Vision in Light of Evolution

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Thanks To

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Monday, April 16, 12
Dangerous Question

When does natural selection favor true perception?
Vision Shaped By Selection
Vision Shaped By Selection
Vision Shaped By Selection

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Perception and Reality

Plato: Allegory of the Cave
Kant: Noumenal vs. Phenomenal
Gibson: Direct Perception
`... usually our perceptual processing ... delivers a true description of what is there.'
`... one interesting aspect of the evolution of visual systems is the gradual movement toward the difficult task of representing progressively more objective aspects of the visual world.'
The primary function of perception [is] that of generating a fully spatial virtual reality replica of the external world in an internal representation.
`Evolutionarily speaking, visual perception is useful only if it is reasonably accurate ... Indeed, vision is useful precisely because
`Evolutionarily speaking, visual perception is useful only if it is reasonably accurate ... Indeed, vision is useful precisely because it is so accurate. By and large, what you see is what you get. When this is true, we have what is called veridical perception ... This is almost always the case with vision ...`
`In general, it is true that much of human perception is veridical under natural conditions.'
`In general, [perceptual] estimates that are nearer the truth have greater utility than those that are wide of the mark.'
`Visual perception ... involves the evolution of the organism’s visual system to match the structure of the external world.’

Knill et al 1996
Bayesian Decision Theory

\[ p(S/I) = \frac{p(I/S) \cdot p(S)}{p(I)} \]

\( I \) images
\( S \) scenes

posterior likelihood prior normalizer
Bayesian Decision Theory

\[ p(S/I) \]

\[ G \quad \text{loss/gain} \]
Bayesian Ideal Observer

Choose the interpretation that maximizes expected gain.

Dirac mode

Quadratic mean
Bayesian Decision Theory

perception
Structure From Motion Demo
Ullman’s Theorem

Three orthographic views of four noncoplanar points

- a.s. have no rigid interpretations

- a.s. have two rigid interpretations, if any
Bayesian Decision Theory

perception
Bayesian Decision Theory

perception

S → G

P ↑ L

R^{18}
Bayesian Decision Theory

$R^{27}$ \rightarrow G \rightarrow \textit{perception}

$P \uparrow \downarrow L \downarrow \leftarrow R^{18}$
BDT and Measured World

Measured world

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BDT and Measured World

Cognitive extension of S.
Correct vocabulary to describe objective world.
`... the primary objective of an ideal observer is to compute the probability of each possible true state of the environment ...’
When does natural selection favor true perception?

Marr: Not in primitive vision.
`... Visual systems like the fly's serve adequately and with speed and precision the needs of their owners, but they are
`... Visual systems like the fly's serve adequately and with speed and precision the needs of their owners, but they are not very complicated; very little objective information about the world is obtained.
Visual systems like the fly's serve adequately and with speed and precision the needs of their owners, but they are not very complicated; very little objective information about the world is obtained. The information is all very much subjective....’
One reason for this simplicity must be that these facts provide the fly with sufficient information for it to survive.
Julodimorpha bakewelli
Moose Mating Mistake
If primitive vision sees no truth, why should advanced vision see truth?
`The payoff is more flexibility; the price, the complexity of the analysis and hence the time and size of brain required for it.'
Is it possible that human vision, like fly vision, sees no truth?
Evolution: Fitness Function

\[ f: \]
Fitness Function

\[ f : W \]
Fitness Function

\[ f : W \times O \]
Fitness Function

\[ f : W \times O \times T \]
Fitness Function

\[ f: W \times O \times T \times A \]
Fitness Function

\[ f: W \times O \times T \times A \times D \]
Fitness Function

\[ f: W \times O \times T \times A \times D \rightarrow R \]
A framework to study the evolution of perceptual strategies, and the conditions in which selection favors truth.
Sensory Strategy
No Dispersion

c : \mathcal{W} \rightarrow \mathcal{X}

\mathcal{W}, \mathcal{W} \quad \text{objective world}

\mathcal{X}, \mathcal{X} \quad \text{sensory representations}

c \quad \text{measurable function}

\forall A \in \mathcal{X}, \quad c^{-1}(A) \in \mathcal{W}
Computational Evolutionary Perception

\[ W, \mu, f \rightarrow P \rightarrow S, p(S) \rightarrow M \rightarrow \text{perception} \]

\[ I, p(I) \downarrow \text{L} \uparrow P \]

\[ c_1, c_2 \]
Probability of Perceptual Events

$W, \mu, f$

c : W \rightarrow X

\forall A \in X, \ c\mu(A) = \mu(c^{-1}(A))$
Fitness of Perceptual Events

$W, \mu, f$

$\mu f(B) = \int_B f \, d\mu$

$c : W \rightarrow X$

$\forall A \in X, \; c\mu f(A) = \mu f(c^{-1}(A))$
Computational Evolutionary Perception

\[ W, \mu, f \rightarrow P \rightarrow L \rightarrow I, p(I) \]

\[ S, p(S) \rightarrow G \rightarrow \text{perception} \]
Naive Realist

\[ c : W \rightarrow X \]

\[ X = W \]

\( c \) isomorphism
Strong Critical Realist

c : W → X

X ⊂ W

c homomorphism
Weak Critical Realist

\[ c : W \rightarrow X \]

\[ X \not\subseteq W \]

\[ c \text{ homomorphism} \]
Interface

\[ c : W \rightarrow X \]

\[ X \not\subset W \]

\[ c \text{ arbitrary, measurable} \]
Hierarchy of Sensory Strategies

- naive realist
- weak critical realist
- strong critical realist
- interface
Darwinian Ideal Sensory Strategy

\[ W, \mu, f \]

\[ P \]

\[ L \]

\[ I, p(I) \]

\[ S, p(S) \]

\[ M \]

\[ G \]

perception
Darwinian Ideal Sensory Strategy

A strategy that allows an organism to maximize expected fitness.
Where in the hierarchy of sensory strategies are Darwinian ideal strategies generically found?
CEP Framework

$W, \mu, f$ → $S, p(S)$ → $M$

$S, p(S)$ → $G$ → $perception$

$M \leftarrow P \leftarrow L \leftarrow I, p(I)$

$W, \mu, f$ → $P$

$c_1$ → $P$

$c_2$ → $S, p(S)$

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Territory Game

51

26

74
Territory Game
Green-Red Observer

![Diagram of green and red circles with a graph showing fitness vs. world state.](image-url)
Darwinian Sensory Strategy

Fitness

World State

0 50 100
Territory Game

Truth

Darwin

<table>
<thead>
<tr>
<th>51</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
<td>100</td>
</tr>
<tr>
<td>74</td>
<td>100</td>
</tr>
</tbody>
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Fitness vs. World State

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RGBY Observer

Image of RGBY Observer with a graph showing fitness over world state.
Territory Game

Truth

Darwin

51
0

26
100

74
100

Fitness

World State

Fitness

World State

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Payoffs

- total payoff = fitness
- payoffs: costs for time, energy per bit
- frequency dependent selection
Selection Dynamics

- *Darwin wins*: \( a > c, \ b > d \)
- *Truth wins*: \( a < c, \ b < d \)
- *Bistable*: \( a > c, \ b < d \)
- *Stably coexist*: \( a < c, \ b > d \)
- *Neutral*: \( a = c, \ b = d \)
Selection Dynamics

Truth

Critical Realist

Darwin
Selection Dynamics

Truth

Critical
Realist

Darwin
Dangerous Question

Where in the hierarchy of sensory strategies are Darwinian ideal strategies generically found?

Answer: Strict Interface
Why Darwin Is a.s. Interface

\[ W \xrightarrow{c} X \]
\[ W \xrightarrow{f} R \]
\[ R \xrightarrow{g} X \]

- \( f \): fitness function
- \( W \): objective world
- \( X \): sensory representations
- \( R \): real numbers
Why Darwin Is a.s. Interface

Natural selection shapes $g$.
Only if $f$ is a homomorphism of $W$, can $g$ be also.
Interface Theory

Our perceptions are a user interface between us and an objective world.
When Is Perception a Homomorphism of $W$?

$$f_i : W \times O \times T \times A_i \times D \rightarrow R$$
When Is Perception a Homomorphism of $W$?

Perhaps, as $i$ increases, perception converges to a homomorphism.
When Is Perception a Homomorphism of $W$?

Perhaps we evolve one sensory strategy to satisfice for several actions.
CEP vs BDT

$W, \mu, f$

\[ c_1 \]

\[ c_2 \]

$S, p(S)$

$P$

$L$

$M$

$I, p(I)$

$G$

perception

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CEP vs BDT

$W, \mu, f \xrightarrow{c_2} S, p(S) \xrightarrow{G} perception$

$W, \mu, f \xrightarrow{c_1} I, p(I)$
CEP vs BDT

Perception

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CEP vs BDT

M

perception

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What Is The True Color When You Don’t Look?

What is the true momentum or position when you don’t look?
Future Work

• Non-stationary worlds, dispersion
• Structured worlds: causal, spatial
• Finite populations, Moran processes
• Foraging
• Prototype and other category structures
• Ontogenetic learning
• Quantum games
• Theorems
Dangerous Question

When does natural selection favor true perception?
Dangerous Answer

Almost surely never.
`... what we observer is not nature herself, but nature exposed to our method of questioning.'

Heisenberg 1958
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