

東京大学教養学部学際科学科 2017年度 人間情報学VI 意識の神経科学: 盲視・統合失調症・自由エネルギー原理

6月21日(水) 3-4限 13:00-16:40, 駒場キャンパス15号館1階104講義室
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要旨 Part 1:

- 意識を科学的に研究するってどういうこと?
 - 「意識は定義できないから科学の対象にならない」というのは正しくない(Searle)
 - 「意識」という言葉で指している対象が共有できていれば充分(Searle)
 - 「意識のハードプロブレム」という問題群がある(Chalmers)
 - 現象的意識とアクセス意識を分けて扱う考え方がある(Block)
- 脳損傷の症例からわかる意識経験の様々な形
 - 「知覚のための視覚」と「行動のための視覚」は脳の別の部分を使っている(Goodale)
 - 盲視の症例では現象的意識だけ欠けているように見える(Weiskrantz)
 - 盲視は動物でも再現できる。つまり「見えない」ことは行動的に示すことができる(Cowey)
 - 盲視動物で「見えないこと」を示すためには信号検出理論を使うとよい(吉田)
 - 盲視動物は視覚サリエンスが使える(吉田)
 - 我々人間でも意識経験と視覚サリエンスが並行して処理されているのかも(吉田)
 - 意識が受け身の反応ではなくて行動とのループで作り上げるものという説がある(Noë)
 - この説を使うと盲視で起きていることが説明できる(吉田)

要旨 Part 2:

- 意識は受け身の反応ではなくて環境への働きかけ
 - 同じ考え方はフッサール現象学にもある
 - 脳が仮説を作ってそれを検証することで知覚を構成するという説がある(Frith)
 - 視覚サリエンスはこの考えからベイジアン・サプライズとしてモデル化できる(Itti)
 - ヘルムホルツの無意識的推論も同じ方法で「予想コーディング」としてモデル化できる(Rao)
 - ベイジアン・サプライズは予想コーディングでの予測誤差そのもの(Friston)
 - 予測コーディングを行動に拡張したものが active inference (Friston)
 - 知覚、行動、注意、価値、みんな自由エネルギー最小化で説明できる(Friston)
 - 自由エネルギー原理 (or 予測処理)で意識も説明できる(Hohwy, Clark)
- 統合失調症: 自己、世界に対する意識経験の変容
 - 統合失調症で起きていることが自由エネルギー原理で説明できる(Friston)
 - 統合失調症での妄想、幻覚はサリエンスの経験の変容で説明できる(Kapur)
 - 統合失調症での視線は視覚サリエンスの変容で説明できる(吉田)
 - 統合失調症での視線はベイジアン・サプライズの変容でもっと説明できる(吉田)
 - 統合失調症のサリエンス説と自由エネルギー原理説は同じことを言ってるのかも(吉田)
 - 主体感と存在感の失調も予測コーディングで説明ができる(Seth, 鈴木)
- 意識のハードプロブレム再訪
 - ハードプロブレムは「回帰する擬似問題」(山本、吉川)
 - だからこそ「人が意識を科学的に理解する仕方」そのものを拡張してゆく必要がある
 - 経験の構造と一回性を重視する「神経現象学」(Varela)

PART 1

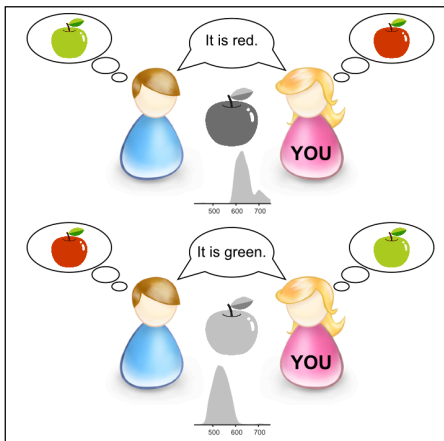
1. 意識を科学的に研究するってどういうこと？

1-1. Definition of consciousness

- “Consciousness is not a subject of science because we cannot define them.”
- Let’s start from a common-sense definition, not from an analytic definition. ¹
- A common-sense definition of consciousness: “consciousness refers to those states of sentience or awareness that typically begin when we wake from a dreamless sleep and continue through the day ...”
- Level/state of consciousness と content of consciousness を区別する ²

1-2. The hard problem of consciousness

- The hard problem of consciousness: The problem of explaining how and why we have qualia or phenomenal experiences — how sensations acquire characteristics, such as colors and tastes.
- Philosophical zombie: A philosophical zombie is a hypothetical being who is physically identical to a normal human being, but completely lacks conscious experience.
- If a philosophical zombie is possible, then conscious experience is independent of physical world.
- The inverted spectrum: “... if the idea that a violet produced in one man’s mind by his eyes were the same that a marigold produced in another man’s, and vice versa ...”



- In his (Ned’s) class, ~2/3 of the students usually say, ‘Oh yeah, I see what you’re talking about’ and some of them even say, ‘Oh yeah, I’ve wondered about that since I was a kid.’ ~1/3 of people say, ‘I don’t know what you’re talking about.’³
- Two kinds of consciousness:
 - Qualia or phenomenal experiences: “How sensations acquire characteristics, such as colors and tastes.”
 - Awareness: “a state wherein we have access to

some information, and can use that information in the control of behavior.” “the psychological concept of mind” ⁴

- Two kinds of consciousness:
 - Phenomenal consciousness (= qualia): experience; the phenomenally conscious aspect of a state is what it is like to be in that state.
 - Access-consciousness (= awareness): functional, psychological aspect; availability for use in reasoning and rationally guiding speech and action ⁵

2. 脳損傷の症例からわかる意識経験の様々な形: 視覚失認

2-1. What and where pathways

- The neurons in the dorsal pathway are selective to motion and binocular disparity.
- The neurons in the ventral pathway are selective to shape and color. ⁶
- Bilateral removal of area TE impairs object discrimination: Which is the unfamiliar object?
- Bilateral removal of posterior parietal cortex impairs landmark discrimination: Which is near to the landmark? ⁷

2-2. Vision for perception and vision for action

- Two visual system hypothesis⁸
 - Dorsal pathway: Vision for action
 - Ventral pathway: Vision for perception
- Optic ataxia (視覚性運動失調)
 - Damage in the posterior parietal cortex (supramarginal gyrus and angular gyrus)
 - Orientation error does not depend on hand but on visual field.
 - Damage in the dorsal pathway affects vision for action. ⁹
- Visual form agnosia (視覚失認):
 - Hypoxia from CO poisoning at 34 years old
 - Bilateral cortical damage in the ventrolateral occipital region, sparing V1
 - Most salient symptom was visual form agnosia
 - Very good performance in ‘posting’ task ¹⁰
 - Degraded vision for perception but retained vision for action
 - DF matched her card orientation to the slot during the course of the movement, well before contacting the target. ¹¹
 - Vision emerges from action.
- Functional double dissociation

	Site of Damage	Perception	Action
Visual form agnosia (視覚失認)	Ventral	damaged	retained
Optic ataxia (視覚性運動失調)	Dorsal	retained	damaged

- Dorsal and ventral visual pathways may have different roles on vision for action and vision for perception.

3. 脳損傷の症例からわかる意識経験の様々な形: Blindsight (盲視)

3-1. What is blindsight?

- “The visually evoked voluntary responses of patients with striate cortical destruction that are demonstrated despite a phenomenal blindness”¹²

	conscious vision	Visual information processing
Normal vision	OK	OK
Blindsight	Impaired	OK
Hemianopia	Impaired	Impaired

- Phenomenal consciousness can be dissociated from visual information processing.
- Blindsight: Cortical damage wakes up the frog's vision.
- Blindsight as “philosophical zombie”:
- David Chalmers⁴ Ch.6.3: “(The description of blindsight) is compatible with the coherence between consciousness and awareness.”
- Ned Block⁵: “But stimuli in the blind field (of blindsight) are BOTH access-unconscious and phenomenally unconscious.”
- Daniel Dennett¹³ Ch.11.2: “As we shall see, however, blindsight does not support the concept of a zombie; it undermines it.”
- What exactly is blindsight?

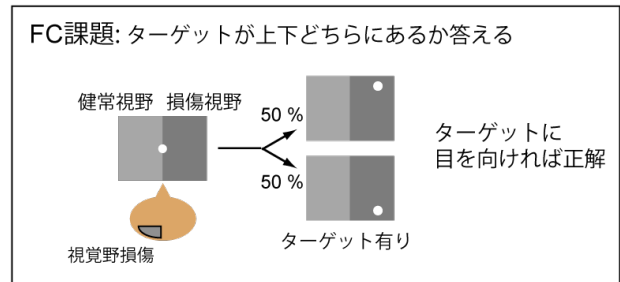
3-2. Blindsight in human

- G.Y. became blind in his right visual field due to traffic accident in eight years old. He was diagnosed as homonymous hemianopia.
- 80% correct in motion discrimination (moving bar) => Blindsight¹⁴
- ‘Awareness’ in Case G.Y.: When a rapidly moving target is projected ... GY sometimes reports an “awareness” ... or a “feeling” that something has moved, although he denies any experience of “seeing” as such.
- He described his experience as that of ‘a black shadow moving on a black background’, adding

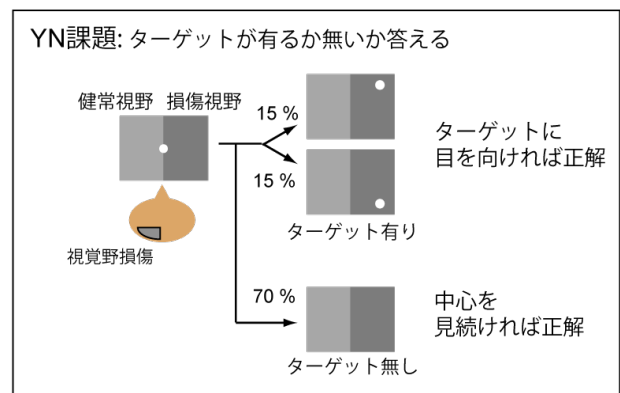
that ‘shadow is the nearest I can get to putting it into words so that people can understand’.¹⁵

3-3. Blindsight in monkey

Recovery after 2-3 months training¹⁶



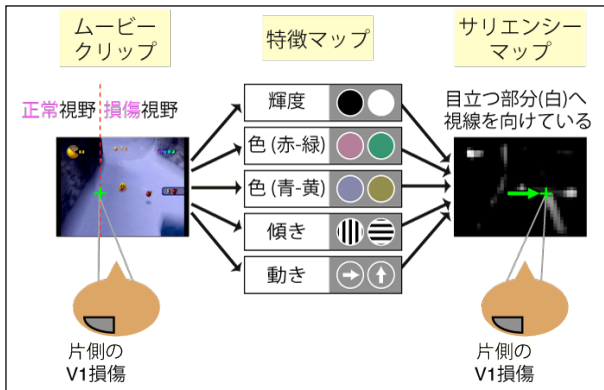
- Are the monkeys really ‘blind’ to the visual stimuli?



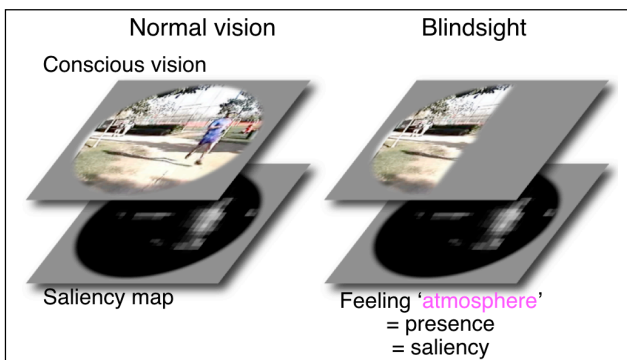
- The monkeys behaved as if it is a No-target trial.
- The monkeys are ‘not able to see’, as in human blindsight¹⁷.
- Signal detection analysis revealed that blindsight occurs due to dissociation of sensitivity rather than decision bias. Such dissociation occurs only when V1 is damaged.
- We succeeded in measuring awareness in animal.

3-4. Saliency in blindsight

- What is retained in blindsight? Blindsight monkeys respond to motion¹⁸. => Visual saliency?
- What is saliency? - The distinct subjective perceptual quality which makes some items in the world stand out from their neighbors and immediately grab our attention¹⁹
- * Saliency computational model²⁰
 - Iterative calculation of center-surround differentiation and normalization
 - Intracortical lateral inhibition is mathematically equivalent to second derivative. It is used for edge detection.
- * Salient stimuli attract gazes of blindsight monkeys²¹



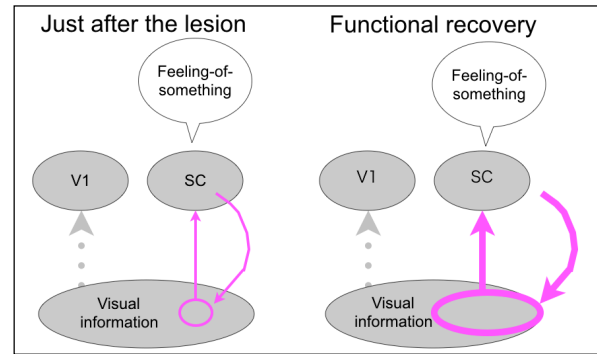
- Color saliency or color identification?
 - The blindsight monkey responded to color saliency.
- What is it like to be blindsight?



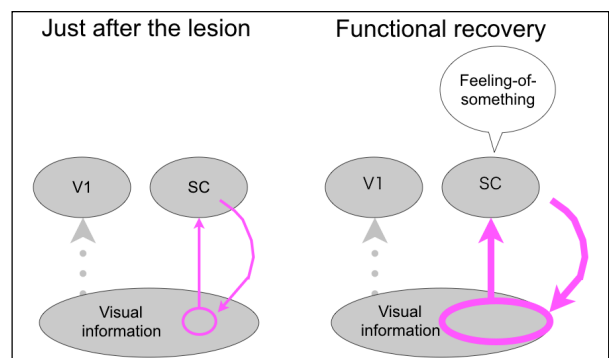
- Dual system for conscious vision and saliency.

3-5. Sensorimotor contingency theory

- Standard view: Seeing is making an internal representation
- New view: Seeing is knowing about things to do²²
- Alva Noe's Sensorimotor contingency theory²³: "An object looms larger in the visual field as we approach it, and its profile deforms as we move about it. As perceivers we are masters of this sort of pattern of sensorimotor dependence. ... our ability to perceive not only depends on, but is constituted by, our possession of this sort of sensorimotor knowledge."
- Hurley and Noë's argument²⁴:
 - Based on Enactive view, sensorimotor contingency, rather than brain region, is the determinant of conscious experience.
- This is empirically testable. sensory input? (=> Externalism) or brain activity? (=> Internalism)
 - Phantom limb: the case for brain activity => Internalist view
 - Inverted glass: the case for sensory input²⁵ => Externalist view
- What occurs in blindsight? - internalist view



- V1 activity and SC activity evoke different kinds of conscious experience. In normal vision, 'feeling-of-something' caused by SC activity is masked by 'vivid red experience' caused by V1 activity.
- Just after the lesion, 'feeling-of-something' is unmasked.
- After recovery, 'feeling-of-something' can be stronger as the SC activity get stronger.
- What occurs in blindsight? - externalist view:



- Sensorimotor contingency is formed in the V1 pathway, which causes 'vivid red experience'.
- Just after the lesion, SC is not functional. Since the subject has no sensorimotor contingency, he/she has no experience.
- After recovery, expanded availability of visual information (= altered sensorimotor contingency) in the SC pathway causes 'feeling-of-something'. It is different from normal experience because of limited availability of visual information.
- The case of blindsight may support the externalist view because blindsight is not available just after the lesion.
 - We can devise empirical tests to validate it.
 - Is it possible to induce 'feeling-of-something' in normal subjects if we transiently suppress V1?
 - Is it possible to abolish 'feeling-of-something' in blindsight subjects if we transiently suppress SC?

PART 2

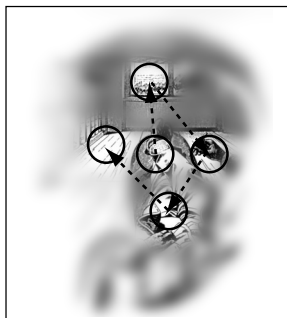
4. Predictive Brain

4-1. アクティブ・ビジョン

- 我々の視覚経験そのものってどんなかんじ？



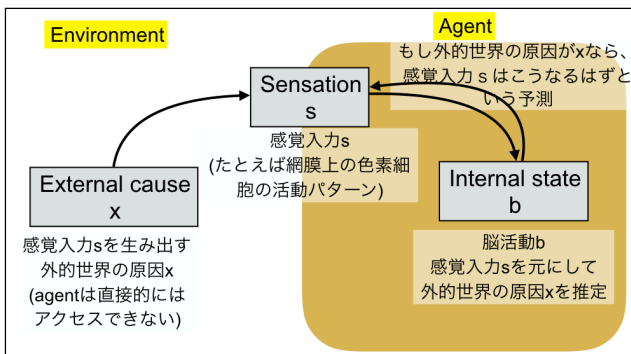
- 我々の視覚は視野の中心以外はぼやけてる
- 我々は絶えず視線を移動しながら視覚シーンを構成している



- 視覚とは受け身での表象形成ではなくて、行動(例えば眼球運動)によって主体が視覚情報をサンプルすることである。
- "An active visual system is a system which is able to manipulate its visual parameters in a controlled manner in order to extract useful data about the scene in time and space"²⁶

4-2. 無意識的推論

- 「無意識的推論」としての視覚²⁷



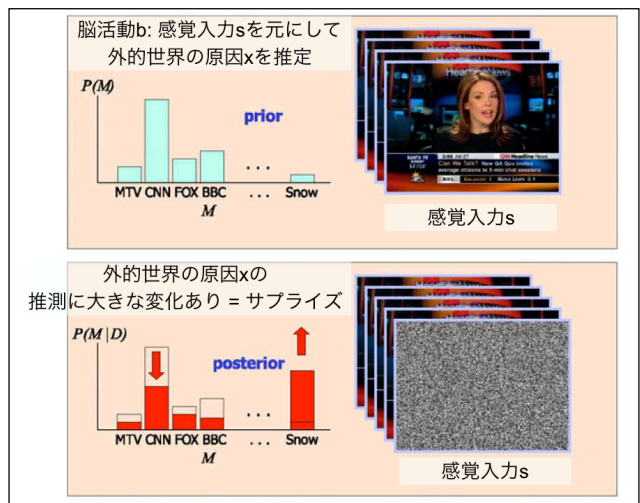
- 脳活動 b はつねに外的世界の原因 x を推定しながら、感覚入力 s の予測を生み出す。

4-3. ベイジアン・サプライズ

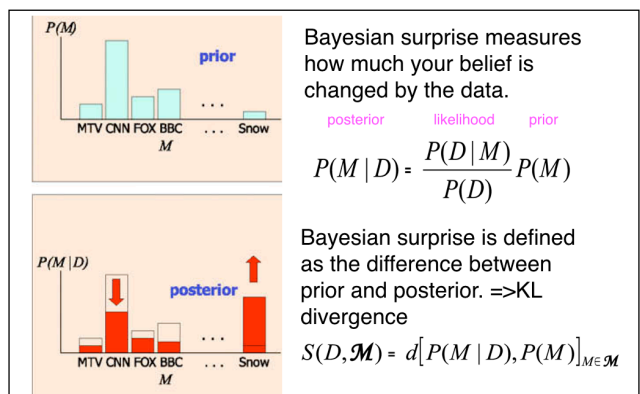
- Saliency map: spatial outlier
- 従来のサリエンシー: 空間的に目立つ部分を計算 =>

生物学的モデル

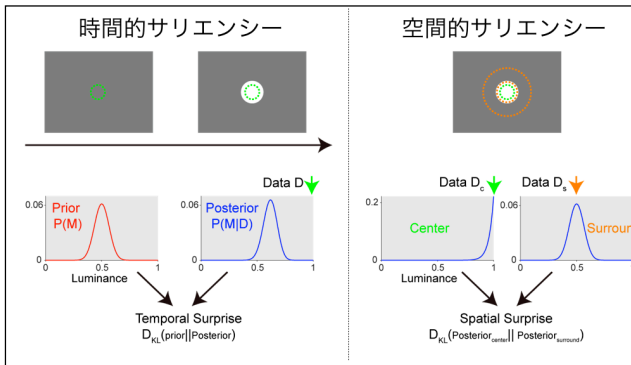
- 大脳皮質の側抑制の性質を真似て、隣り合った部分の差の大きさを計算(=> エッジ検出)
- 「サリエンシー」は二次元画像の中でどこが「目立つか」を「空間的配置」の中で評価する。
- では「時間的変動」の中でどこが「目立つか」を評価するにはどうすればよいだろう? => ベイジアン・サプライズ
- なぜ私たちは砂嵐になったら驚くのだろう?
 - 砂嵐そのものがサプライズなわけではない。- 砂嵐を見続けていれば退屈になる。
 - 「いま私はニュースを見ている」という信念が崩れたことがサプライズ。



- Bayesian surprise measures how much your belief changed by the data.
- Bayesian surprise is defined as the difference between prior and posterior. => KL divergence²⁸



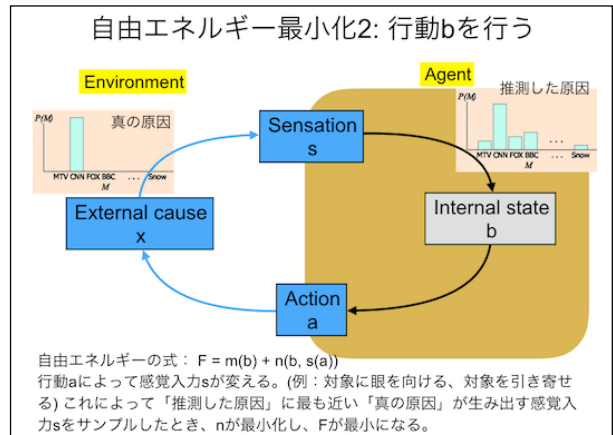
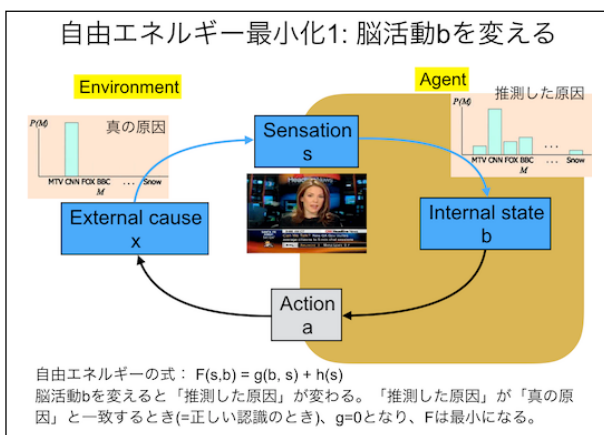
- 画像のベイジアン・サプライズの計算



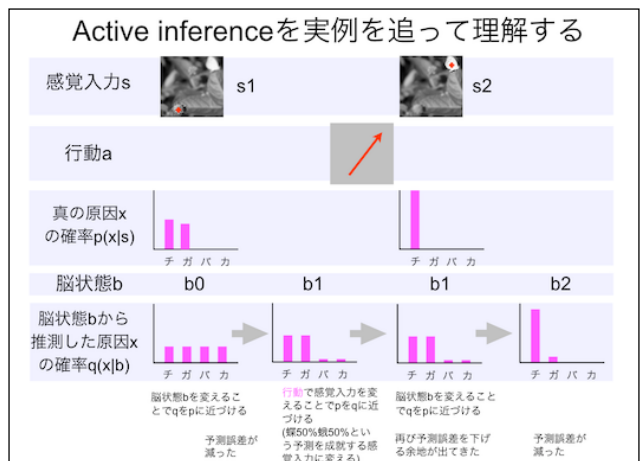
- ベイズ更新過程を用いて時間的・空間的に目立つ部分をそれぞれ別に計算
- 繰り返し刺激によってベジアン・サプライズは減弱する
- 静止画の提示直後は至るところで高いが、だんだん収束してくる=>Winner-take-all の自然な実装
- Surprise is better predictor than saliency for gaze patterns during free-viewing
- Standard view: A neuron is a feature detector.
- Since neural responses are transient and adaptive, a neuron can be regarded as a surprise detector.
- V1 response can be modeled by surprise

4-4. Friston の自由エネルギー原理

- The free-energy principle says that any self-organizing system that is at equilibrium with its environment must minimize its free energy.²⁹
- The principle is essentially a mathematical formulation of how adaptive systems (that is, biological agents, like animals or brains) resist a natural tendency to disorder.²⁹
- 「意識についての理論」そのものではない。適応的なシステムが持続的に存在しつづけるために必要な条件を統一的に説明する「原理」
- 上半分は「無意識的推論」と同じ: 脳活動 b はつねに外的世界の原因 x を推定しながら、感覚入力 s の予測を生み出す。



- 自由エネルギー原理 = 無意識的推論 + Active inference
- (1) 脳活動 b を変える=> 「推測した原因」を「真の原因」に近づける=>無意識的推論
- (2) 行動 a で感覚入力 s を変える => 「推測した原因」に近い「真の原因」をサンプルする =>Active inference²⁹



- 自由エネルギー原理は意識に関係しているか？
- Hohwy: Binocular rivalry can be explained by predictive coding³⁰
- Clark: Interoceptive および exteroceptive な predictive coding の相互作用³¹

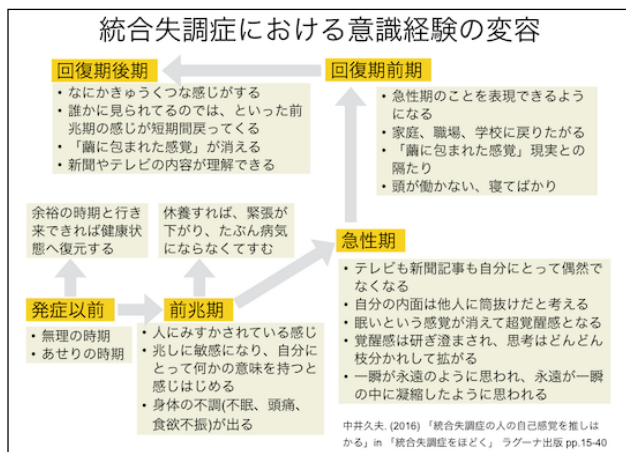
5. Schizophrenia (統合失調症)

5-1. 統合失調症とは何か

- A chronic mental illness characterized by persistent psychotic and negative symptoms and relatively subtle cognitive impairment.³²
- Positive symptoms (陽性症状) = Psychosis (精神症状):
 - Delusions (妄想): A fixed implausible, preoccupying belief (例:「私の耳の後ろにマイクロチップが埋め込まれていて、それが私の考えを支配している」)
 - Hallucinations (幻覚): A voice, vision, or other

percept in the absence of a stimulus. 典型的には「患者の行動にコメントしたり、患者を侮蔑する声」

- Negative symptoms (陰性症状):
 - Apathy, reduced social interactions, poor self-care
- Socio-developmental-cognitive モデル³³
 - 統合失調症は主に思春期から青年期くらいの時期に発症する。それ以前に神経発達の障害が見られる。これが社会的困難と重なることによって発症する。
- DSM-5 による統合失調症の診断基準
 - 以下の A,B,C,... をすべて満たす
 - A. 特徴的症状: (1)-(5)から2つ以上、(1)-(3)から少なくとも1つ (1) 妄想 (2) 幻覚 (3) 解体した言語 (4) 無秩序または緊張病的行動 (5) 陰性症状
 - B. 社会的/職業的機能障害: 職業、対人関係、セルフケア、の1つ以上で発症前の水準を著しく下回る
 - C. 期間: 少なくとも6ヶ月以上障害の兆候が持続している



- 中安による「初期分裂病」の概念
 1. 自生思考: 「自分で意識して考えていることと無関係な考えが、急に発作的にどんどん押し寄せてくる」
 2. 気付き亢進: 「他人の声や不意の音、たとえば戸を開閉する音や近くを走る電車の音などを聞くときビクッとして落ち着かなくなる」
 3. 緊迫困惑気分: 「何かが差し迫っているようで緊張を要するものの、なぜそんな気持ちになるのか分からなくて戸惑っている」
 4. 即時的認知の障害 - 即時理解の障害: 「他人の話の内容、テレビの内容などが理解しにくくて、なかなか頭に入らない」
- 統合失調症から回復した当事者が前駆期の神経症状について回顧的に記述した例
 - 「いちばん最初に起きたのは、私の脳の眠っていた部分の一部が目覚めて、さまざまな人、出来事、場所、考えに対して興味が惹かれるようになったことです。それらは普段だったらなんの印象も憶えないようなものでした。」

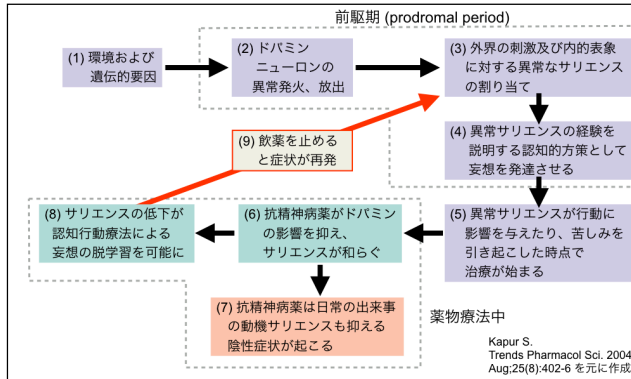
- 「全てのことになにか圧倒的なまでに意味深いものがあるように思えるのです...知らない人が道を歩いているのを見ると、そこに私が解釈しなければならぬなにか徴(sign)があるように思えました」
- 「私が入院をした頃には、窓枠の光や空の青さがあまりに重要な意味を持ちすぎて叫びたいような、そんな「覚醒状態」の段階にまで到達していました」
- => サリエンシーの亢進?
- 意識研究における意義
 - 陽性症状(幻覚、妄想)の解明には自己についての意識経験の変容が関わっている
 - 発症前の前駆期に世界についての意識経験の変容が起きている
- 統合失調症研究が難しい理由
- Schizophrenia is not a single entity:
 - Paranoid schizophrenia (妄想型: delusions or hallucinations)
 - Hebephrenic schizophrenia (破瓜型: thought disorder)
 - Catatonic schizophrenia (緊張型: abnormal motor behavior)
- No single cause:
 - No single gene (RGS4, DISC1, DTNBP1, NRG1, HTR2A,...)
 - No single environmental factor
 - No single brain area (STG, Str, HC, AI, ACC, DLPFC,...)
 - No single neurotransmitter (DA, Glu, 5HT, ACh,...)
- No animal model but endophenotype (中間表現型):
 - Pre-pulse inhibition, latent inhibition
 - Anti-saccade, inhibition-of-return
 - Working memory task
- We need a working hypothesis which explains how the symptoms develop.

5-2. 妄想、幻覚のベイズ的説明

- ドパミン活動の亢進は sensory evidence の分布を狭く見積もる。この結果、不十分な evidence で belief を変えてしまう。=> jumping to conclusion bias³⁴
- What do you see in this scene?
 - Normal vision: sensory evidence に対して prior が適切な prediction を作ることによって prediction error=0 にする。
 - Delusion(妄想): 適切な prediction を作ったのに prediction error=0 にならない。そこで prior を変えて prediction error=0 にした。
 - Hallucination(幻覚)の場合: sensory evidence なしで prior が不適切な prediction を作るが prediction error=0 になっている。
- Hollow-mask illusion (URL: rucss.rutgers.edu/~papathom/index.php/demos/2-uncategorised/37-rotating-hollow-mask)
 - 統合失調症患者は hollow-mask にだまされない
- The positive symptoms of schizophrenia can be explained from Bayesian perspective.

5-3. 妄想、幻覚の異常サリエンス仮説

- 発症初期に注目する
- 外的刺激や内的意味についてのサリエンシーを過大評価することが妄想、幻覚の引き金となる³³
- 妄想と幻覚の異常サリエンス仮説³⁵



- (2)->(3): During the 'prodromal' period (前駆期) there is a context-independent firing of DA neurons and subsequent DA release. This produces a perplexing sense of novelty in patients. Patients continue to accumulate several experiences of altered novelty and salience without a clear explanation for them.
- (3)->(4): The perplexing sense crystallizes into a delusion – and then it all 'makes sense' to the patient. A delusion is a 'top-down' cognitive explanation that the individual imposes on these aberrant novelty and salience experiences in an effort to make sense of them.
- (4)->(5) : These delusions or hallucinations impact on the patient's behavior, and this is typically when patients are brought to care and antipsychotics are administered.
- (6)->(8) : Antipsychotics, by blocking dopamine transmission, attenuate aberrant salience. Antipsychotics do not directly erase delusions but (with it) new aberrant salience is less likely to form. They do not immediately abandon the delusion or hallucination but instead report that it 'doesn't bother me as much anymore'.

5-4. 異常サリエンス仮説の検証

- 仮説:統合失調症であるとは? 視覚サリエンシーが亢進し、すべてが意味ありげに見える(動機サリエンシーが高い)
- 仮説:眼球運動計測によってサリエンシーの異常が検出できるのでは?
- フリービューイング課題³⁶
 - どうしてスキャンパスの低下が生まれるのだろうか? 「眼球運動」の異常というよりは「視覚的注意」の異常として捉えるべきでは?
 - 統制群では、視線はサリエンシーの高いところに向かう。それからよりサリエンシーの低いところに向かう。

う。

- 統合失調症患者では、視線がサリエンシーの高いところに誘引されやすい。「異常サリエンス説」と整合的³⁷。
- Analysis of free-viewing revealed eye movement patterns that is consistent with aberrant saliency hypothesis.

5-5. 主体感と存在感

- Why can't you tickle yourself?³⁸
 - 自分の行動による感覚への影響を予測してしまっているから。
 - 時間差によって予測不可能にすると自分をくすぐることができる!
- 統合失調症患者は自分をくすぐることができる³⁹
 - 自分の行動による感覚への影響をキャンセルアウトすることに失敗している=> Agency (主体感)の失調
- 自己運動の結果をキャンセルしている脳部位: SII, ACC⁴⁰
- コンパレータ仮説による幻聴の説明
 - Agency の失調は「させらせ経験」を説明できる。
 - 幻聴による命令(頭のなかの声)が患者の行動に命令したりコメントする)
 - 自分で行った内言(inner speech)の主体の錯誤
 - 記憶の想起の錯誤
- What is presence? "the subjective sense of reality of the world and of the self within the world"⁴¹
- Presence and predictive coding⁴¹
 - Agency and presence are functionally coupled.
 - Presence is the result of successful suppression by top-down predictions of informative interoceptive signals evoked (directly) by autonomic control signals and (indirectly) by bodily responses to afferent sensory signals
- Insula and salience⁴²
 - The key to the cortical (that is, mental) representation of the sentient self is the integration of salience across all relevant conditions at each moment.
- Insula and schizophrenia⁴³
 - Meta-analysis of VBM suggests that the gray matter volume of salience network (AI-ACC) is smaller in first-episode subjects.

6. 意識のハードプロブレム再訪

6-1. 「回帰する擬似問題」

- (To be added)

6-2. Neuro-phenomenology (神経現象学)

- [Phenomenological accounts of the structure of experience] and [their counterparts in cognitive science] relate to each through reciprocal constraints. (<=>correlation)
- (1) the neurobiological basis
- (2) the formal descriptive tools mostly derived from

- nonlinear dynamics
- (3) the nature of lived temporal experience studied under (phenomenological) reduction
 - An example of Neurophenomenology: 'Aura' experience before epilepsy {LeVanQuyen:ge}
 - Neuro-dynamic structure and Pheno-dynamic structure
 - Homeomorphism: field-based correspondence (<=> Isomorphism: point-to-point correspondence)

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