The Necker-Zeno Model

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Collaboration with T. Filk, J. Kornmeier, H. Römer

Some Remarks

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Mathematics serves the precise formulation of conceptual questions in terms of abstract structures (algebras, graphs, etc.).

Data processing includes the numerical quantification of observables, statistical analysis of measurement results, etc.

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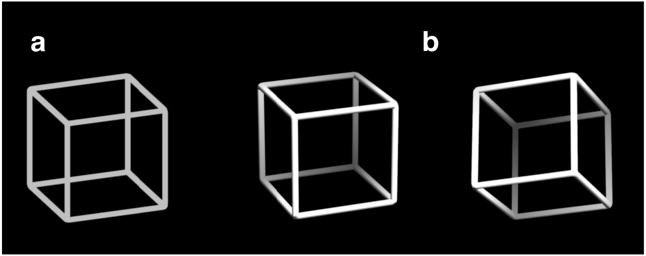
Psychology:

Almost every action of O entails a significant effect on S.
Non-commutativity is the rule rather than the exception.

$\longrightarrow$ generalized quantum theory details

Bistable perception of ambiguous stimuli: the Necker cube



spontaneous switches between two possible 3–D representations at a time scale of some seconds

Misra and Sudarshan (1977): Quantum Zeno Effect

- Two kinds of processes in an unstable two-state system:

  "observation": $\sigma_3 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$ switching dynamics: $\sigma_1 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$

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- The switching dynamics is a continuous rotation according to

  $$U(t) = e^{iHt} = \begin{pmatrix} \cos gt & i \sin gt \\ i \sin gt & \cos gt \end{pmatrix} ,$$

  with $H = g\sigma_1$, and $t_o = 1/g$ characterizes the decay time of the system.

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- "Observation" process is a projection P_+ or P_- onto one of the two eigenstates of σ_3.

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$$\begin{aligned} w_N(t) &= (\cos^2(g\Delta T))^N \\ &\approx \exp(-g^2 \Delta T^2 \cdot N) = \exp(-\frac{\Delta T}{t_o^2} t) \end{aligned}$$

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- Effect of observations: stabilization of the system in its unstable states, "dwell time" increases from unperturbed t_o to an average time $\langle T \rangle$:

$$\boxed{\langle T \rangle \approx t_o^2 \,/\, \Delta T}$$

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- Associated cognitive time scales:

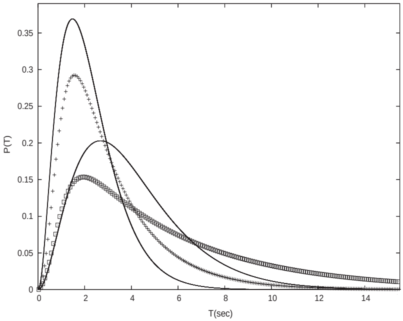
  intrinsic update interval $\Delta T \approx 30$ msec
  (sequentialization of successive stimuli, wagon wheel illusion)
  $t_o \approx 300$ msec (time for a stimulus to become conscious, P300)
  $\langle T \rangle \approx 3$ sec (average "dwell time" for bistable states / representations)

Observed Γ-distribution of dwell times T: $P(T) \propto T^b \exp(-\gamma T)$

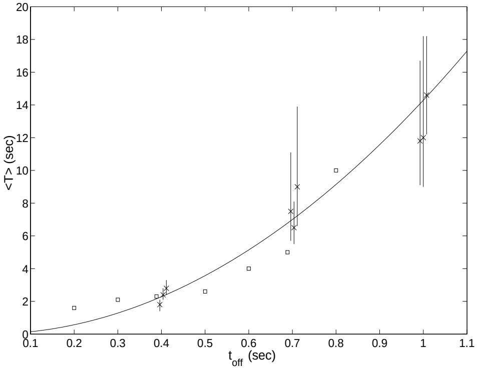
Model so far has $b = 0$ (purely exponential decay of $P(T)$),
refine with initial behavior due to effects of attention:
(a) increasing ΔT, (b) decreasing t_o.

– solid lines: Γ-distribution with $b = 2$ and $t_0 = 300$ msec for $\Delta T = 70$ msec (highest maximum) and $\Delta T = 30$ msec

– $P(T)$ according to Necker-Zeno model with decreasing t_o for $\Delta T = 70$ msec (crosses) and $\Delta T = 30$ msec (squares)



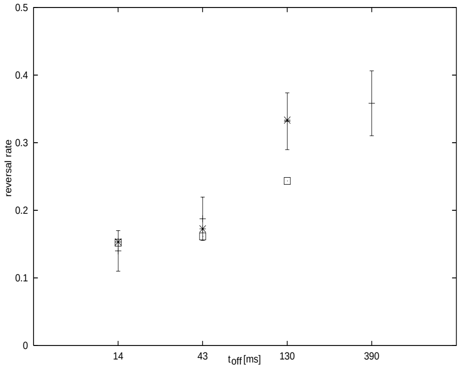
Dwell times $\langle T \rangle$ for off-times $t_{\text{off}} > 300$ msec



experimental values: crosses from Kornmeier and Bach (2004), squares from Orbach *et al.* (1966)

plotted curve according to the Necker-Zeno model for $\Delta T \approx 70$ msec

Reversal rates $1/\langle T \rangle$ for off-times $t_{\mathrm{off}} < 300$ msec



experimental values with error bars: from Kornmeier *et al.* (2007)

asterisks: best fit according to the Necker-Zeno model, yielding $\Delta T \approx 16$ msec and $t_0 \approx 210$ msec

squares: values for $\Delta T = 30$ msec and $t_0 = 300$ msec

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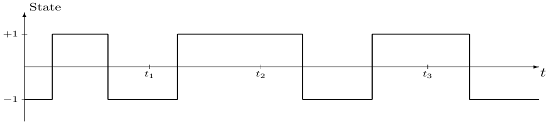
- Violations of temporal Bell inequalities would indicate temporal nonlocality (but in quantum mechanics time and dynamics are commutative).
- In the Necker-Zeno model there are two kinds of non-commuting dynamics, so there is a chance to violate temporal Bell inequalities in bistable perception.

Sudarshan (1983)

... a mode of awareness in which "sensations, feelings, and insights are not neatly categorized into chains of thoughts, nor is there a step-by-step development of a logical-legal argument-to-conclusion. Instead, patterns appear, interweave, coexist; and sequencing is made inoperative. Conclusion, premises, feelings, and insights coexist in a manner defying temporal order."

- Specify three different instances t_1, t_2, t_3 in a classical trajectory in which the state of the system at t_i is $s(t_i) = \{+1, -1\}$.



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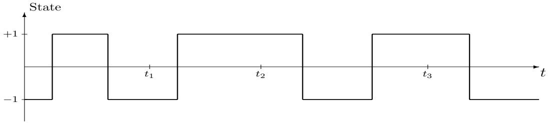

- Any classical trajectory falls into one of $2^3 = 8$ possible classes: 111, 11-1, 1-11, -111, 1-1-1, -11-1, -1-11, -1-1-1.

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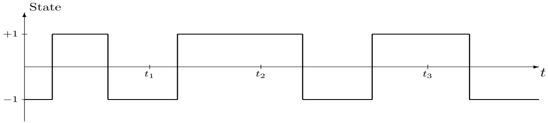

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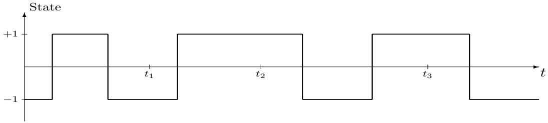

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- For each trajectory, $N^-(t_1, t_3) \leq N^-(t_1, t_2) + N^-(t_2, t_3)$. Normalize N to p, replace (t_i, t_j) by $(t_j - t_i)$:

  $p^-(t_3 - t_1) \leq p^-(t_2 - t_1) + p^-(t_3 - t_2)$ (temporal Bell inequality)

- In the Necker-Zeno model, the probability for state $|-\rangle$ at time t_2 under the condition of state $|+\rangle$ at time t_1 (and vice versa) is:

$$w_{+-}(t_1, t_2) = w_{-+}(t_2, t_1) = \sin^2 g(t_2 - t_1)$$

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- For $\tau := t_3 - t_2 = t_2 - t_1$, Bell's inequality turns into the sublinearity condition
$$p^-(2\tau) \leq 2p^-(\tau)\,,$$
maximally violated for $g\tau = \pi/6$ $(\sin^2 g\, 2\tau = 3/4,\ \sin^2 g\, \tau = 1/4)$.

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- Problem: measurements must be as non-invasive as possible to establish a significant violation of Bell's inequality.

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- Observables $A \in \mathcal{A}$ are (identifyable with) mappings $A : \mathcal{Z} \mapsto \mathcal{Z}$ which associate to every state $z \in \mathcal{Z}$ another state $A(z)$.
- To every observable A belongs a set $specA$ of possible outcomes of an evaluation (e.g., "measurement") of A.
- With A and B, also $A \circ B$ is an observable. (An addition of observables is not defined.)
- There is a unit observable $\mathbb{1}$, $spec\mathbb{1} = \{\text{true}\}$, such that: $\mathbb{1}A = A\mathbb{1} \;\; \forall \; A \in \mathcal{A}$.
- For a zero state o and a zero observable O, $specO = \{\text{false}\}$, we have: $A(o) = o, \quad AO = OA = O, \quad \forall \; A \in \mathcal{A},$ $O(z) = o \;\; \forall \; z \in \mathcal{Z}.$
- Observables P with $specP = \{\text{true, false}\}$ are propositions with the operations negation, conjunction, adjunction as usual.

- $\mathcal{A}$ has the structure of a monoid, generally non-commutative. The non-commutative case implies the concepts of:
  complementarity (incompatibility) of observables, dispersive states;
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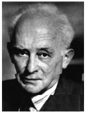
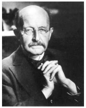
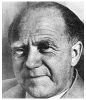
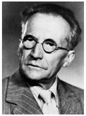
- The axiomatic framework of generalized QT does not prescribe the decomposition of a system Σ into subsystems. In particular there is no tensor product construction for composite systems.
- For the dynamical evolution of Σ one may assume a one-parameter (semi-) group of endomorphisms. However, there is no prescribed kind of dynamical evolution for subsystems of Σ and their interaction.

"Most generalized" QT does not use key features of ordinary QT

no  algebra, no  space, no  rule,

no  action, no  uncertainty, no  equation,

no  inequalities

return