Solving Complexity & Search

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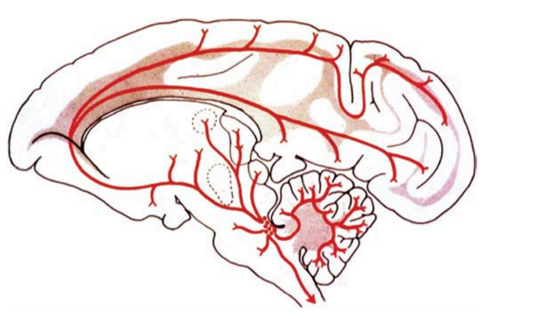
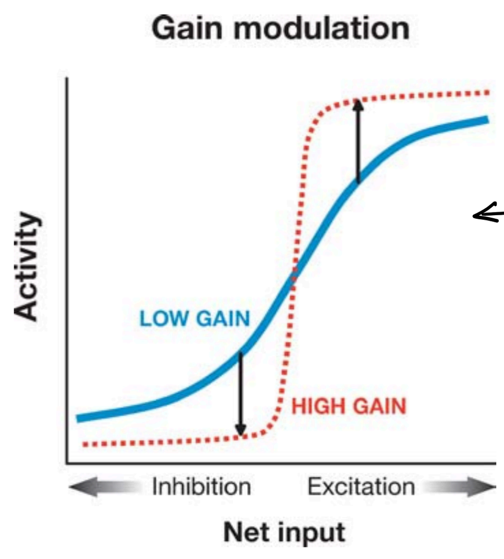
LC-NE System Solves the Overt Computation Issue

Adaptive is the key to the changing world,
How to balance the trade off between exploiting known source of reward and exploring potentially more valuable targets



The LC-NE System is widely distributed and ascending projections all the way to neo cortex
↓
Such system exhibit 2 types of working mode, which has been thought to solve this problem of exploitation v.s. exploration
LC-NE system is responsible for ongoing evaluation of task utility, provided by the input from frontal structure
↑
Sort of like the Q-Table's role
not the actor, but provide crucial input to the actors



← LC-NE try to make things binary, try to distinguish between high util tasks

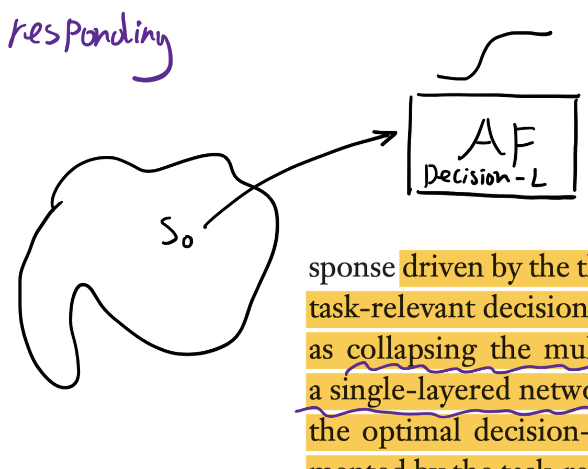
$$\text{activation} = \frac{1}{1 + e^{-(gain^{*}\, net\ input)}}.$$

An increase in gain (*dotted line*) increases the activity of units receiving excitatory input (*upward arrow on right*) and decreases the activity of units receiving inhibitory input (*downward arrow on left*),

Phasic response is only triggered
when sufficient activity accumulates
in one of the units in the decision layer
of the behavioral network → output LC response
Elevate the gain of all units → Binary responding

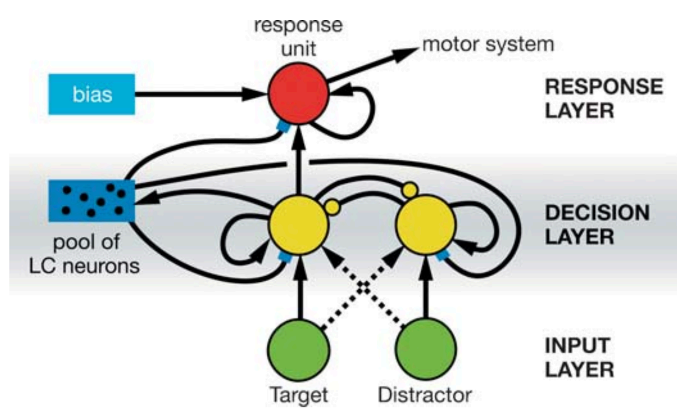
① Phasic: Driven by task-related decision process
→ ensuring behaviors to optimize task performance
→ only aroused by highly salient signals → NE release → NE is found in signals in all sensory brain areas
→ LC is the brain's adrenal gland, augmenting the process of motivating relevant stimuli
→ Really high attention focus, hard to be distracted (like me reading this now)

ular input. Thus, we can think of the sudden increase in gain as an adaptive sampling bias (this is the sense in which the LC acts as a temporal filter), favoring the selection of states of the entire system that are most heavily influenced by the activity of the units in the decision layer, and thereby allowing that layer efficiently to determine the behavioral response. Thus, the effect of an LC phasic re-



sponse driven by the threshold crossing in the task-relevant decision layer can be thought of as collapsing the multilayered network into a single-layered network, thus approximating the optimal decision-making process implemented by the task-relevant decision layer. In

② Tonic: When no task is at hand
→ Disengagement from the current task and search for alternative behaviors
→ Baseline is elevated but not bursting



Phasic system resolves fundamental tradeoff

Different Tasks require decision processes
that integrates information of different types
at varying levels of analysis and from varying sources

Though may be fundamentally the same, they are implemented in different layers
↑
This poses a optimization issues
→ What about when one task's cross over threshold is reached but need to wait for others to process

We need a task-relevant decision layer crosses threshold
→ A signal that would be issued ensuring that the current given information rapidly and directly influence behaviors

this way, the LC phasic response resolves a fundamental trade-off between the flexibility of a complex, multilayered system (that can support a wide variety of decision processes responsive to information from different sources and different levels of analysis) and the optimality of a single-layered decision mechanism. From this perspective, the

Tonic System Solves Adaptability

On the other hand, tonic activity ensures that we are also sensitive to task irrelevant stimulus

From this perspective, optimization involves not only determining how to best perform the current task, but also considering its utility against alternative courses of action and pursuing these if they are more valuable. This is, of course, a more complex and less well-defined problem, which presents significant challenges to formal analysis. Reinforcement

→ Classical Conundrum faced in RL, do we sample more or commit more

In RL we deal with this issue by regulates the amount of random behaviors
→ Annealing in thermodynamics (molten metal slowly cool down to ensure achieving good thermal dynamics optimal equilibrium)
↓
However, this is not adaptive to the environment
LC solves this: Adaptive gain theory modulated by OFC/ACC:

adaptive gain theory: Increased baseline release of NE increases the gain of units in the network indiscriminately, making them more responsive to any stimulus. This uniform increase in responsivity is tantamount to increasing noise and favoring exploration. The

→ If there are high tonic firing:
Phasic firing must be really really strong for it to have a good effects
(Kicking into exploitation)
→ Intermediate tonic level tends to help "push" exploitation a bit
(when you explore moderately, you can exploit really good)

↑
From a Bayesian modeling perspective, tonic system can also determine whether a failure of prediction reflects
Variability inherent in the task or an Underlying change in the environment
↑ Mediated by Ach
↑ Revision of expectations, mediated by increase baseline NE firing

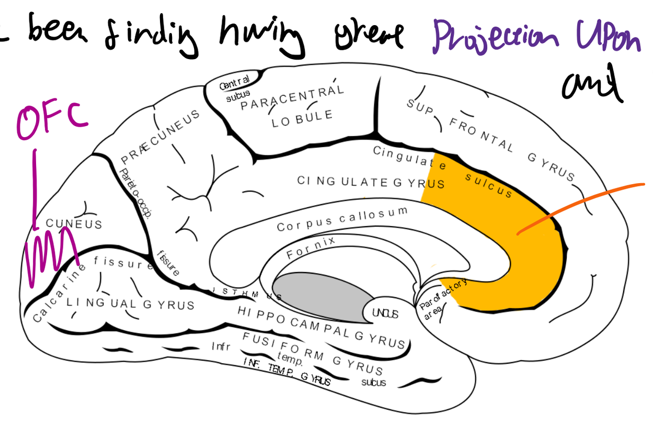
All of the above would only work base on the assumption that they are responsive to such performance evaluative information from the Frontal Cortex projecting to LC

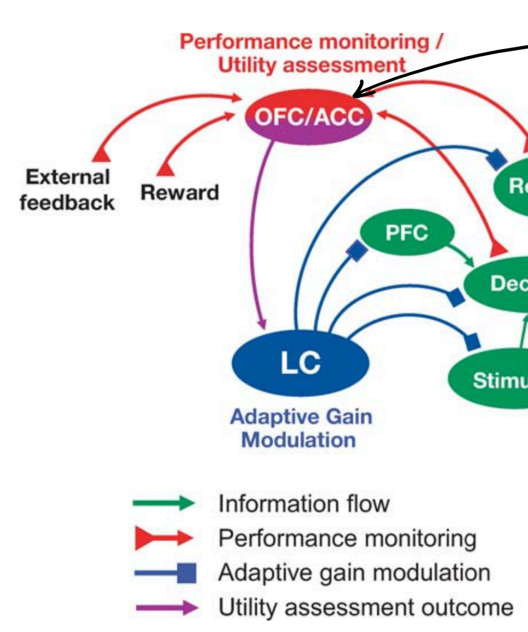
Determination of Errors

Both Orbital Frontal Cortex and Anterior Cingulate Cortex have been finding having great projection upon LC-NE system
and in-sense of the role for both
1. giving evaluation outcome and induce phasic mode
2. Regulation of the balance in LC-NE system

OFC plays a role in the evaluation of reward. The OFC receives input from all modalities of high-order sensory cortices, in particular areas processing information with strong appetitive significance, such as taste and olfaction, as well as primary limbic structures such as the ventral striatum and amygdala (Baylis et al. 1995; Carmichael et al. 1994; Carmichael & Price 1995a,b; Ongur & Price 2000; Rolls

ACC plays a role in the evaluation of cost. Like OFC, ACC receives convergent inputs from a broad range of neocortical and subcortical structures, including somatosensory areas and limbic structures such as insular cortex, amygdala, and ventral striatum (Devinsky et al. 1995, Mesulam 1981). ACC is known to be directly responsive to aversive interoceptive and somatosensory stimuli, and to pain, in particular (e.g., Peyron et al. 2000).





← Include both Internal Conflicts and External feedback

The evaluation need to incorporate both long/short term utility (computed in ACC and OFC)

by a transition to the LC tonic mode. Importantly, the determination of when to promote exploration over exploitation requires that evaluative mechanisms take account of both short- and long-term changes in utility. There are many ways of doing so. The following equation describes one simple means (shown graphically in **Figure 10**):

Engagement in current task
$$= [1 - \text{logistic(short term utility)}] * [\text{logistic(long-term utility)}], \quad \text{(Equation 1)}$$

where *logistic* refers to the sigmoid function $1/(1+e^{-\text{utility}})$, and high values of the equation favor the LC phasic mode, whereas low values favor the tonic mode.

↓
Activation of binary not only in LC system but also existed in a layer of abstraction above when deciding the signal output to LC-NE

High Long term but Low short term (Phasic/Exploit)

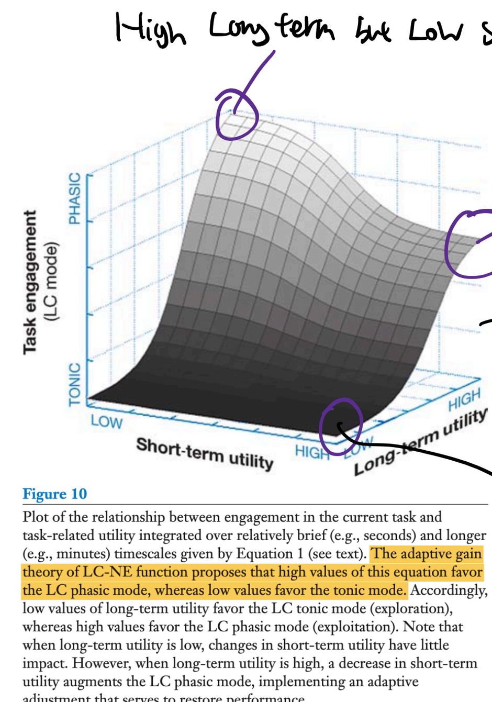


Figure 10
Plot of the relationship between engagement in the current task and task-related utility integrated over relatively brief (e.g., seconds) and longer (e.g., minutes) timescales given by Equation 1 (see text). The adaptive gain theory of LC-NE function proposes that high values of this equation favor the LC phasic mode, whereas low values favor the tonic mode. Accordingly, low values of long-term utility favor the LC tonic mode (exploration), whereas high values favor the LC phasic mode (exploitation). Note that when long-term utility is low, changes in short-term utility have little impact. However, when long-term utility is high, a decrease in short-term utility augments the LC phasic mode, implementing an adaptive adjustment that serves to restore performance.

High Long-term and high Short-term
(Phasic/exploit while tonic/explore)

When utility diminishes sufficiently over prolonged duration, OFC and ACC drives towards a tonic mode

High Short-term + Low Long-term Effect
Try to explore a little bit more (Tonic)

All low long term → Then Let's just exploit more!!!

↓
It's a Continuum, once phasic starts to fade out
on long term utility modeling → Tonic starts kicking in more
Raising baseline, so when next phasic comes, it must be really high reward/low cost for it to kick out off the tonic mode

(Can we design an algorithm where ↑ in phasic ↑ in tonic?)