Consciousness as an Adaptive Phenomenon

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Developing an analytic theory of consciousness

Types of theories of consciousness

Reductive/fade-away

Dualist

a) end type

b) beginning type - its advantages

Dualism in Science/beginning type

Analogy in physics

Dualist construct: Specific force

Token: pressure

Tokens

A construct (dualist or derived) complimented by a measurable quantity called a token

Tokens allow specification of experiments validating the approach

Theory to be presented is an adaptive process

Darwinian concepts (for growth of complexity)

competition for nutrient
survival of the fittest
reproduction

Bacteria- the starting point

A theory at the level of bacteria

Remote resemblance to human level counterparts

The dualist construct

A notion of primitive awareness (a proto-consciousness)

Neural assemblies-the (current) ending point

Speciation

Triple of dynamical systems

1. Dynamics of the environment (n)
2. Dynamics of the construct
   a) dualist aspect (a)
   b) Physical aspect (tokens) ($\hat{a}$)
3. A mirroring population dynamics (p)

Philosophical features of consciousness

1. Qualia
2. Intentionality
3. Self

Applications (observable features of consciousness)

1. Inability to experience certain qualia
   in the absence of sensory input
2. Why does the brain locate the perception of a quale
   (pain, taste, smell) in the peripheral nervous system?

   The existence of a threshold for such a perception
3. How do visual and auditory imagery come to be
   located 'out there' in the surrounding space?
4. How do dream images come to be
   located in virtual space?
5. Phantom pain
6. Threshold process involved in unconscious sensing
   (pheromones)

Comments on the evolution of consciousness

The theory informs the evolution of consciousness

Bacterial Awareness/Cognition

Nutrient bath concentration: $n(x,t)$

Measurements made by the bacteria

2.0) $n(x_r,t)$ and $n(x_l,t)$

2.1) $$\Delta n(t) = n(x_r,t) - n(x_l,t)$$

2.2) $$\overline{n}(t) = \frac{n(x_r,t) + n(x_l,t)}{2}$$

Motion: A rectilinear displacement followed by a rotation.

2.3-4) $$y(t+1) = x(t) + \alpha g z \Delta n, \quad z = \mathrm{sgn}(\Delta n)\frac{x_r - x_l}{d},$$

2.5) $$x(t+1) = R(\theta,\varphi)\big(y(t+1) - \overline{y}(t+1)\big)$$

Colony population and nutrient supply

2.6) $$\boxed{n(x,t+1) = n(x,t) - \beta p(x,t) + n_e(x,t)}$$

Fitness of a bacterium, a notion of affect

2.7) $$\boxed{a(t+1) = \mathrm{sgn}\left[\frac{\overline{n}(t+1)}{\overline{n}(t)} - 1\right], \text{ with } \mathrm{sgn}0 = 1}$$

Bacterium is fit or not-fit: $a(t) = 1$ or -1

Virtual gene

2.8) $$g(t+1) = g(t) + a(t+1)$$

Changes in colony population $p(x, t)$

(*i*) Motion

(*ii*) Reproduction by fission

Daughters are assigned fitness values at random from four possibilities, $\{\pm 1, \pm 1\}$

Except that $(1,1)/(-1,-1)$ are denied to the daughters of a not-fit/fit mother

(*iii*) Competition for survival

Adequate nutrient for s bacteria to survive

2.9)
$$s = \left\lfloor \frac{n(x, t+1)}{\beta} \right\rfloor$$

If there are f fit bacteria, $u = \min(s, f)$ of them survive

Population dynamics: Combining these three effects,

2.10)
$$\boxed{p(x, t+1) = \min\left\lfloor f, s, \sum_{x(t)} \{p(x,t)\}_{x(t+1)} \right\rfloor}$$

Fitness causal in the propensity for survival?

Heuristic: A bacterium moving from poorer to richer nutrient supply is better adapted at consuming, and reversely

Updating the value of the gene

2.11)
$$g_{daughter} = g_{mother} + a_{daughter} + \nu\chi$$

Dualist construct, observer of measurement

Two aspects of measurement (physical and ideal)

The construct

1. Dualist awareness process denoted by $\hat{a}$
   Fitness value a ((2.7)) termed a **token** of process $\hat{a}$

2. Quality of being aware/not-aware attributed to a process
   if its token is positive/negative

3. At the bacterial level: aware/not-aware equivalent to
   fit/not-fit

Causality

If $\hat{a}$ guides reproduction, it may be regarded as causal

Colony level awareness

Awareness density token of the colony

2.12) $$A(x,t) = \sum_{bacteria\ at\ x} a(t)$$

Colony awareness density construct

2.13) $$\hat{A}(x,t) = \bigcup_{bacteria\ at\ x} \hat{a}(t)$$

Migration

Colony migrates towards its nutrient supply

Mirroring

$p(x,t)$ develops so as to approximate $n(x,t)$

mirroring of nutrient $n(x,t)$ by $p(x,t)$

Colony snapshots at end of three different simulations

Color code

White, pink, red: concentration of nutrient is ascending order.

Green represents centers of living bacteria.

Data: $m = n = 30$ $p = 100$ bacteria, and $\alpha = 1$.

Simulation snapshots

From left to right, snapshots correspond to values $\nu = 1.0, -1.0, 0.0,$

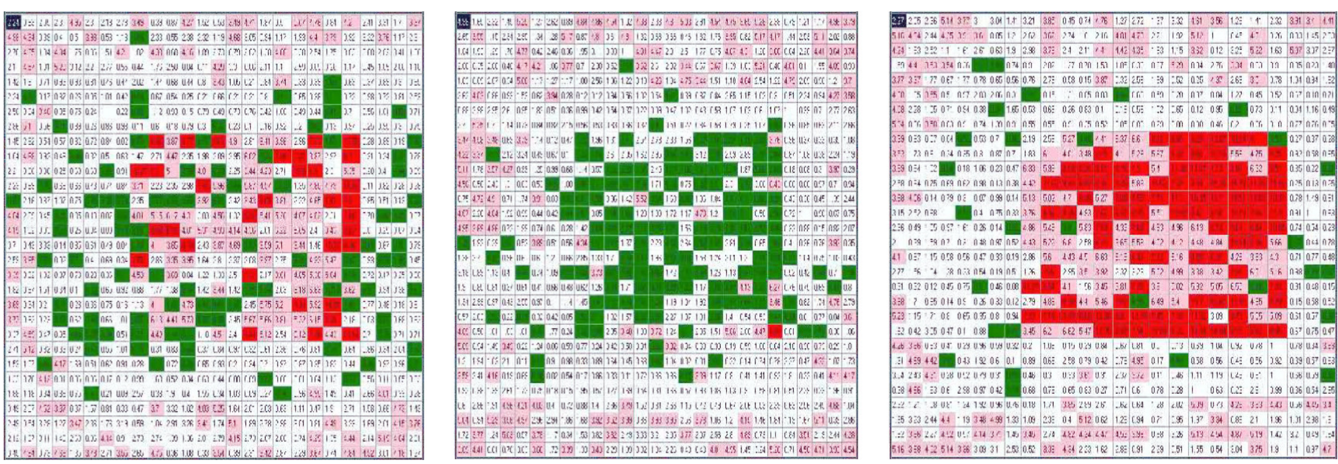

Figure 3.2: Bacterial sensitivity to nutrient location for different values of ν

Applications (Type A)

a) Qualia

2.14)

$$n(x,t) \overset{\textit{mirroring}}{\longleftrightarrow} p(x,t) \overset{\textit{duality}}{\longleftrightarrow} \hat{A}(x,t)$$

$$\textit{stimulus} \rightarrow \underbrace{\textit{token of the quale} \rightarrow \textit{experiencing of the quale}}_{\textit{quale}}$$

b) Intentionality

Human intentionality: experiencing of

observable unconscious decisions

made prior to the experiential effect (Libet)

In our model (summarized in (2.14))

unconscious competition for survival is an

externally observable feature

(token *a* of the affect in (2.7): via $\bar{n}$ values)

that informs population changes, $p(x,t)$

(via dynamics summarized in (2.10))

which drive the unobservable adjustment to

the experiencing process, the awareness $\hat{A}(x,t)$

c) Self

(1) Measurement and motion

where an externally observable unconscious procedure

of assigning bacterial level fitness a occurs (see (2.7))

(*2*) followed by reproduction where

a random assignment of the fitness a to progeny occurs

This corresponds to a dualist experiential process

Namely, the awareness $\hat{a}$ (a proto-consciousness).

(3) physical change of population

via dynamics of competitive survival process; (2.9-10))

and a modification of the colony's awareness density

both token and construct, $A(x,t)$ and $\hat{A}(x,t)$

Interpretation as self

Computation in (1): a process lacking awareness

(like a human level unconscious proto-thought process)

Posit: (2) is an experiencing called $\hat{a}$ (a proto-consciousness)

of this thought process in (1)

(3) is the competitive survival process taken as the

mirroring and experiencing of the quale $p(x,t)$

Biotic pan-psychism

Discussion of self frames a pan-psychism for living matter
organized to forage for nutrients for survival
and with the ability to reproduce

Cartesian dualism

Modify Descartes (as suggested by Libet's result)

"***I*** (experience) ***think***(ing***), therefore I am.***"

Consciousness in a Neural Assembly

Analogies

Model bacterium replaced by model neuron

Binary valued neural activity

Afferent synaptic weights: vector $w \in W$

Bacteria's position *x* replaced by

neuron's location *w* in *W*

Neuron better/poorer **consumer** of transmitter flux

depending on position in *W*

Neuron **more/less fit** is

better/poorer **producer** of this flux as well

Transmitter flux is analog of nutrient flux, $n(x,t)$

Motion in *W* is response to measurements of information

Competition replaced by **inhibition**

Reproduction replaced by **opportunity to fire**

Virtual **gene** replaced by virtual **chromosome**

The assembly model

3.1) $$h_i = \begin{cases} 1, & \text{if } N_i(w) \text{ fires} \\ 0, & \text{otherwise}. \end{cases}$$

Afferents

$n_i(w,t)$ number of afferents of $N_i(w)$ receiving endogenous (assembly) signal

Assembly's transmitter flux dynamics

3.2) $$n(w,t+1) = \sum_{i:\, neurons\, at\, w} h_i \kappa_i(w,t) - n(w,t) + n_e(w,t)$$

$$n(w,t) = \sum_{i:\, neurons\, at\, w} n_i(w,t)$$

$\kappa_i(w,t)$ axonal arborization multiplicity

$n_e(w,t)$ number of afferents of neurons at *w* receiving exogenous signal

Fitness

$$a_i(w,t) = \operatorname{sgn}\left[\frac{n_i(w,t)}{n_i(w,t-1)} - 1\right], \quad \forall i \qquad \text{3.5)}$$

Corresponding proto-consciousness

$\hat{a}(x,t)$ is **observer process** of

measurement and computation represented

the **token** $a_i(w,t)$ given in (3.5).

Virtual chromosome

Synaptic weight vector w

Motion in *W* (Hebbian dynamics)

$$w_i(t+1) = w(t) + a_i(w,t) H\left(v_i^a(t), v_i^e(t+1)\right) + \nu\chi, \quad \forall i \qquad \text{3.6)}$$

Population dynamics

3.7) $p(w,t) =$ # of neurons at w specified as **winners** at time t

Specification of winning neurons

Transmitter flux per firing neuron

3.8) $$s = s(w,t) = \frac{\sum_i n_i}{\sum_i h_i}$$

random variable s_j **with mean value** $\bar{s}_j$

3.9) $$s_j = \sum_i^{(s)} w_{ji}$$

sum over $\lfloor s \rfloor$ of the components of w_j chosen uniformly at random

winning neuron $N_j(w)$ if

3.10) $$\bar{s}_j > \theta_j$$

θ_j is the firing threshold

Heuristic

During sustained epoch of neuro-processing
neurons that satisfy (3.10) expected
to fire more frequently (be more fit, on the average)
than neurons that do not

Awareness hypothesis

Dualist construct $\hat{A}(w,t)$

Physical quantity $p(w,t)$, the number of winning neurons corresponds to assembly fitness density $\hat{A}(w,t)$

Token

3.4) $$A(w,t) = \sum_{i: neurons\, at\, w} a_i(w,t)$$

Construct

3.5) $$\hat{A}(w,t) = \bigcup_{i: neurons\, at\, w} \hat{a}_i(w,t)$$

3.6) $$A(w,t) = \frac{n(w,t)}{n(w,t-1)} - 1$$

Mirroring

$p(w,t)$ to mirror transmitter flux $n(w,t)$

Measurable

$p(w,t)$ (say, unconscious)

Unobservable

$\hat{A}(w,t)$ (say, a proto-consciousness density)

Interpretations

$\hat{A}(w,t)$ (proto-conscious) / $p(w,t)$ (unconscious)

sensations/sensors of the encoded information

being processed by the neural assembly

Information

Conventionally specified in terms of

collection of action potentials (the efferents v^e of (3.2))

in turn, each proportional to a quantity of transmitter flux

Experiencing

Posit: $\hat{A}(w,t)$ is experiencing of its dual $p(w,t)$

Experiencing of aninformation density value encoded

& being processed by neuronal sub-assembly at $w \in W$.

Quale density: $(p(w,t),\hat{A}(w,t))$

corresponding to **stimulus** $n(w,t)$

latter **mirrored** by $p(w,t)$

$$\underset{stimulus}{n(x,t)} \underset{\rightarrow}{\overset{mirroring}{\leftrightarrow}} \underbrace{\underset{\substack{token\ of\\ the\ quale}}{p(x,t)} \underset{\rightarrow}{\overset{duality}{\leftrightarrow}} \underset{\substack{\exp eriencing\\ of\ the\ quale}}{\hat{A}(x,t)}}_{quale}$$

Sense organ

Stimulus conveyed (whole or in part) from neuronal assembly

Intentionality and self

Same as for the colony

Applications (Type B)

1. Colony awareness vanishes with $n_e(x,t)$ (sensory input)

Set $n_e(x,t) = 0$. Then from (2.6), (2,7)

4.1) $$a(t) = \operatorname{sgn}\left[\frac{\overline{n}(x,t) - \beta\overline{p}(x,t)}{\overline{n}(x,t)} - 1\right]$$

$$= \operatorname{sgn}\left[-\beta\frac{\overline{p}(x,t)}{\overline{n}(x,t)}\right] = -1$$

$$a(t) < 0 \Rightarrow \hat{a} = \varnothing$$

Neural assemblies, threshold effect for generating qualia

Inserting (2.13) into (3.6),

4.2) $$A(w,t) = \frac{\sum\limits_{j:neurons\,at\,w} h_j \kappa_j(w,t-1)}{n(w,t-1)} - 2$$

Assembly awareness token

4.3) $$\mathbf{A}(t) = \sum_{\substack{w\ specified\\ by\ assembly}} A(w,t)$$

Assembly awareness

4.4) $$\hat{\mathbf{A}}(t) = \bigcup_{w} \hat{A}(w,t).$$

$$A(w,t) \leq -1 \qquad \Rightarrow \qquad \hat{\mathbf{A}}(t) = \varnothing.$$

2. Threshold effect to experience a quale

$$n_e(w,t-1)/n(w,t-1) \geq A(w,t)$$

3. Qualia located in peripheral nervous system

Three-layer compartmental model

Layer 0: the sensory input layer

Layer 1: peripheral nervous system plus cord

Layer 2: brain

To reflect these three compartments, (2.13) replaced by

$$n^{(j)}(w,t+1) = \sum_{i:\text{neurons at } w} h_i^j \lambda_i^j(w,t) - n^{(j)}(w,t) + (2-j) n^{(0)}(w,t)$$

$$+ \sum_{i:\text{neurons at } w} h_i^j \kappa_i^{jk}(w,t), \quad j,k = 1,2, \quad j \neq k. \qquad \text{4.5)}$$

$n^{(0)}(w,t)$: sensory input from layer 0 to layer 1

$n^{(j)}(w,t)$: number of afferents in layer j, $j = 1,2$ receiving input

$\kappa_i^{jk}(w,t)$, $k = 1,2$: part of the axonal arborization $N_i(w)$

that enervates a neuron in layer j, $j = 1,2$, $j \neq k$

$\lambda_i^j(w,t)$: lateral enervation within layer

h_i^j is 1/0, if in layer j, $N_i(w)$ fires/not-fires.

Awareness tokens

4.6) $$A^{(j)}(w,t) = \frac{n^{(j)}(w,t)}{n^{(j)}(w,t-1)} - 1 \quad j = 1,2$$

4.7) $$A^{(j)}(w,t) = \Phi(j) + \frac{(2-j)n^{(0)}(w,t-1)}{n^{(j)}(w,t-1)} - 2, \;\; j,k = 1,2, \; j \neq k$$

$$\Phi(j) = \sum_{i:neurons\,at\,w} \left[h_i^j \left(\lambda_i^j(w,t-1) + \kappa_i^{jk}(w,t-1) \right) \right] / \, n^{(j)}(w,t-1)$$

$$\Phi(j) < 1 \qquad \Rightarrow \qquad A^{(j)}(w,t) < 0, \quad j = 1,2$$

The term

$$(2-j)n^{(0)}(w,t-1) / n^{(j)}(w,t-1)$$

in (4.7) survives and dominates only for

$j = 1$ (for layer 1)

and

$n^{(0)}(w,t) \neq 0$

$\hat{A}(w,t) \neq \varnothing$ only in peripheral nervous system $(j = 1)$

and then only in presence of

adequately strong sensory input

4. Visual and auditory imagery are located out in space

Three layer (generalized) model

Layer 0: light supplies nutrient in form of light flux (photons)

Layer 1: three successive compartments.

First compartment: the objects seen
Flux from layer 0 processed
by absorption and reflection from the first
compartment resulting flux (processed light
stream) passed on to

Second compartment: the eye.
The eye processes flux from first compartment
first focusing it on the retina
which after some preliminary processing
passes flux (action potentials) via optic nerve to

Third compartment: LGN

Layer 2: rest of the visual cortex
interacting reciprocally with LGN

Awareness corresponding to vision

Occurs in layer 1, whose first compartment
consists of the objects seen

Role of the environment in consciousness

Vision uses mix of structure and flux types

Structures are neuronal, corporeal (but not neuronal) and extra-corporeal

Nutrient flux changes from streams of photons to customary neural transmitter

Processing of flux is disparate.

Consciousness is not only a product of the corpus, but of environment as well

Model complexity

Layer 2 neuronal processing of more than 20 richly

enervated reciprocally connected visual brain regions

4. Dream imagery located in a virtual space

Postulate: a sufficiently complex brain is able

to simulate a visual sensory system

(say as described previously) endogenously

The three layers are brain compartments

1) a source of imagery (from memory, say dream memory)

2) an intermediate structure where the awareness of the imagery is manifest

3) the remainder of the brain

Conclusion

Dream images located in intermediate structure 2)

Virtual space

We are not able to assign a specific

physical location to the intermediate structure

So we perceive location as some virtual space

5. **Phantom pain, a pathological phenomenon**

Explanation: model variables behave pathologically

Missing limb: layer 0 and part of layer 1 are absent

To accommodate layer 0, set $n^{(0)}(w,t-1)=0$

Next set $j=1$ and $k=2$ in (4.7)

4.8) $$A^{(1)}(w,t)=\frac{\sum_{i:neurons\,at\,w}\left[h_i^1\left(\lambda_i^j(w,t-1)+\kappa_i^{12}(w,t-1)\right)\right]}{n^{(1)}(w,t-1)}-2$$

Normative conditions: No phantom pain, since

$$A^{(1)}(w,t)>0 \qquad \Rightarrow \qquad \hat{A}^{(1)}(w,t)=\varnothing$$

No perceptual awareness (in missing part of layer 1)

Physiology

Phantom pain results from abnormally high levels of

Nav1.3, a sodium channel in thalamic neurons

causing a cortical stimulation (Waxman (2005))

These are layer 2 events in our model

characterized as pathologically augmented creation

of neurotransmitter flux in layer 2

This flux-stimulates layer 1, in turn

Model

Events characterized in our model as

pathological and excessively high value of κ_i^{12} in (4.8)

If κ_i^{12} large enough,

$$A^{(1)}(w,t) \le -1 \quad \Rightarrow \quad \hat{A}^{(1)}(w,t) \ne \varnothing$$

Thus perception, namely (phantom) pain in missing part of layer 1

Compare perception of phantom pain and location of vision

6. Pheromones

Awareness of a sensory input can only occur in layer 1

in the presence of adequately strong input

Adequate means that the relative input

4.9) $$\frac{n^{(0)}(w,t)}{n^{(1)}(w,t)} > 2$$

Derived by setting $j=1$ in the term $(2-j)\frac{n^{(0)}(w,t)}{n^{(j)}(w,t)}$ in (4.7)

Postulate

An unconscious sense (such as a response to a pheromone)

corresponds to a neuronal structure

wired up so that the inequality in (4.9) is never satisfied

Conclusion

Limitation of circuitry of layer 1 and/or its activity

inhibits consciousness of pheromones

Evolution

Argument on pheromones suggests

how sensory ability might be an evolving property

appearing (strengthening even to awareness)

as the relevant neural circuit/activity becomes more robust

alternatively

a deteriorating property, evanescing as the relevant

neural circuit/activity degenerates

Examples of deterioration

Axtyanax fasciatus mexicanus (blind cave fish)

Brain injuries furnish examples on scale of a lifetime (Sachs (1995))

Appendix: Simulations for the bacterial case

Nutrient bath

Rectangular region pixilated into sub-rectangles called cells.

Subset C of cells steadily receives a much greater exogenous supply of nutrient than cells not in C.

Mirroring measures

3.4) $$m_1 = \frac{\sum_{cells \in C} p(cell)}{\sum_{cells \in bath} p(cell)},$$

3.5) $$m_2 = \frac{fitin}{fitout},$$

where

3.6) $$fitin/fitout = \frac{\sum_{cells \in C} \left| bacterium\, i\, at\, cell,\ a(i) > -1 \right|}{\sum_{cells \in / \notin C} p(cell)}.$$

m_1 grades mirroring of exogenous nutrient supply by the colony population (symbolized by $p(x,t) \propto n(x,t)$)

m_2 grades mirroring of exogenous nutrient supply by colonial fitness (symbolized by $A(x,t) \propto n(x,t)$)

Nutrient bath, population

$m \times n$ cells is populated randomly with $p << m \times n$ bacteria.

Injection of nutrient flux

3.7)

$$n_e(x,t) = \begin{cases} k\beta, & if\ x \in C \\ \beta, & otherwise, \end{cases}$$

C: centered sub-rectangle of the bath

3.8)

$$x \in C,\quad iff\ x = \{(a,b) | \{(.25m < a < .75m) \wedge (.25n < b < .75n)\}\}$$

Data

α (see (2.3)) and ν (see (2.11)) specified at beginning of each simulation.

Statistical variance

Ten simulations of every variant are performed and means calculated

Mirroring

α	0.1	0.5	1.0
m_1	0.55	0.25	0.15
m_2	1.1	1.9	2.0

ν	-3.0	-1.0	1.0
m_1	0.28	0.57	0.13
m_2	1.8	1.2	2.0

Table 3.1: Mirroring effects as a function of α and ν values

Colony snapshots at end of three different simulations

Color code

White, pink, red: concentration of nutrient is ascending order.

Green represents centers of living bacteria.

Data: $m = n = 30$ $p = 100$ bacteria, and $\alpha = 1$.

Simulation snapshots

From left to right, snapshots correspond to values $\nu = 1.0, -1.0, 0.0,$

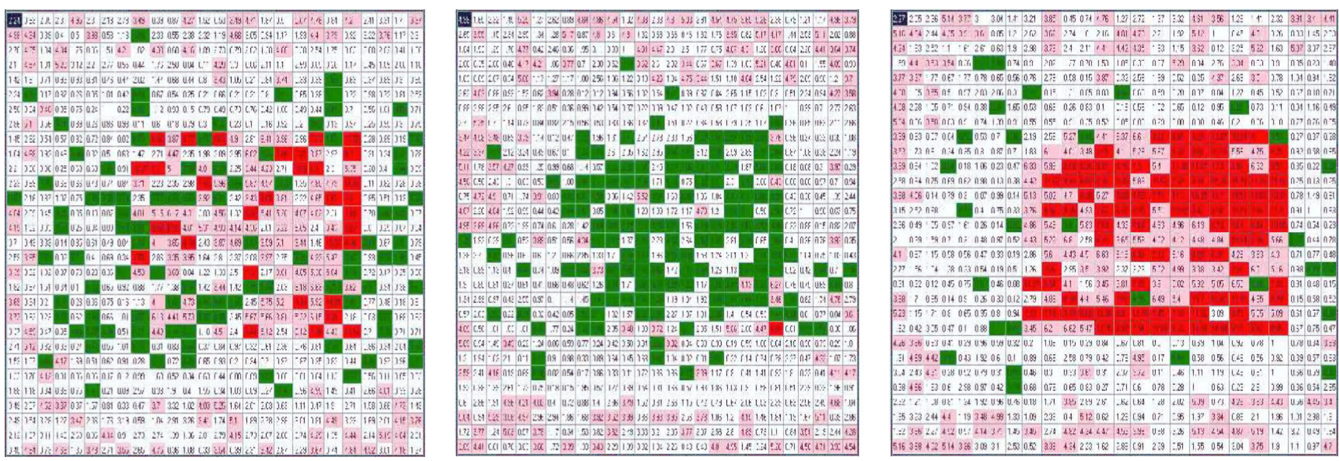

Figure 3.2: Bacterial sensitivity to nutrient location for different values of ν

Comments

Since the nutrient rich area C occupies a quarter of the bath, the mirroring effect #1/#2 can be said to have occurred if m_1>.25/ m_2>1.0.

From Table A.1 we see #1 is validated only for certain parameter values, while #2 is always validated.

Note that increasing α results in decreasing mirroring. So over sensitivity to local nutrient changes is counterproductive.

m_1 is very sensitive to variations in ν, with mirroring near a single value (ν = -1.0) and falling off rapidly with changes in either direction.

The snapshots serve as visual confirmation of this feature.

These observations show that mirroring (colonial awareness) and its survival advantages are available and optimized for appropriately selected parameter values, values likely delivered in nature by Darwinian evolutionary effects.