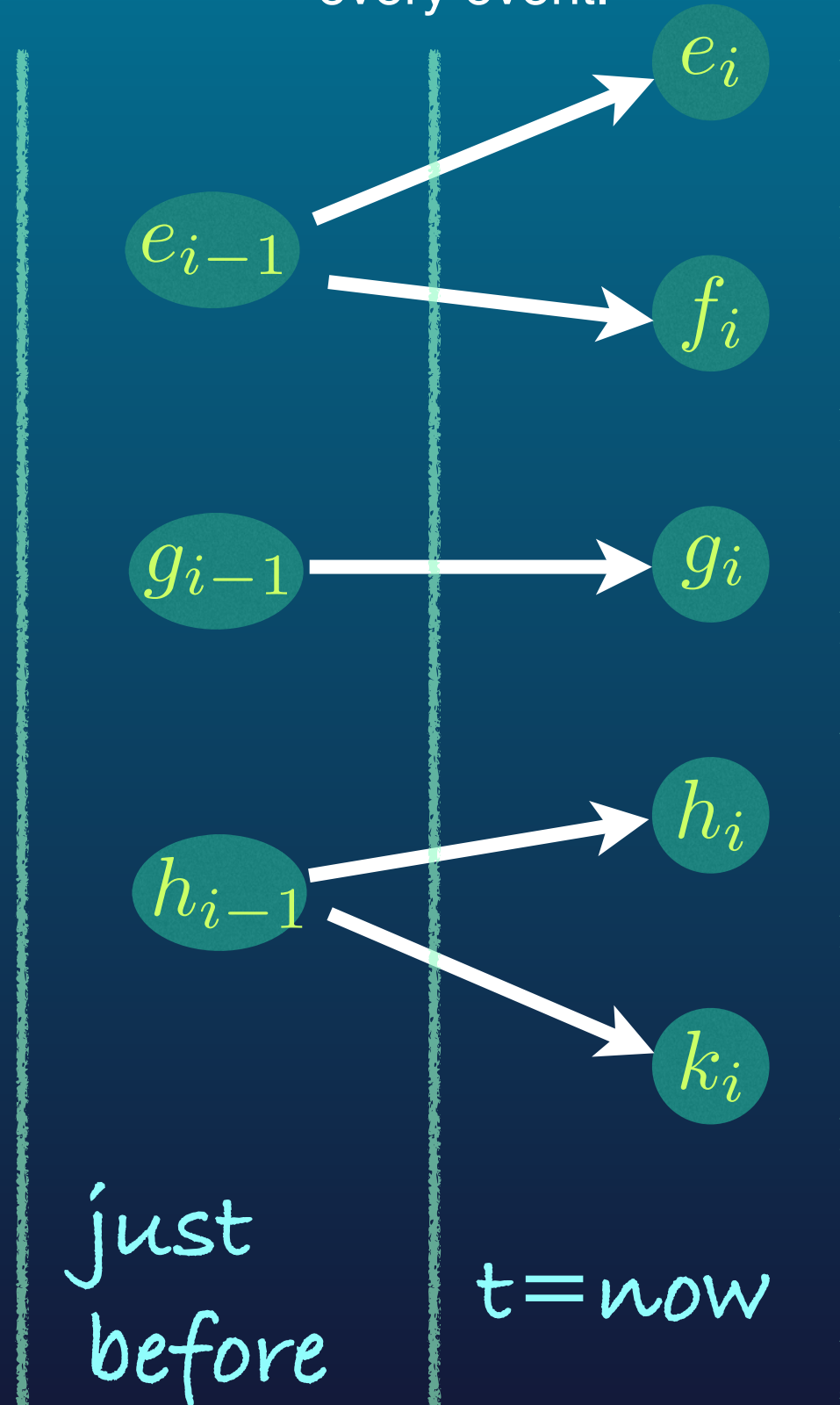
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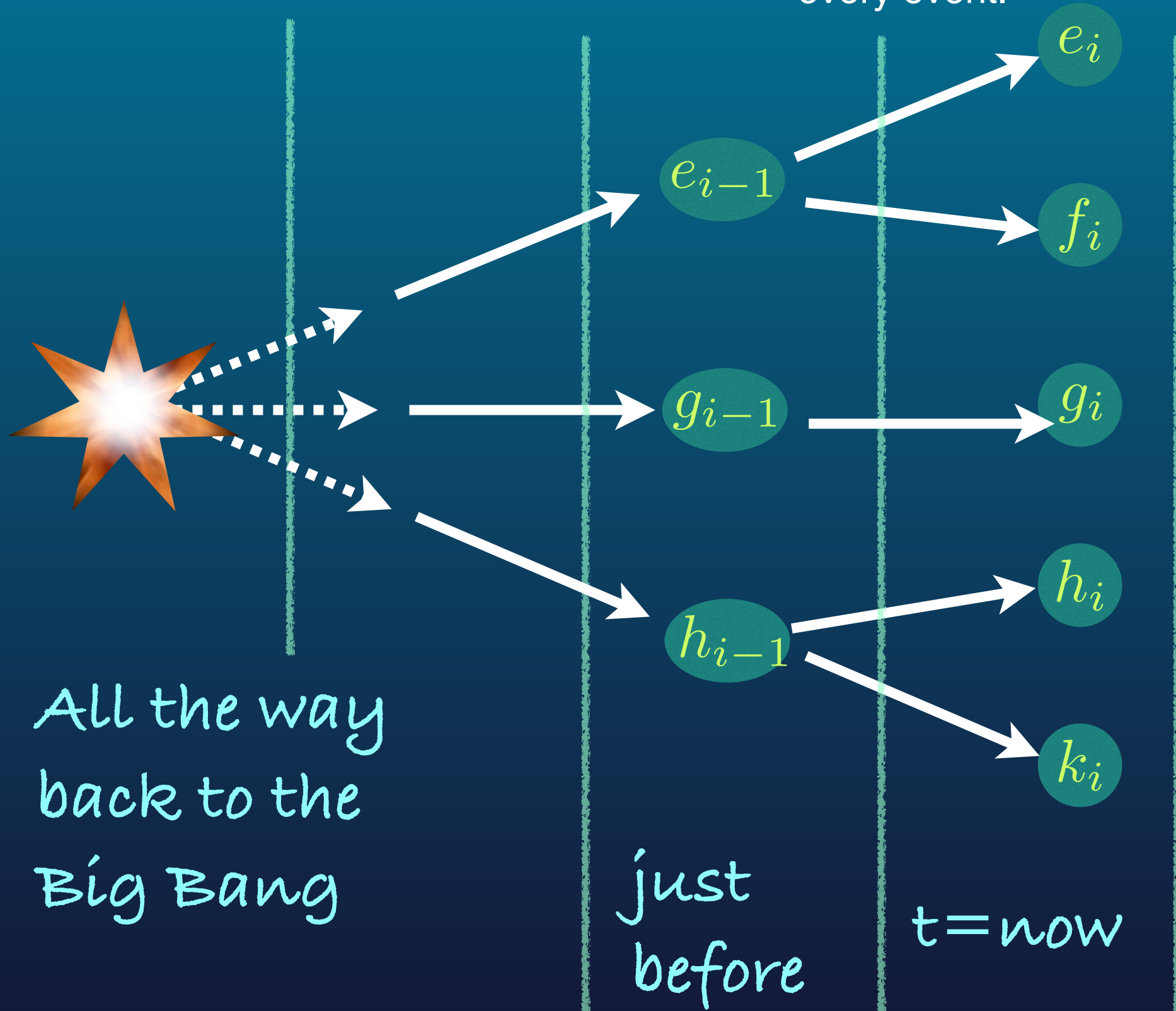
There is a **prior** cause for every event.



There is a **prior** cause for every event.



There is a **prior** cause for every event.



All the way back to the Big Bang

just before

t=now

$$\frac{dx}{dt} = v - gt$$



<https://www.throwballkerala.com/>

The law of cause and effect makes the ball's trajectory predictable\* and totally explicable:

As Newton said -

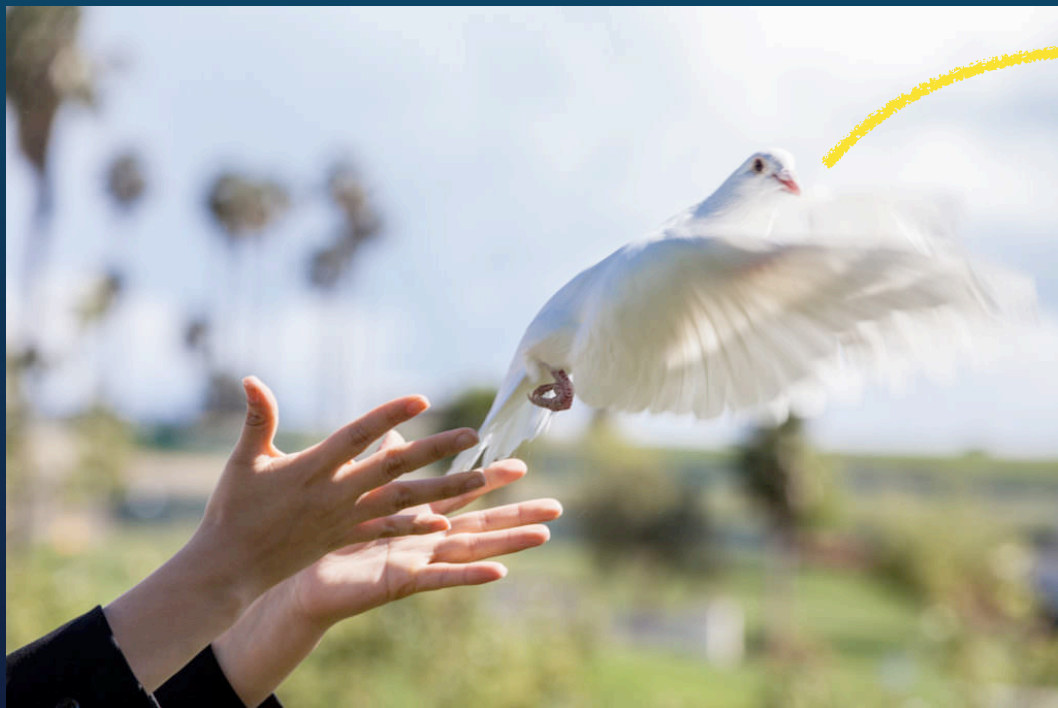
*every force has an equal and opposite reaction.*

\* (As long as you know the initial conditions)



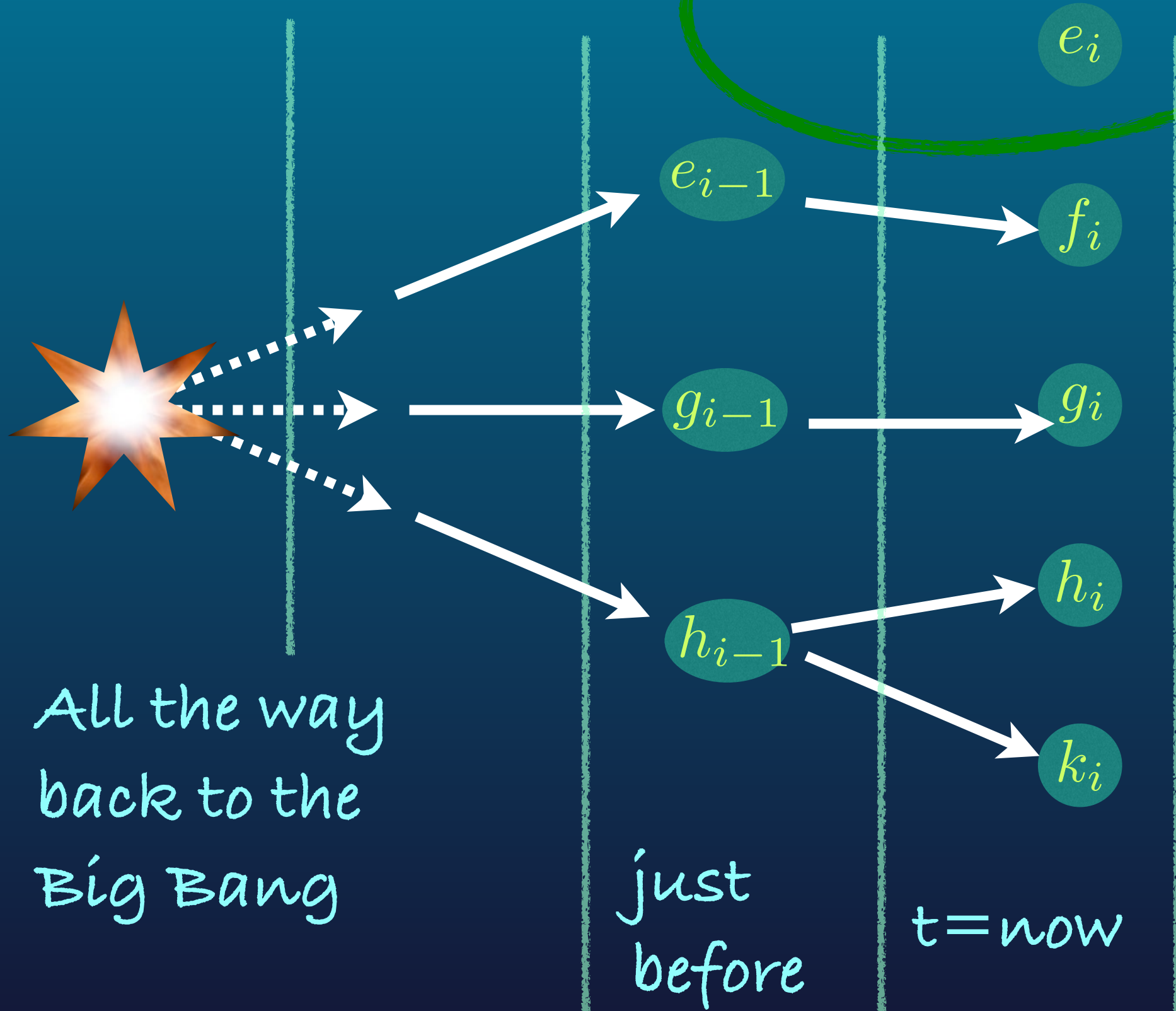
...But try throwing  
a live bird...

... and physics completely  
fails to explain what  
happens next.



?

Life seems to display **agent causation** with no **prior** cause.



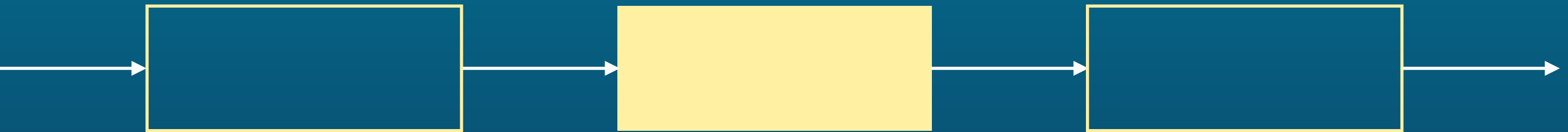
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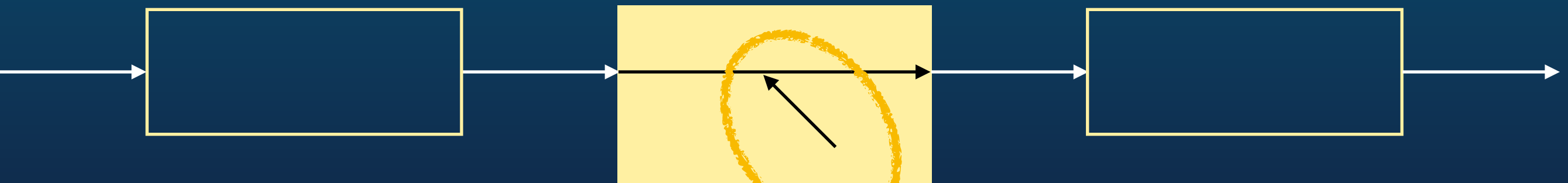
t=now

Autonomy effectively means the introduction of a new cause *from within*.

a normal causal chain



an autonomous agent in the chain



where does this  
cause come from?

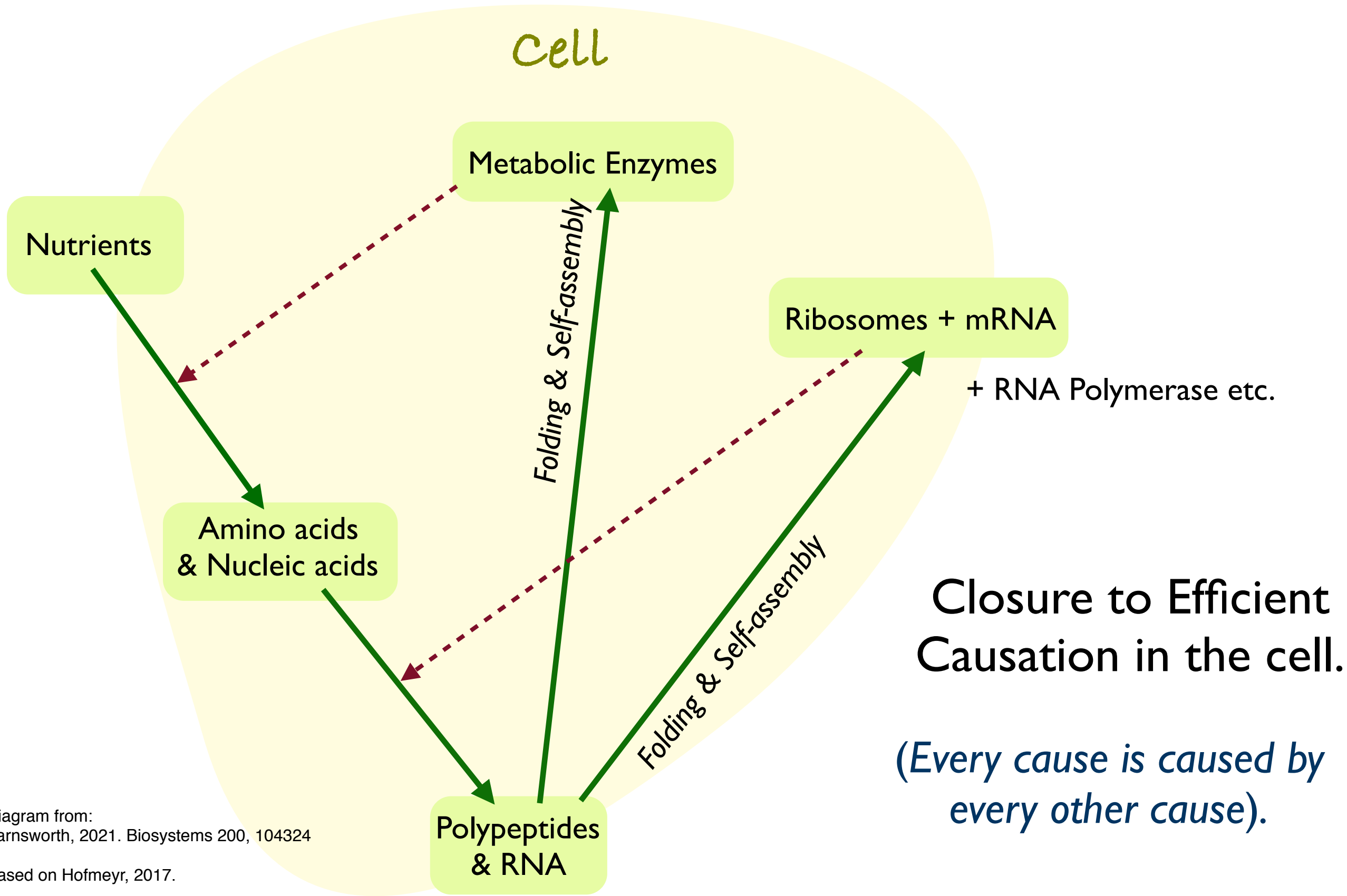
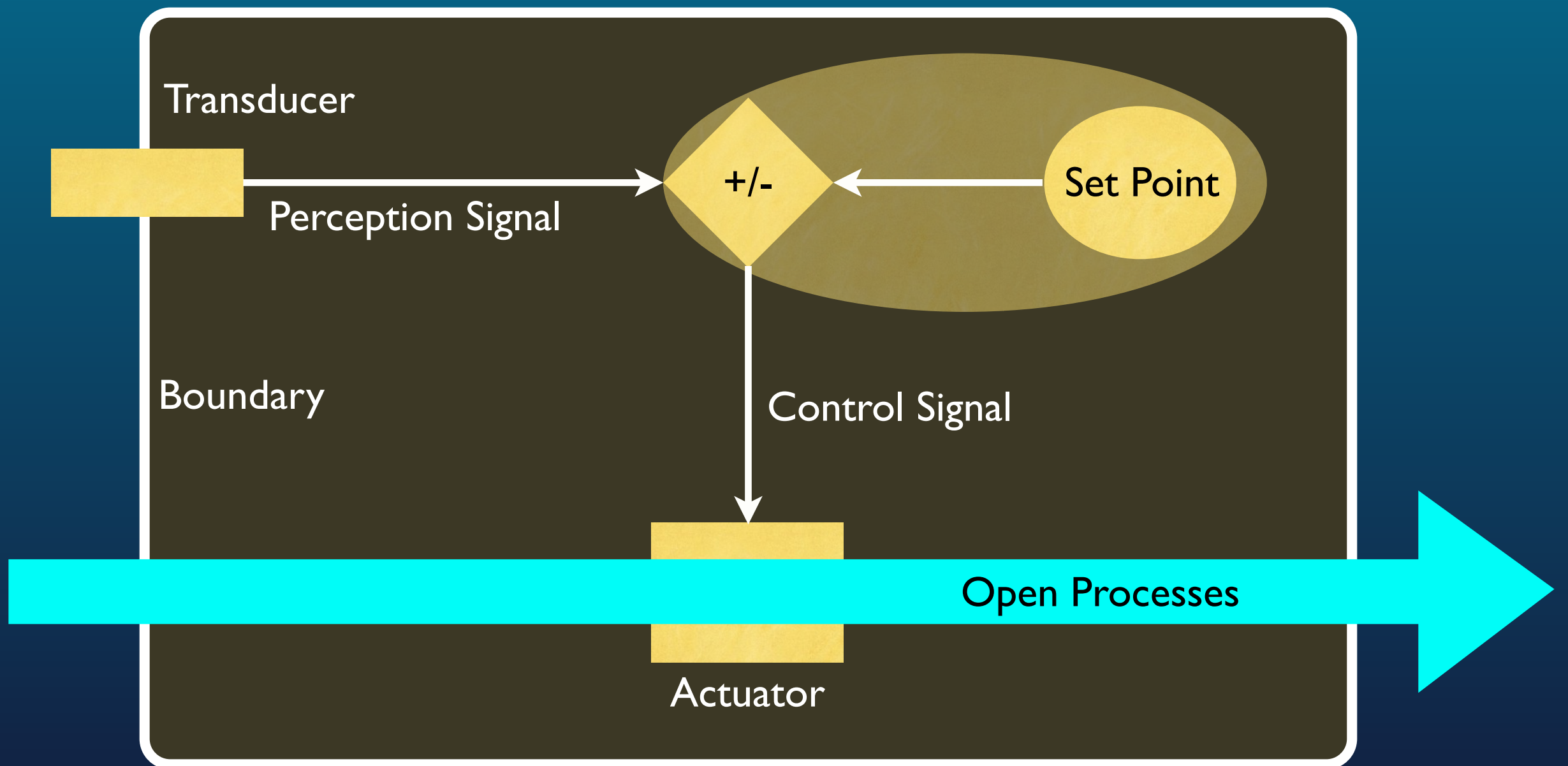


Diagram from:  
Farnsworth, 2021. Biosystems 200, 104324  
Based on Hofmeyr, 2017.

**Material transformation (material cause)**

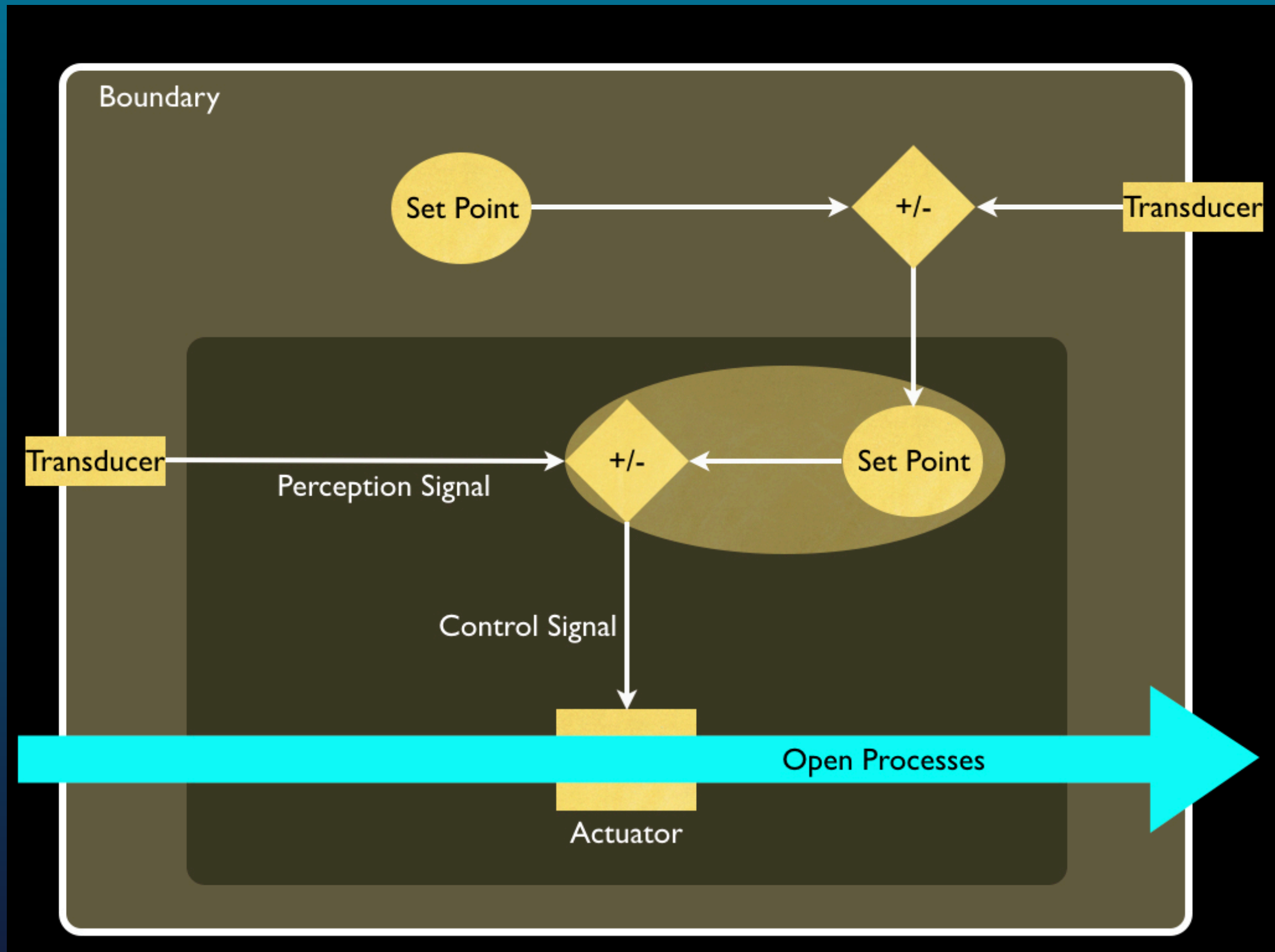
**Catalysis (efficient cause)**

Circular causation allows cybernetic independence based on homeostatic set-points (internalised information).





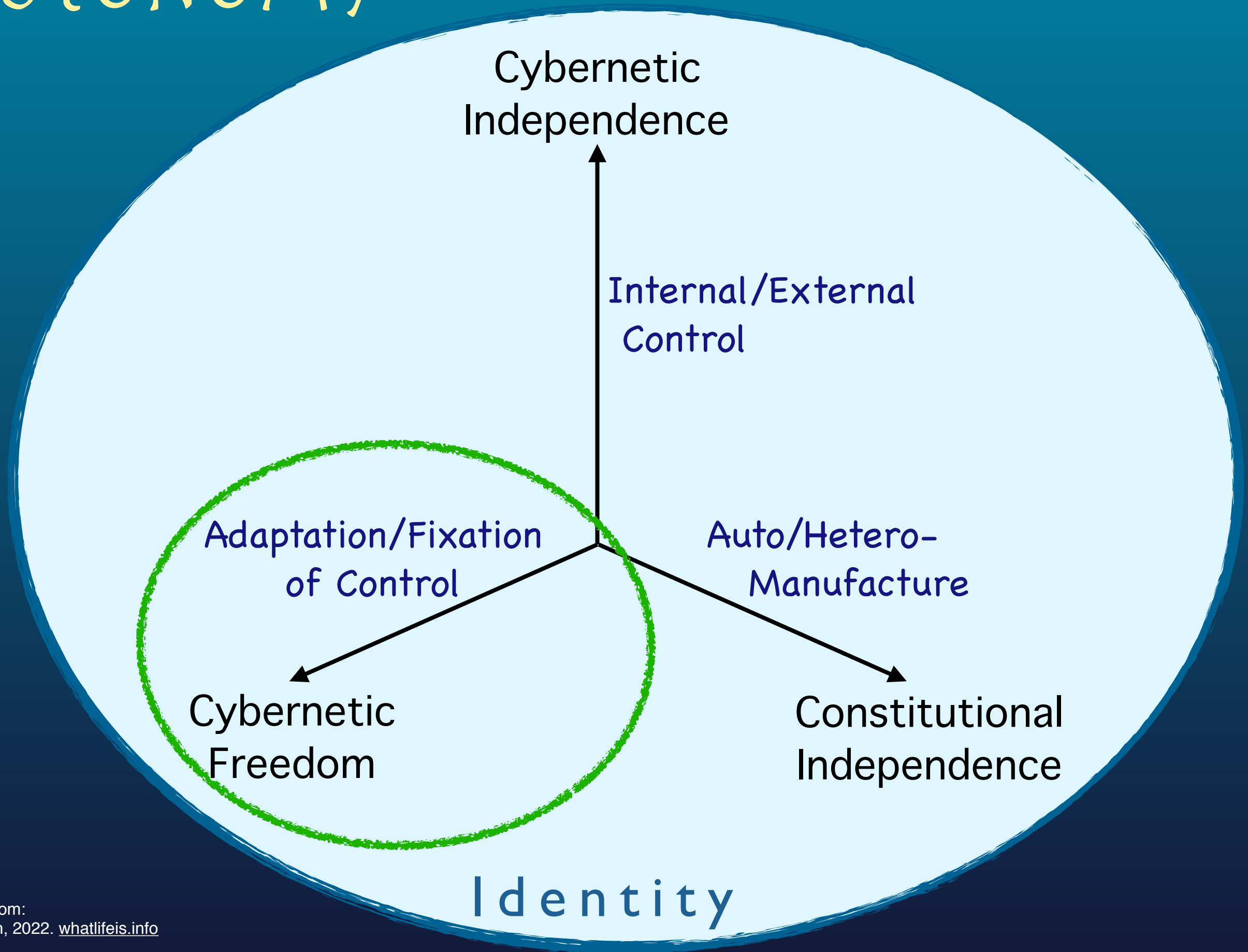
# Nesting set points creates cybernetic flexibility



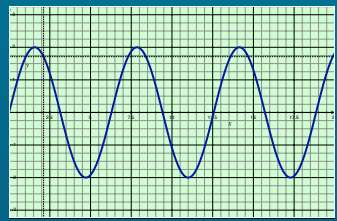
# How biological autonomy is constructed



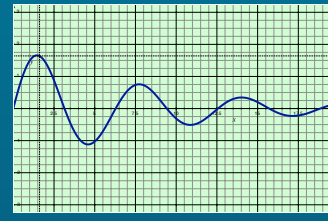
# AUTONOMY



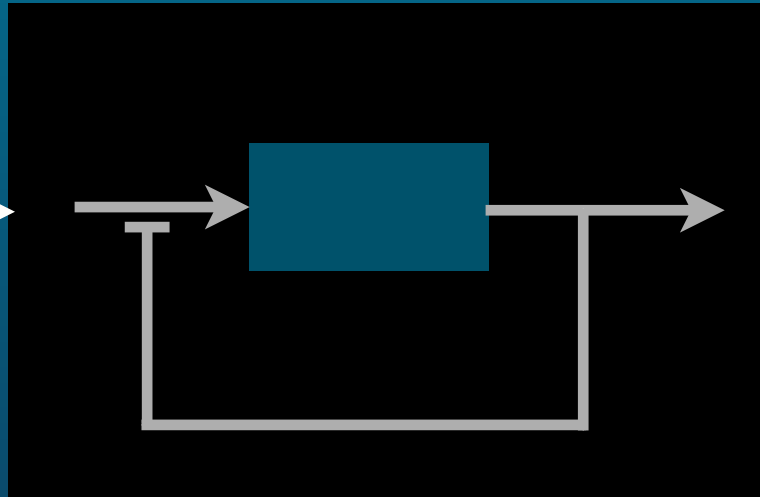
*Behaviorists believe in a **direct causal connection**.*



**Black Box**



**Input**



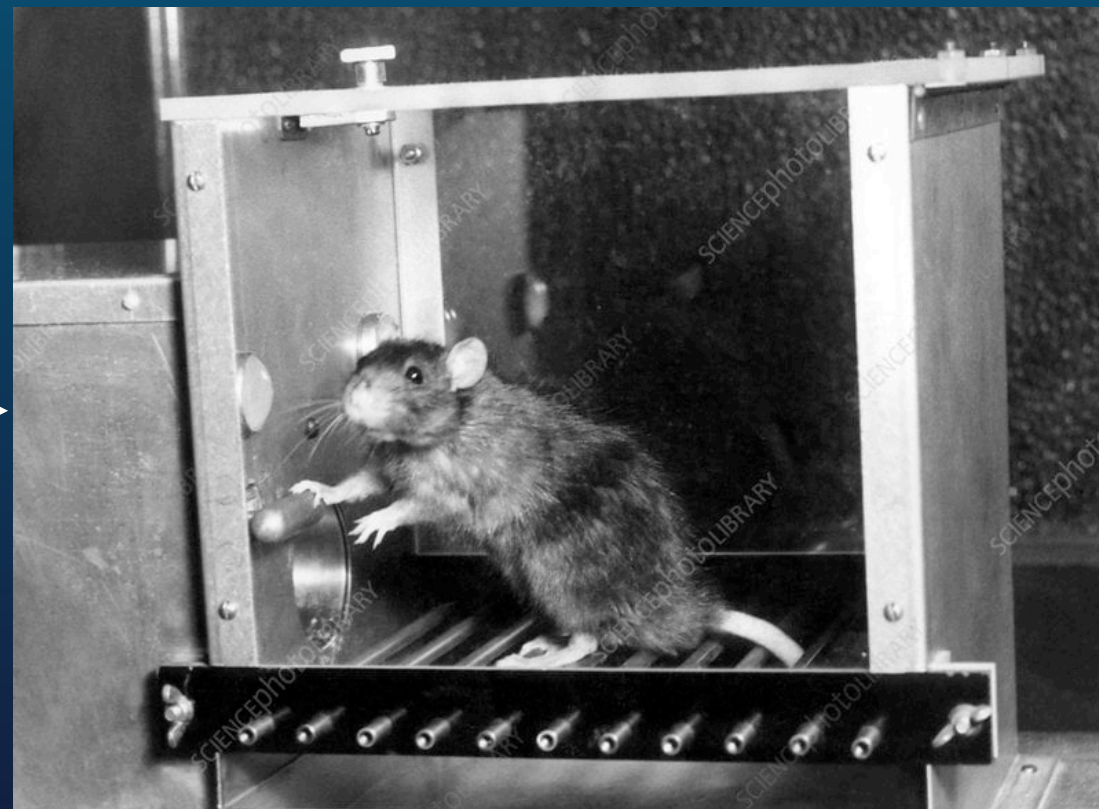
**Output**



**Cause**



**Stimulus**



**Effect**



**Response**

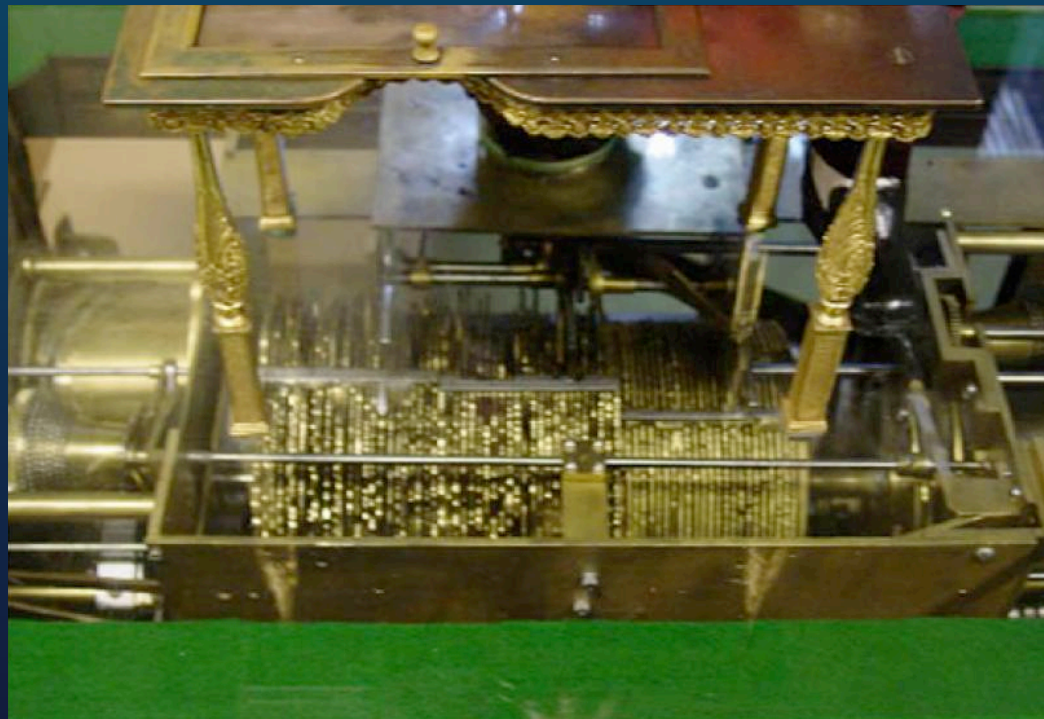
**Skinner Box**

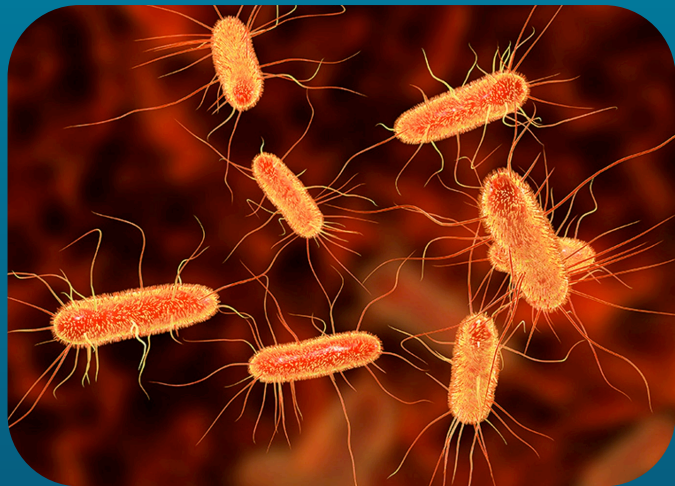


# The Automaton

Maillardet's automaton,  
Franklin Institute, Philadelphia

Toothed wheels embody information in their form,  
which controls the behaviour of the automaton.





*E. Coli*

*C. Elegans*



<http://www.socmucimm.org/>



*Protozoan Stentor.*

Temple University ([www.studyblue.com](http://www.studyblue.com))

Automatons:  
behaviour is under  
algorithmic control,  
“hard wired”.





## Definitely not an automaton

*Cats do just as they please  
and it's rarely predictable*

*But why are they not just  
running a very complicated  
algorithm?*

The answer is that there is no necessary connection between input (stimulus) and output (response).

*A cat is not a black box.*



# But what about these?

hermit crab (~800 spp.)



<http://true-wildlife.blogspot.com/2011/02/hermit-crab.html>

*Melanogaster Neivamyrmex*

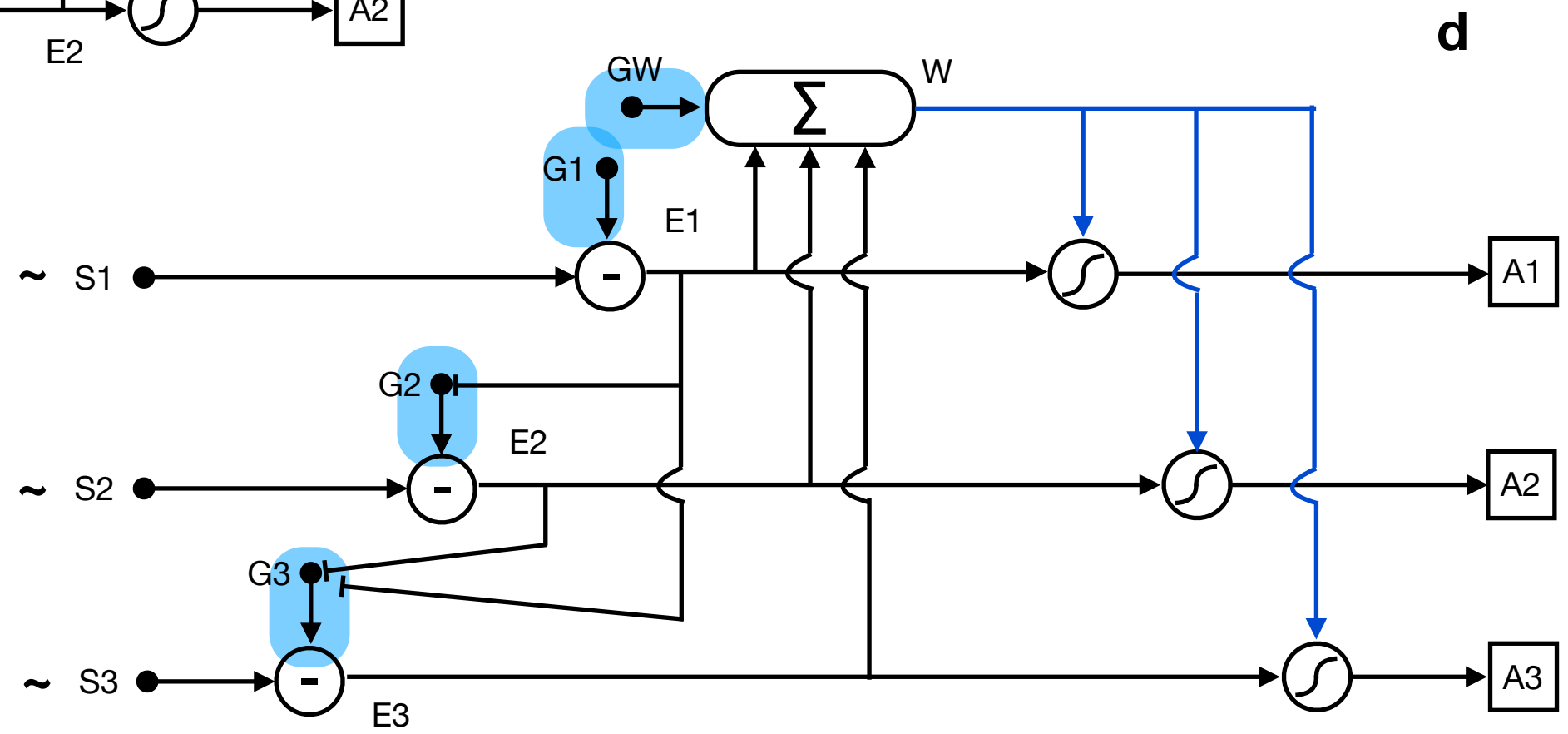
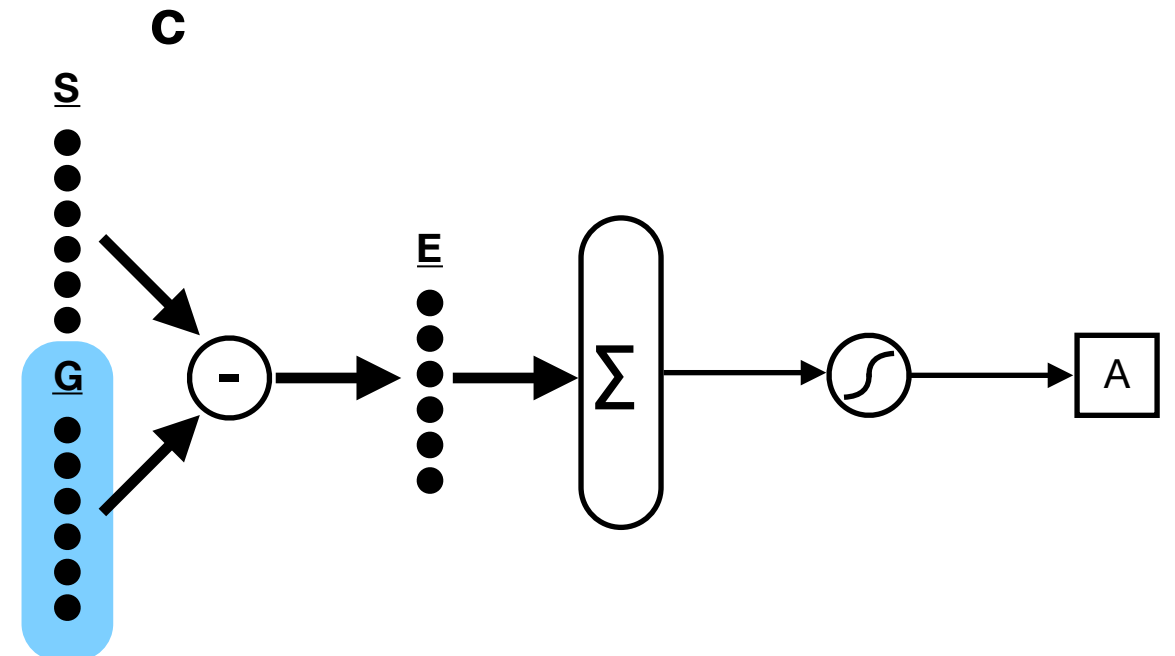
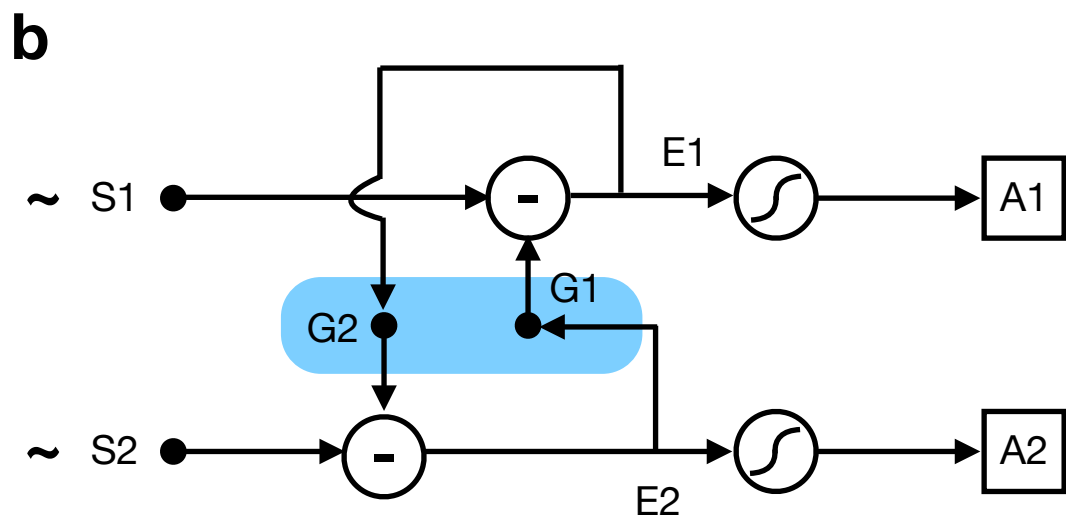
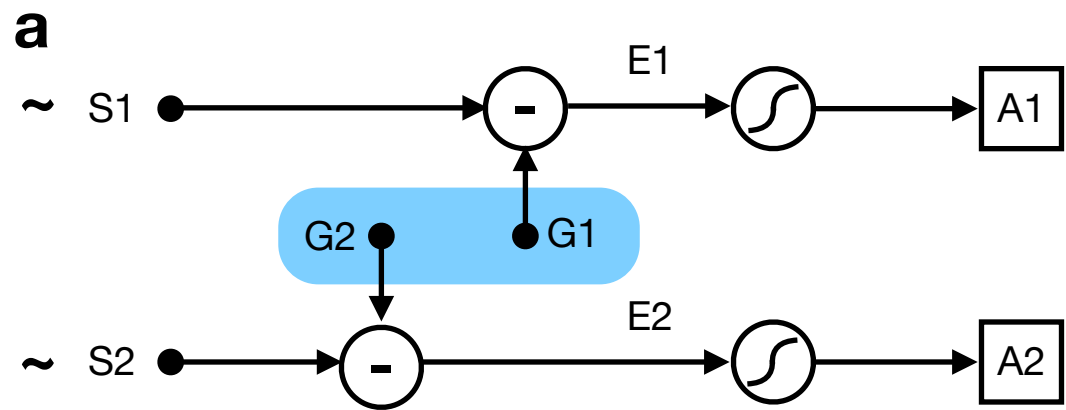


[Phil Hönle](#)

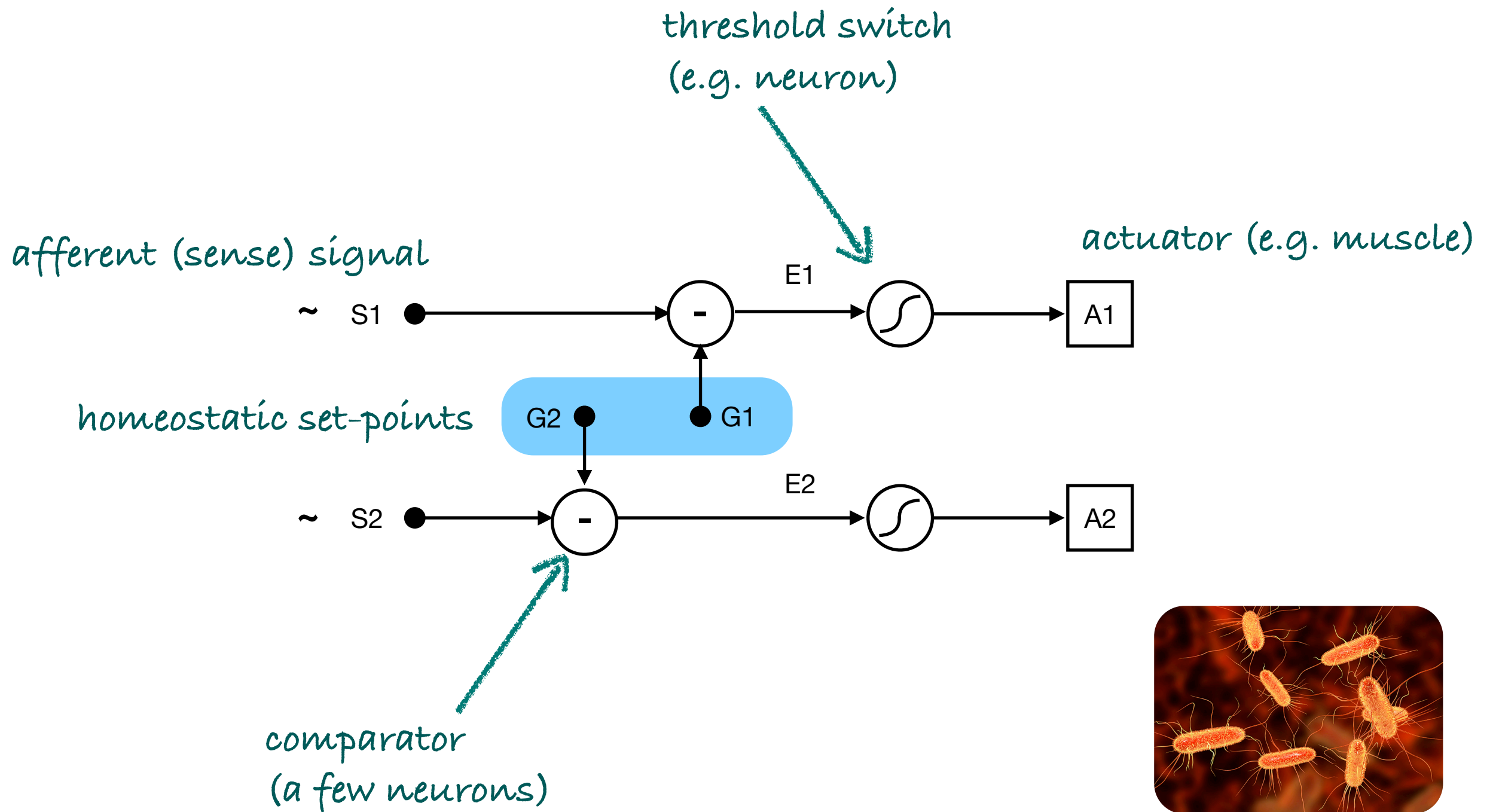
*Drosophila Melanogaster*



Vienna Drosophila Resource Center (VDRC) | VBCF



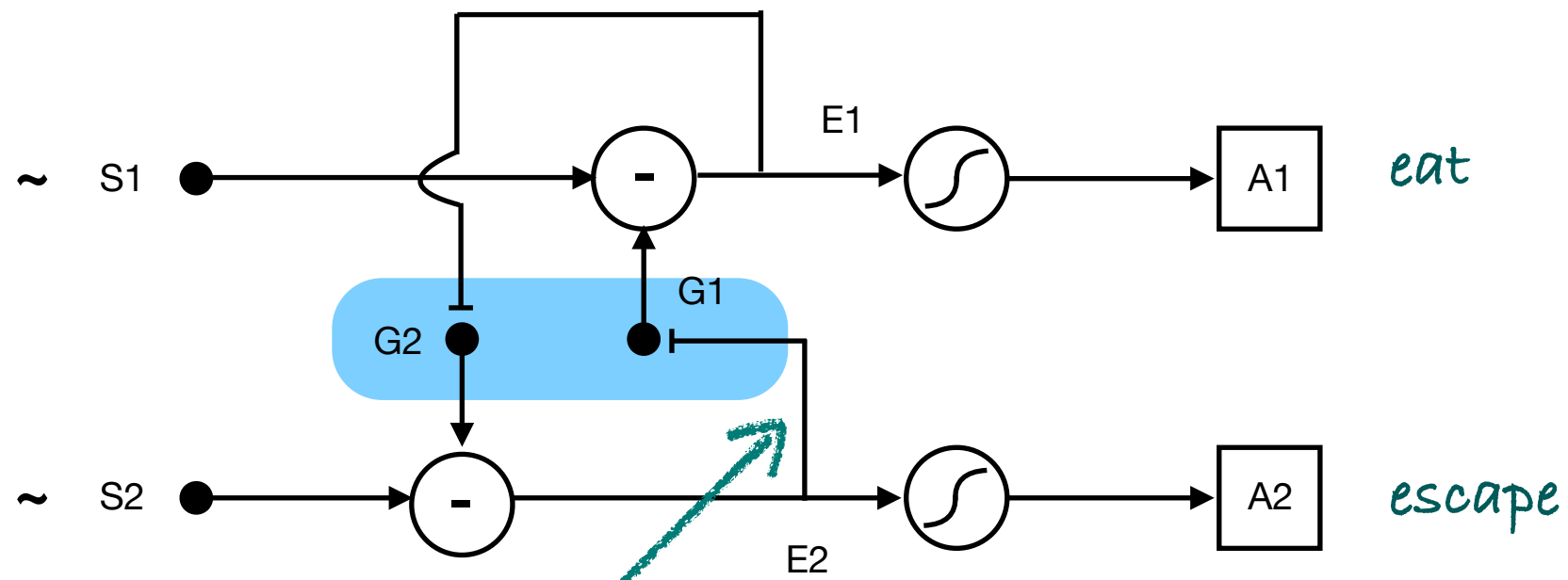
# Simple reactive action-selection system



Can be implemented in biochemical networks



# Reactive action-selection system...

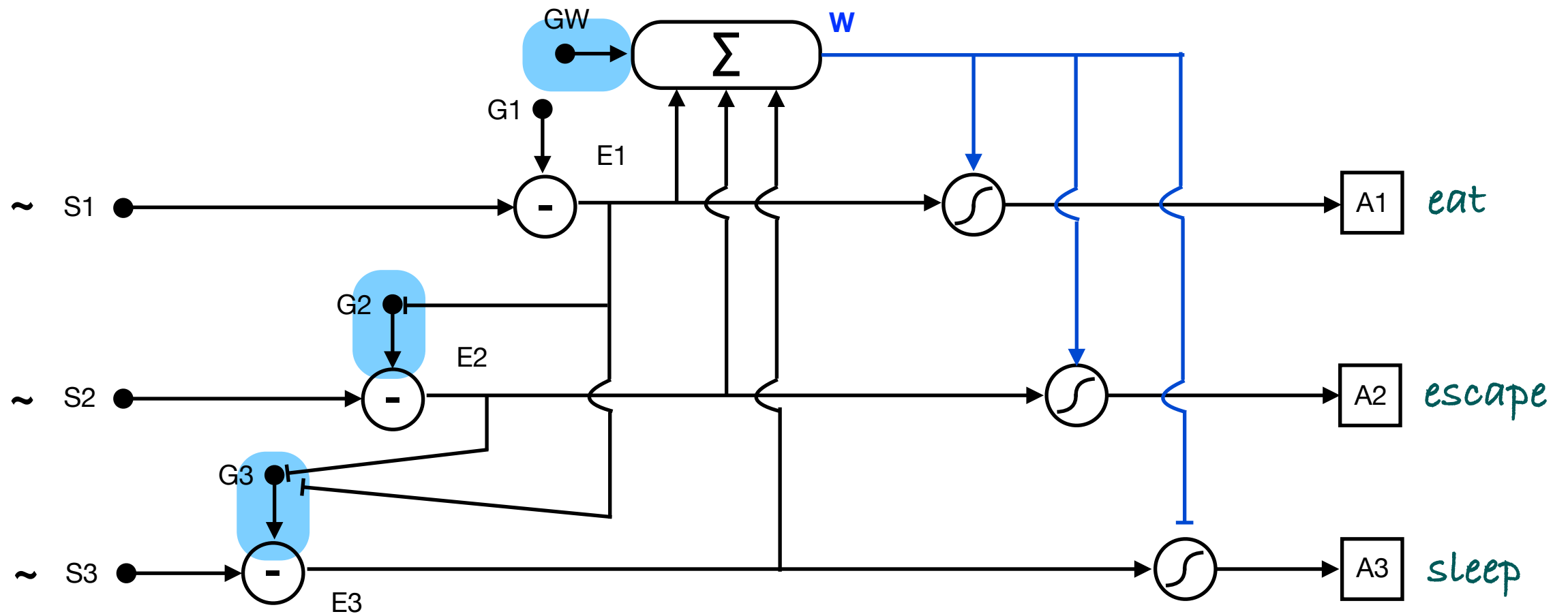


*mutual inhibition of actions  
based on strength of error signals*



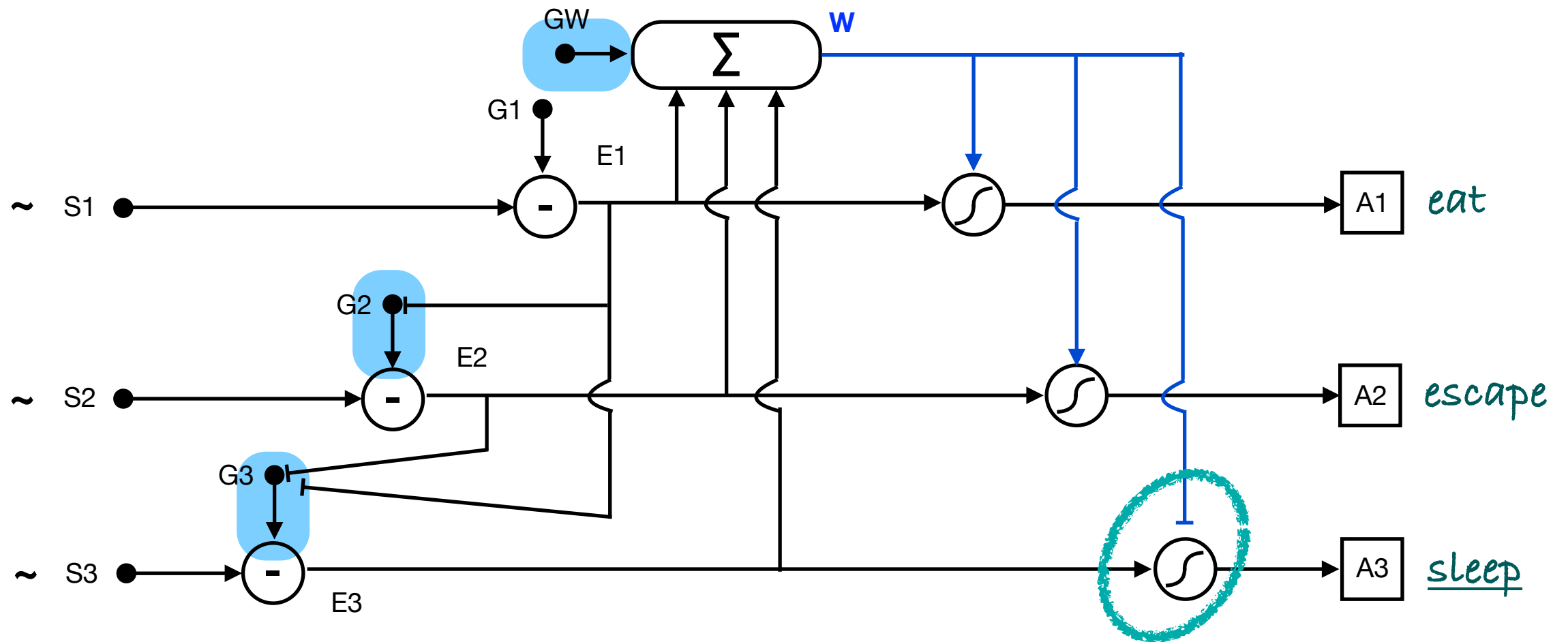
with mutual control over set-points to effect trade-off decision-making

## Reactive action-selection system with common currency



*As well as more complicated mutual inhibition, this sums error signals to create an overall 'arousal' signal that affects all the action thresholds simultaneously.*

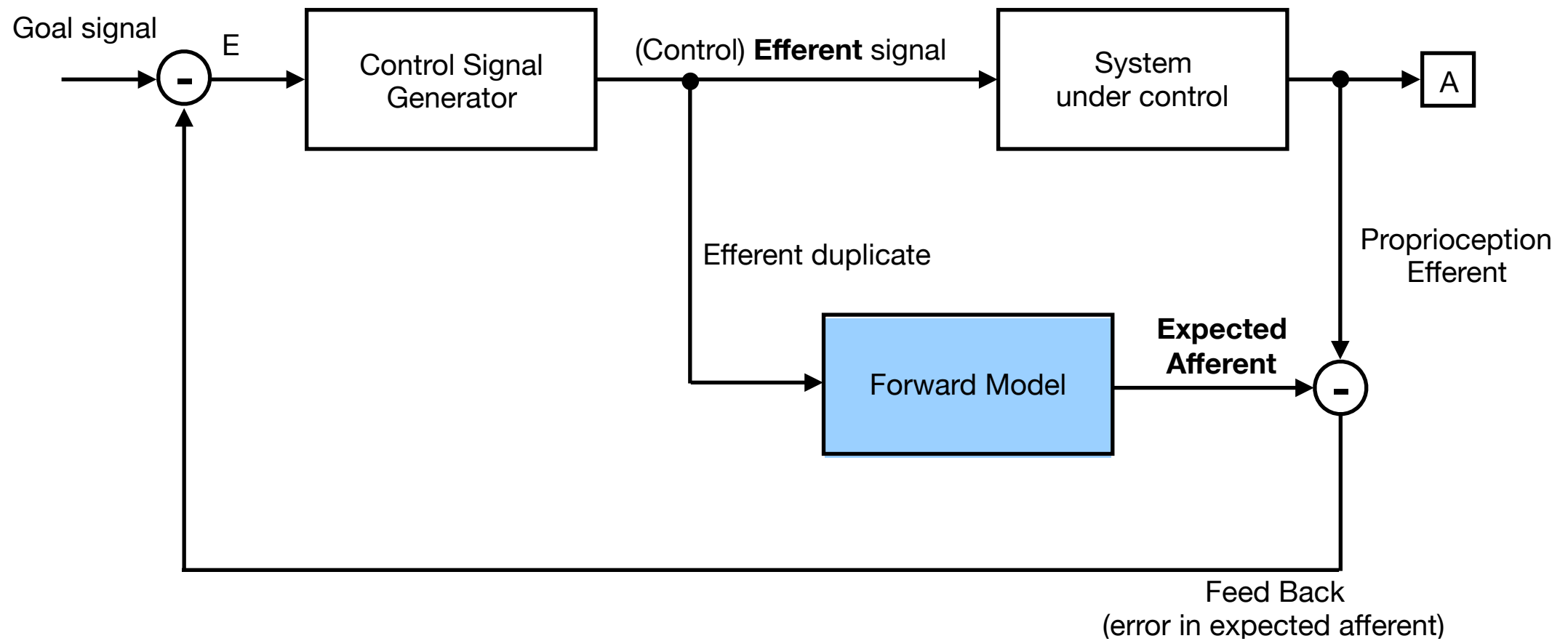
# Reactive action-selection system with common currency



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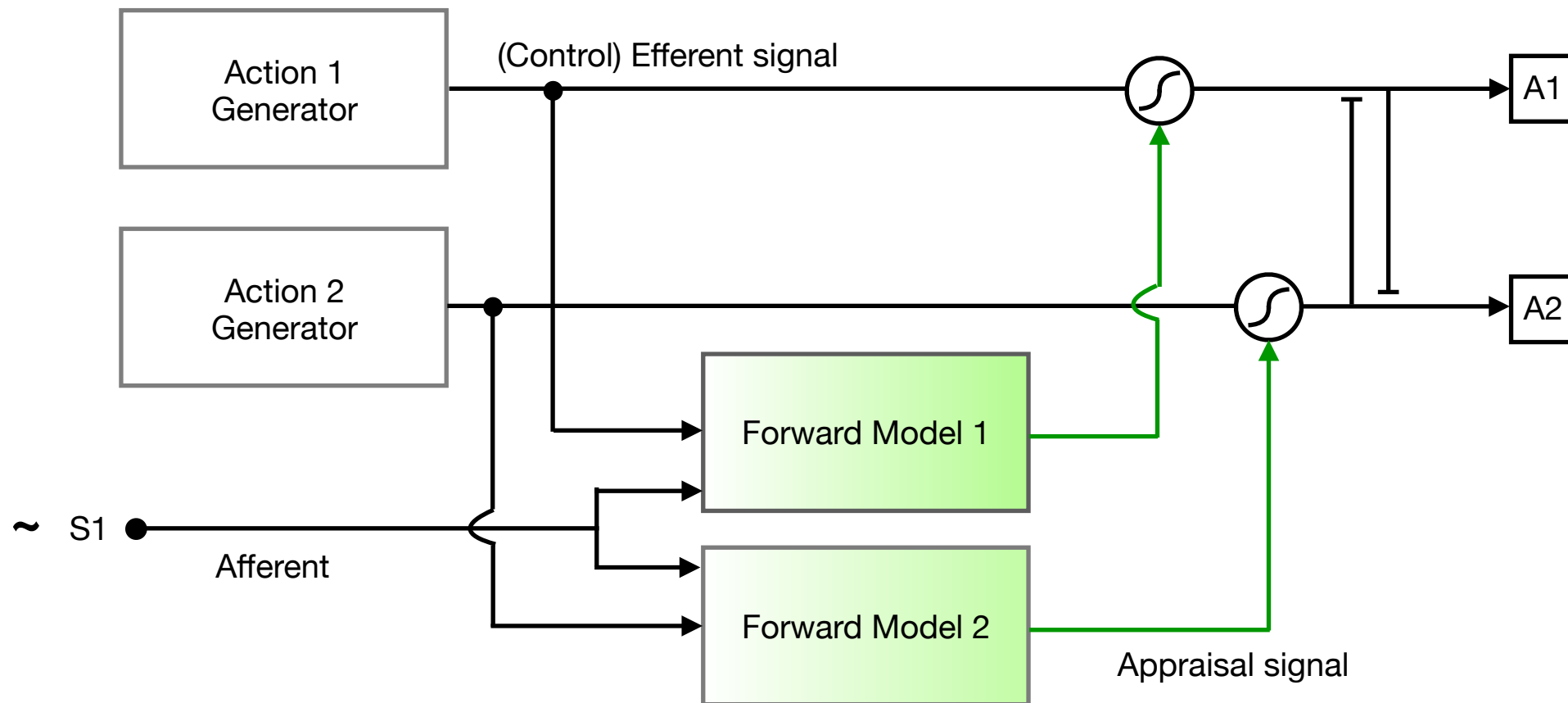
# A feed-forward control system for anticipation



'Spot' the robot dog, by Boston Dynamics, out for a run. It used Feed-forward servo control in the legs to enable it to walk and run like a dog.



# A feed-forward predictive action selection system



*Multiple forward models output an appraisal signal in a universal hedonic currency enabling choices to be made.*

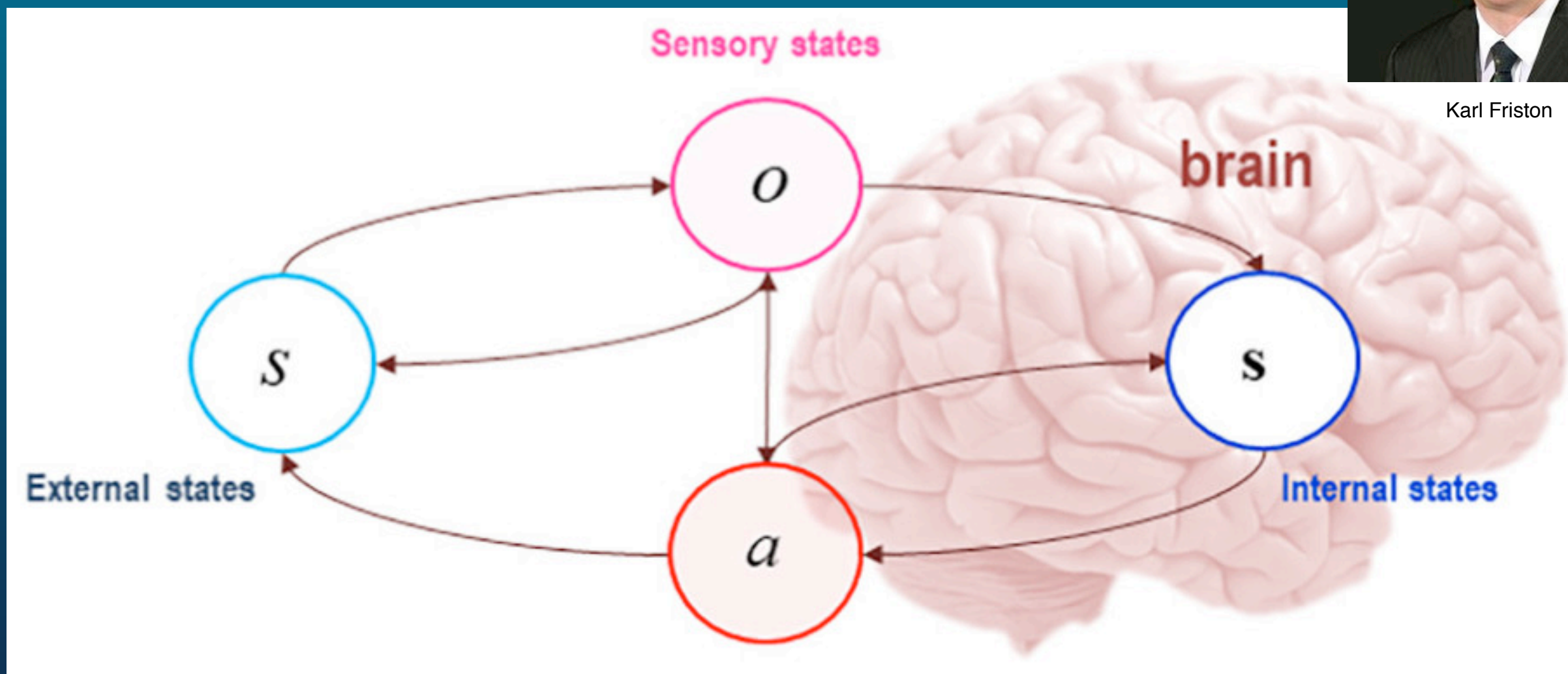
There is no longer a direct link between input and output. We have true autonomy.



# One leading hypothesis about how it is done: **Active inference** (a model of the self)



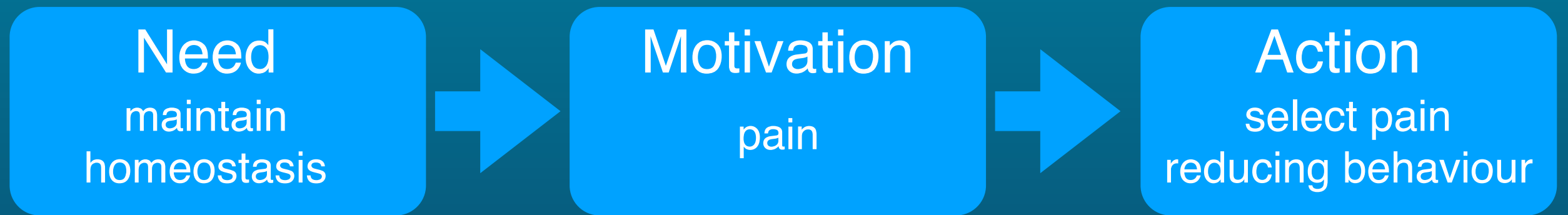
Karl Friston



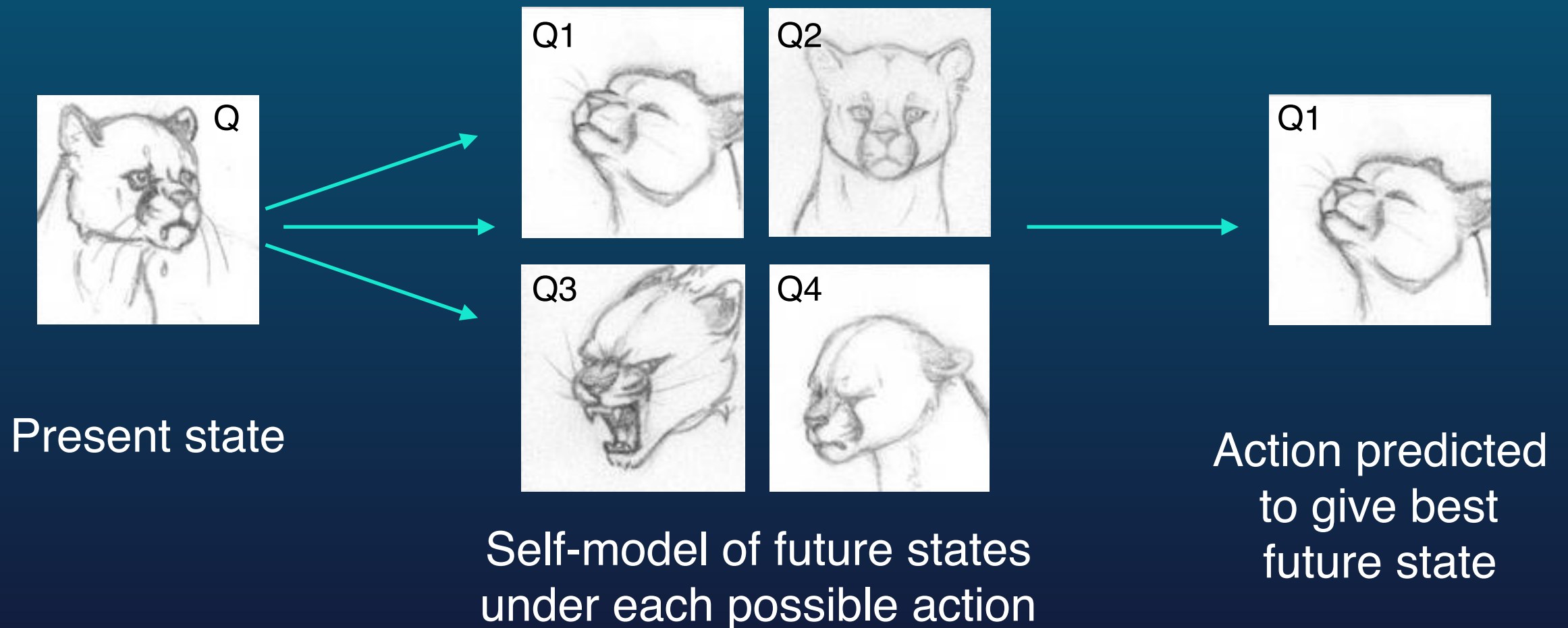
Friston et al. 2017. The graphical brain: Belief propagation and active inference. *Network Neuroscience*, 1, 381–414.

## Uses hidden Markov model implemented in a neural network

# What the control system tries to do



## and how self-modelling helps



# The Q-state

exactly what it is like to be the system in a particular state.

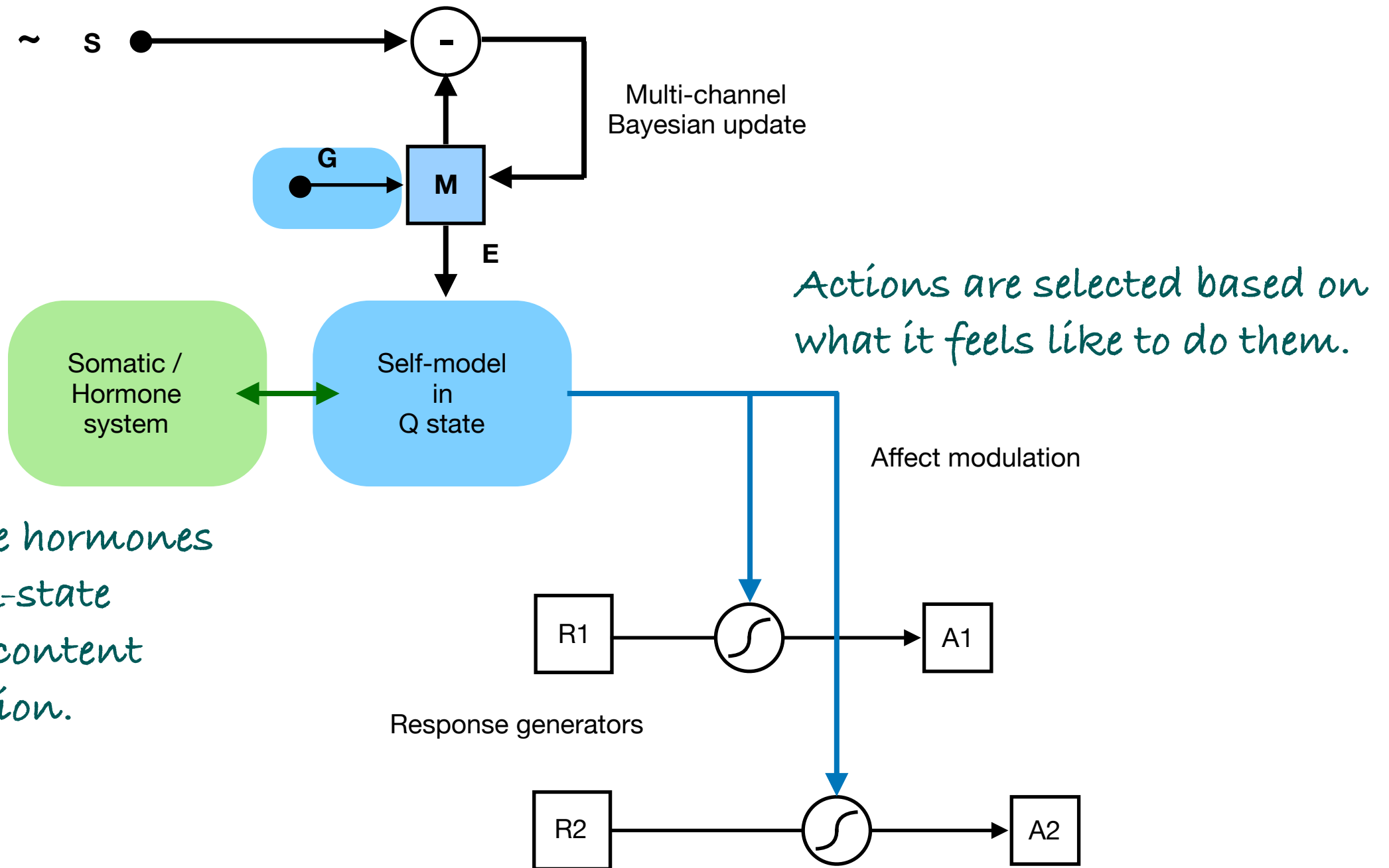
*Neural network in one of billions of possible states*

*An integrative summary of the state, suitable for evaluation.*





# Anticipatory Behavioural Autonomy system



# Empirical Evidence for Anticipatory Behavioural Autonomy

# Pain should elicit **persistent** changes of behaviour through modulation of action selection

- *changed shell preference in hermit crabs*<sup>1</sup>
- *anxiety-like states in fish and amphibians*<sup>2,3</sup>
- *conditioned place avoidance (crabs fish and octopus)*<sup>4,5,6</sup>

1 Appel & Elwood, 2009

4 Magee & Elwood, 2009

2 de Abreau et al., 2020

5 Crook, 2021

3 Brown et al., 2013

6 Milsop and Laming, 2008

# Evidence for ABA in animals.

*(Anticipatory Behavioural Autonomy)*

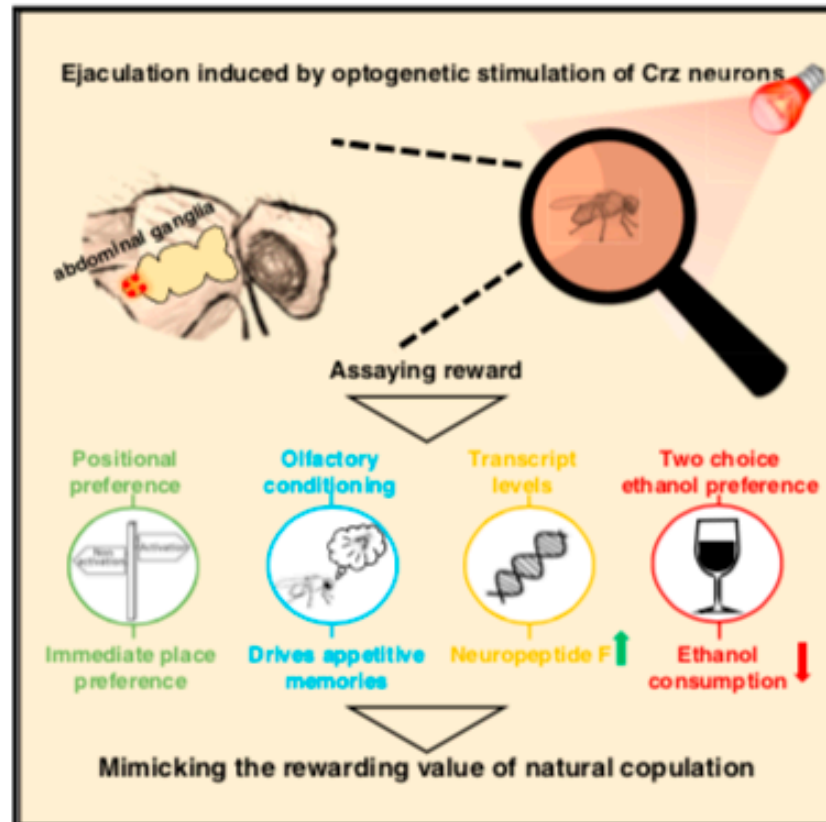
- 1) Models of the self / environment with **hedonic signal** output.
- 2) **Flexibility** in behavioural responses to stimuli (showing that options are available).
- 3) Proactive choice and forward planning (**actions based on anticipated consequences**).
- 4) Free choice of response to noxious stimuli (shown by e.g. **state-dependent trade-offs**).



# Current Biology

## Ejaculation Induced by the Activation of Crz Neurons Is Rewarding to *Drosophila* Males

### Graphical Abstract



### Authors

Shir Zer-Krispil, Hila Zak, Lisha Shao, ..., Assa Bentzur, Anat Shmueli, Galit Shohat-Ophir

### Correspondence

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### In Brief

Zer-Krispil et al. report that ejaculation induced by the activation of male-specific Crz neurons is sufficient to mimic all the rewarding aspects of successful copulation in *Drosophila*. The activation carries positive valence, induces *npf* transcript levels, drives appetitive memories, and reduces the motivation to consume ethanol as a drug reward.

♂ alcoholic *Drosophila* trade-off booze for sexual stimulation.



hedonic universal signal

### Highlights

- Ejaculation induced by activation of Crz neurons mimics mating reward in *Drosophila*
- Male flies self-administer optogenetic stimulation of male-specific Crz neurons
- The activation of male-specific Crz neurons drives appetitive memories
- Repeated activation of Crz neurons induces *npf* levels and reduces ethanol consumption



Individual differences (temperament) indicate possible behavioural flexibility.

Appel & Elwood, 2009

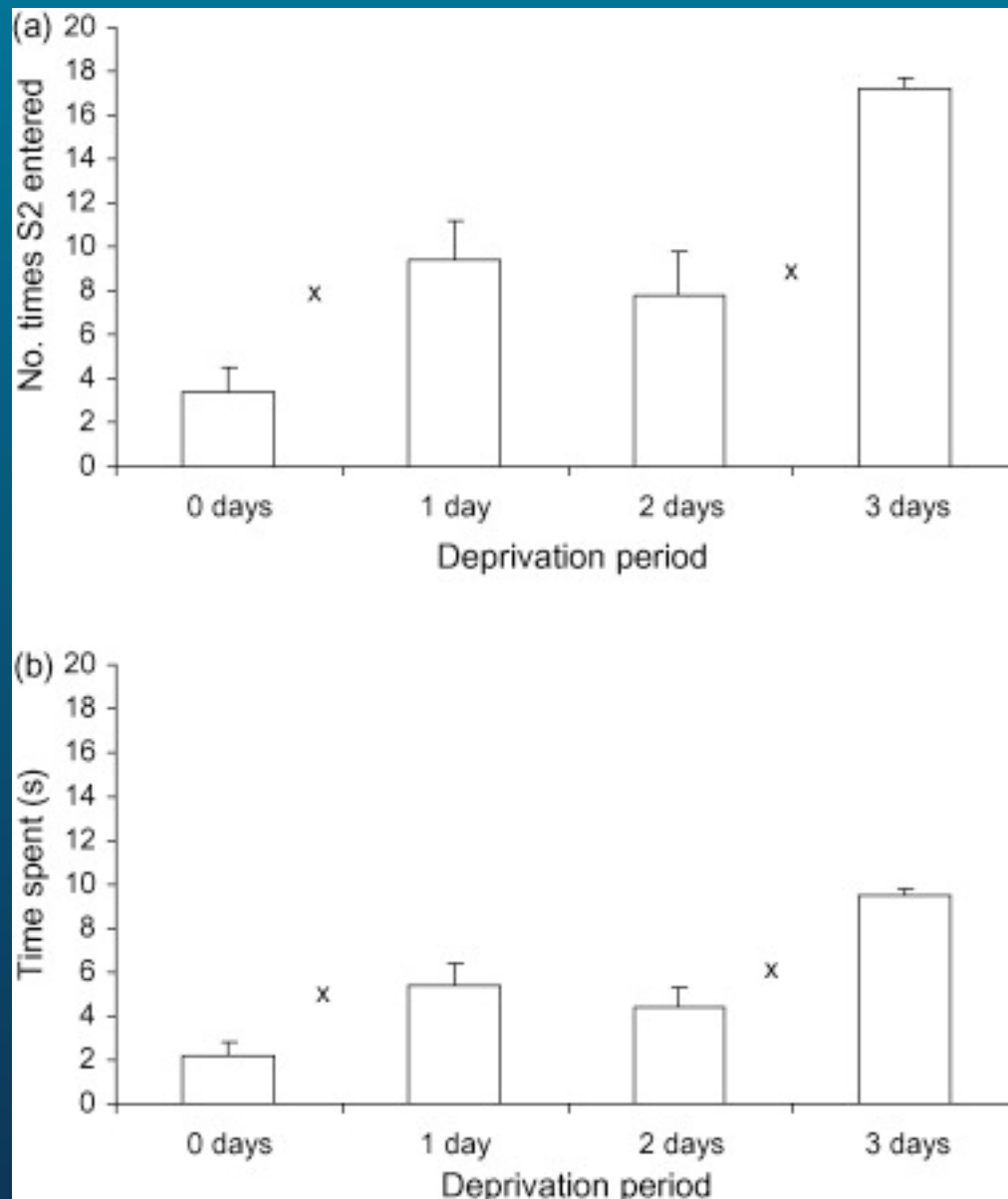


But cuttlefish have been shown to modulate their response to different prey offerings in a way described as “an emotion-like state”

Chung et al., 2022

✓ behavioural flexibility

✓ anticipation



Millsop and Laming 2008.

Goldfish more often visited and spent more time in the ‘feed and shock zone’, the longer they were fasted.

✓ hedonic universal signal

✓ behavioural flexibility

✓ state-dependent trade-off

“Winner and loser effects are modulated by hormonal states”.

Mangrove killifish perceive their own fighting ability

and “adjust contest strategy when that perception is updated following wins or losses”.

Earley et al., 2013.



*Kryptolebias marmoratus*

these fish show all 4 expected features of ABA

✓ hedonic universal signal

✓ behavioural flexibility

✓ anticipation

✓ state-dependent trade-off



The idea that pain is a motivational command and therefore should be available to any animal with an **ABA system** is gaining empirical support.  
*(anticipatory behavioural autonomy)*

But it is still incomplete, especially among invertebrates, where pain remains contentious.

We need more targeted empirical studies now.

*This stuff matters...*

In 2017, then Environment Secretary promised to keep animal sentience as a principle in UK law.



Following Brexit, it has been incorporated as the responsibility of an oversight committee



## **Animal Welfare (Sentience) Act 2022**

**(applies to**

- (a) any vertebrate other than homo sapiens,**
- (b) any cephalopod mollusc, and**
- (c) any decapod crustacean.**



*Thanks from all of us.*



Prof. Bob Elwood

