A quantum approach to multi-agent systems (MAS), organizations and control

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Reasons for this Research

- Reducing errors by human/computational organizations (e.g., DOE/MAS) => regulation, control, and dynamics э mergers
- The game theory-rational theory failure to resolve an organization and its disaggregated members (GT: Luce & Raiffa, 1967; Kelley, 1979, 1992; attitudes v. behavior: Eagly, 1993; Tversky, 1993)
- Can *E* transitions in argument be modeled?

Agent Based Models (e.g., Robotics)

- Currently:
  - **One Predator per 20 human operators** (Pfister, 2002, Annie-02)
    - Single agents (MDP, GA, ANN)
    - Rational individual
    - Limit: *wdp*'s w/few *N*
  - Global Hawk, Predator w/Hellfire, Helios, & X-36
- Future:
  - **One operator per 20 Predators**
    - Social agents
    - Rational group perspective
    - *idp*'s w/unlimited *N*
    - *Swarms?*
- However, Bankes (2002) concluded that many ABM's
  - aren't as complex as the social
  - predictions cannot be validated

Table 1: Some strengths and weaknesses of game theory after 60 years of research

Strengths	Weaknesses
Rational model of the interaction (event trees, conditional probabilities)	Emotion is not integral to the model
Mathematical logic of interdependence	Uncertainty is modeled sequentially, not interdependently (i.e., observation uncertainty is independent of action uncertainty; Von Neumann & Morgenstern, 1953, pp. 147-8)
Mixed motives of conflict and cooperation	Argumentation, incommensurability, and diversity have zero social value (contrast Nash, 1950 with Von Neumann, 1961)
Mathematical equilibria (e.g., Axelrod, 1984)	Static configurations (Von Neumann & Morgenstern, 1953, p. 45) and equilibria imply information processing (*dI/dt*) occurs Ņextra-rationallyÓ (i.e., contingent on others) without regard to social forces, producing descriptive data and increasing observational uncertainty
Quantitative utility of expected outcomes	Arbitrary utilities for cooperation and competition lead to explanation versus prediction, overstating the value of cooperation (e.g., Axelrod, 1984; Shearer & Gould, 1999)
Learning is predicated on rewards and punishments (traditional Social Learning Theory -- SLT)	SLT occurs outside of awareness, devaluing rational problem solving skills (Skinner, 1978)
Models lead to clear predictions	No lab (Kelley, 1992) or field validation (Jones, 1998); further, ABM prediction not possible (Bankes, 2002)
First model of group behavior	Shifts between individual to group or ingroup to outgroup utilities cannot be studied;
Simple model of groups	Model complexity insufficient to model social organizations (Bankes, 2002)
Generalizable	Conclusions are normative (Gmytrasiewicz, 2002); e.g., ŅfairnessÓ

When Cooperation works

- The evolution of cooperation improves civilization (Axelrod, 1984)
- Cooperation is more moral (rejects compromise) and reduces bloodshed (Worchel, 1999)
- For well-defined problems (*wdp*'s) (Lawless et al., 2000b)
- Mathematically, less diversity => + stability (May, 2001, p. 174)

When Cooperation does not Work

- Cooperation does not work with:
  - Social loafing (Latane, 1981)
  - Asymmetric *I* (**terrorism, corruption, blackmail**)
  - Computational blowup as *N* cooperating agents exceed 100 (Darpa, 2002)
  - For ill-defined problems (*idp*'s)(Lawless et al., 2000a)
- Government by Consensus
  - Japan: Unable to reform
  - Germany: More Corrupt (from 14th in 1999 to 20th in 2000, TI, 2002); Tietmeyer (2002), ex-president Bundesbank, "… what we need are majority decisions ... [not] consensus."
  - EC: **"The requirement for consensus in the European Council often holds policy-making hostage to national interests in areas which Council should decide by a qualified majority."** (WP, 2001, p. 29)

Alternatives to Game Theory

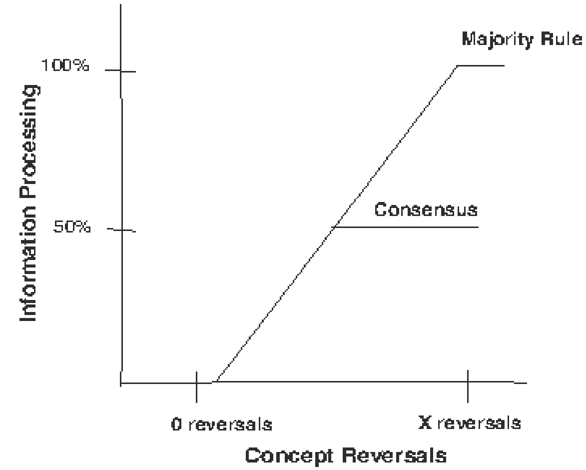
- Quantum Game Theory (Eisert et al., 1999, PRL)
  - Entanglement, Superposition
  - No field support
- Social Quantum Perturbation Theory => Bistable *R* *(Lawless et al., 2000)*
  - Entanglement, superposition -> maps (Zlot et al., 2001)
  - Democratic d.m. (DDM) -> science, politics, courtroom law (Lawless & Schwartz, 2002)
  - Difficult to rationalize b/c meaning arises from convergence into **bistable** beliefs

History of Quantum and Social Theory

- Traditional Signal Detection Theory = continuous ROC curves (Signal-y, S-n) (Swets, 1964)
- Quanta
  - Bèkèsy-Stevens discrete linear model v. ogives
  - Linear 2:1 relationship w/frequency, *E* effects (=> *E* levels)
  - Luce (1963, 1997) HMψ, JMψ
  - Eye as quantum *I* processor (French & Taylor, 1978)

History, continued

- Bistability (Bohr, 1955)
  - Multiple cultures
  - Differences between observation and action
- DDM => *I* processing -> # of concept reversals -> a solution ≈ SDT (Lawless & Castelao, 2001)
- Shifting between *E* levels (cooperation = ground state; competition = excited first state)



Bistability Fundamentals

- Organism exists superimposed simultaneously as
  - Observer and actor
  - Individual organism and member of a group
  - Member of a group A and group B
  - Superposition represented as $\alpha|\uparrow> + \beta|\downarrow>$, where prob($\uparrow$) = α^2 given that $|\alpha|^2 + |\beta|^2 = 1$
- Measurement -> bistable shift to observer (static *I*) or actor (action $I = \Delta I/\Delta t$) (Gibson, 1986)
- Measurement -> individual Event Histories = $K_{EH} = K_{\chi} \neq$ reconstruct interaction (Zeilinger, 1999; Carley, 2003

Models of Bistable (quantum) *R*

- Given Bankes (2002) concerns:
  - Models must be at least as complex as the social
  - However, ABM predictions cannot be validated
- Feynman (1985) found similarly:
  - Traditional computers model quantum *R* w/difficulty
  - Quantum computers easily model *QR*
- Maybe Quantum ABM's could easily model *SR*
- ABM's based on *QR* => parallelization + QIP -> + increased power

Bistable *R* (e.g., Faces-Vase Illusion**) => Multiple Frames**

1. Object acquisition based on + *E* -> convergence (γ waves => + *E*)
2. **(**K&T, 1981**)**: "Framing" => Convergence of beliefs reduces dissonance; e.g., "culture" (Bohr, 1955)
3. Participants can perceive "frame" A or B, but not both simultaneously (Cacioppo et al., 1996)
4. Convergence marginalizes divergent groups (Campbell, 1996)
5. Opposite K&T frames -> tension, disagreement, or conflict (Janis, 1982)
6. Managing opposed frames = argument -> *I* processing, optimal d.m. (compromise) (Schlesinger, 1949)

Interdependent (Social) Uncertainty Relations

- We are actors or spectators (Bohr, 1955)
- Convergence of ingroup worldview increases outgroup uncertainty (Tajfel, 1970)
- Let $\Delta a = \Delta I / \Delta t$ = action uncertainty;
- Let ΔI = information uncertainty;

$$\Delta a \Delta I \geq c \qquad (1)$$

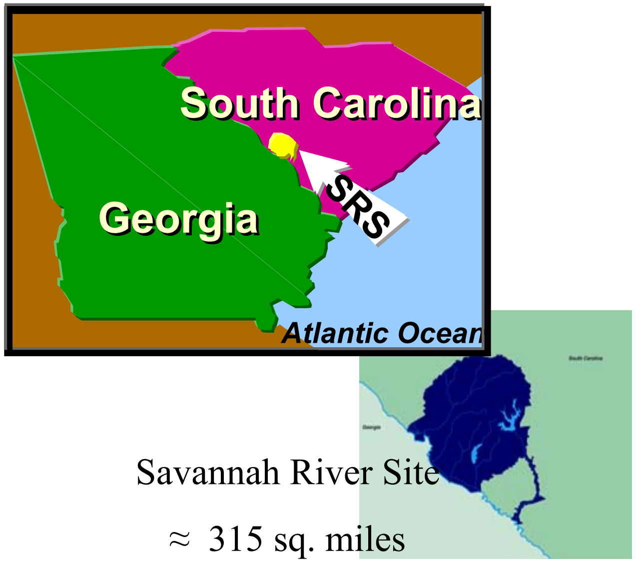
Solving $\Delta a \Delta I \approx c$

- <u>Case i</u>: ΔI -> *0*, Δa -> ∞
- <u>Results</u>:
  - 125 USAF combat pilots in eight 3-min ACM encounters against machines and humans. Book *K* of air combat = multiple-choice exam. Experience = flight-time histories + training.
  - Multiple regressions => experience predicted wins-losses ($\underline{R}$=.34, $\underline{p}$<.03), total aircraft relative E availability ($\underline{R}$=.37, $\underline{p}$<.01), and expert rating of performance ($\underline{R}$=.47, $\underline{p}$<.0001).
  - **Book *K* did not predict wins-losses, *E* availability, or expert ratings** ($\underline{R}$=0.0, $\underline{p}$ n.s.). (Lawless et al., 2000, SMC)

Case ii: Δa -> *0*, ΔI -> ∞ [Nuclear Waste Cleanups]

- Theory => adversarial decision-making (e.g., courts, science)

- **Contrast SAB (competition) v. HAB (consensus)**



Savannah River Site

≈ 315 sq. miles

t-tests: SAB (competition) versus HAB (consensus)		
1. Demographics	More Minority members	2.9 **
2. Member perceptions of Site	Site heeds advice	4.7 **
	Concurs with Site	5.3 **
	Site progressing	1.6
	Trusts Site	1.6
3. Member perceptions of members	Internal conflict	-2.1 **
	Likes consensuses	-3.3 **
	Trusts other members	0.6
	Members share ideas	3.2 **

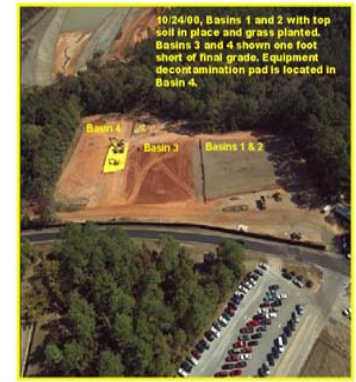
Conclusion: "competition of ideas" improved nuclear waste cleanup + trust (Wendt, 1999); neutral participants decide outcome

SAB Success Examples

- •2 HLW tanks closed
- •1200 vitrified HLW cans
- •Plug-in-Rods (borrowed from Hanford)
- •Old burial ground closed
- •2500 tru drums v 551 drums

Contaminated

Remediated



SRL basins before-after: SAB saved 2 years on cleanup -> plug-in-rods (i.e., *idp*'s -> *wdp*'s)

DWPF/GWSB

F&H and LLW-BG

(Lawless et al., 2000, SMC)

Case ii: Δa -> *0*, ΔI -> ∞ [Inter-Nation Competitiveness]

	1	2	3	4	5	6	7
1. SW	1.0						
2. H	-.72**	1.0					
3. E	.73**	-.66**	1.0				
4. pc's	.93**	-.70**	.78**	1.0			
5. web	.61*	-.37	.74**	.71**	1.0		
6. EF	.88**	-.79**	.70**	.84**	.48	1.0	
7. CPI	.81**	-.72**	.73**	.89**	.60*	.82**	1.0

- **Summary: Increased SW, H, E, EF, reduced corruption** (versus Skinner, 1978, Worchel, 1999)
- Trust in Congress > EU (W.E. Forum, 2003)
- Notes **(**Lawless & Castelao, 2001, IEEE**):**

SW Scientific Wealth (May, 1997, Science)
H Poor Health (infant mortality per 1000 births; World Bank)
E Energy consumption in Energy kg OE per capita, World Bank
pc's personal computers per 1,000 capita, World Bank
web Internet web hosts per 10,000 capita, World Bank
EF Economic Freedom, Cato Institute w/Milton Friedman
CPI Corruption Perceptions Index, Transparency International

Case ii: $\Delta a \rightarrow 0$, $\Delta I \rightarrow \infty$ [U.S. Airspace System]

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GIF decompressor
are needed to see this picture.

Convection Weather =
Single most disruptive
force within NAS

NCWF: Computational Forecasts (**$\Delta I \rightarrow 0$**)

Sep 3, 2001: 19Z

21Z

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are needed to see this picture.

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Collaboration Forecasts:
CCFP (**$\Delta a \rightarrow 0$**)

FAA's Validation Results (FSL RTVS)

Product	Issued (UTC)	Forecast Length	Human/ Automated	Ave area Forecast covered	Average PODy	FAR	Bias
CCFP	1500, 1900	1,3,5 and 3,5,7 h	H	5.2%	.28	.84	1.9
Convective SIGMET	Hourly	1,2 and 0-2 h	H	2.3%	.28	.70	1.0
SIGMET Outlook	Hourly	2-6 h and 6 h	H	14.9%	.04	.92	6.1
NCWF	5 min	1 and 2 h	A	0.5%	.09	.41	.10

Table 1. In this table, better forecasts have a lower convective area covered by the forecast, a greater PODy, a lower FAR, and a Bias closer to one (bias greater than one over-predicts convection; less than one under-predicts). [SIGMET is significant meteorological information; NCWF is the automated computer generated numerical prediction; POD-y is the probability of a forecast being observed = Y(forecast)Y(observed)/(YY+NY); FAR is the false alarm ratio = YN/(YY+YN); and Bias is the tendency to over or under predict convection = (YY+YN)/(YY+NY).]

Forecast Conclusions:

- **Experts Best; CCFP a close 2nd; NCWF worst**
- **However, no conflict w/ CCFP versus SAB**

(Lawless, 2002)

Decision-Making: Conclusions

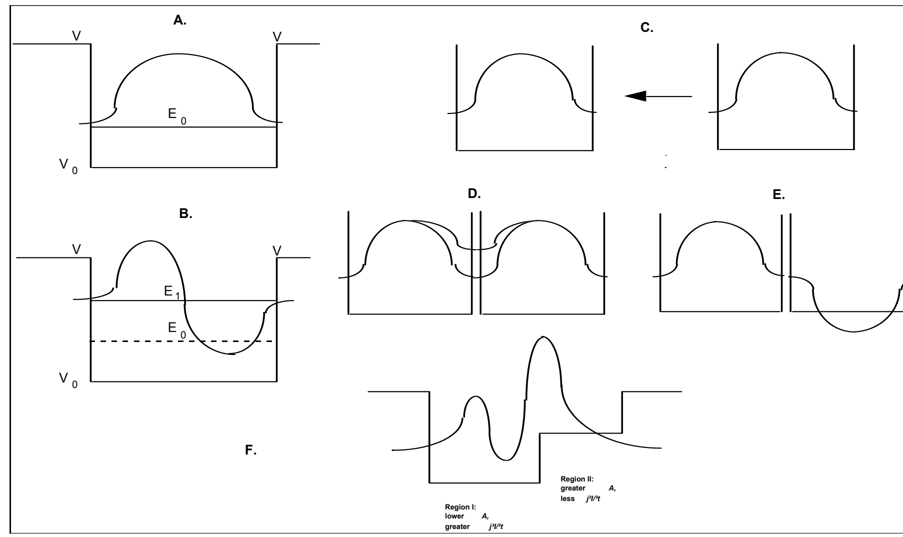
- Bistable *R* => orthogonal operators (competition of ideas) => dissonance arousal + neutral judges => superposition -> + *E* and *I* processing => optimal d.m.
- Resonance tunnels thru social barriers (compromise)
- Converts *idp*’s to *wdp*’s
- Solution ≈ best fit (from increasing number of participants => more Fourier components)

Revising Equation (1)

- Given reactance, j, $\Delta a \Delta I = \Delta\ (\Delta I/\Delta t)\ \ \Delta t/\Delta t\ \ \Delta I = j\ \Delta\ (\Delta I/\Delta t)^2\ \ \Delta t$, giving
- $$\boldsymbol{\Delta a \Delta I = \Delta t \Delta E \geq c} \qquad (2)$$
- Case iii: $\Delta t \rightarrow 0$, $\Delta E \rightarrow \infty$ (e.g., big court cases & science)
- Case iv: $\Delta E \rightarrow 0$, $\Delta \mathrm{t} \rightarrow \infty$ (e.g., vocal resonance)
- Human cognition
  - 40 Hz Gamma waves => object acquisition ≈ 75-150 ms
  - 16 mm movie film ≈ 62.5 ms
  - $\Delta t \Delta E \geq c = \Delta t \Delta hw = h$
  - $\Delta t = 1/\Delta w = 1/(40 \text{ Hz}) = .025 \text{ s} = 25 \text{ ms}$ (Roger Penrose)

Community Set-Point Theory (C-SPT): Square wells of *E* form emotion = set points => SPT (e.g., food, lotto; Diener & Oishi, 2000). Baseline E_0 associated with emotion potential energy, V. As excitation E attempts to redefine meaning, V keeps beliefs stable. C, D, E: Groups. **C-D illustrates E_0, D-E shows first excited state, E_1**. F. **Experts at I, Novices at II**

(Landers & Pirozzolo, 1990; Lawless & Chandrasekara, 2002)



Conclusions:

- 1st model of a group ≠ Σ disaggregated individuals
- Models experts versus novices
- Models ΔE levels for groups

IDFT (organization, mergers, and K)

- $E^{PES}(x,y) = min_{z,Rorg}\, E^{TOT}(x,y,z,R_{org})$ (3)
  - Function, hierarchy, organization (Sallach, 2002) => **Hamiltonian** (Lyapounov)
- $H = H_0 + H_{int}$ (4)
  - $H_0 = E_b^A \sum_k n_k + E_b^B \sum_k m_k + V^{A\text{-}B} \sum_k n_k m_k$ (0 if empty, 1 if occupied)
  - $H_{int} = 1/2V_{1n}^A \sum_{k,a} n_k n_{k+a} + 1/2V_{2n}^B \sum_{k,b} n_k n_{k+b} + 1/2V_{1n}^B \sum_{k,a} m_k m_{k+a} + 1/2V_{2n}^B \sum_{k,b} m_k m_{k+b} + 1/3\, V_{trio}^B \sum_{k,a,a'} m_k m_{k+a} m_{k+a'} + \ldots$

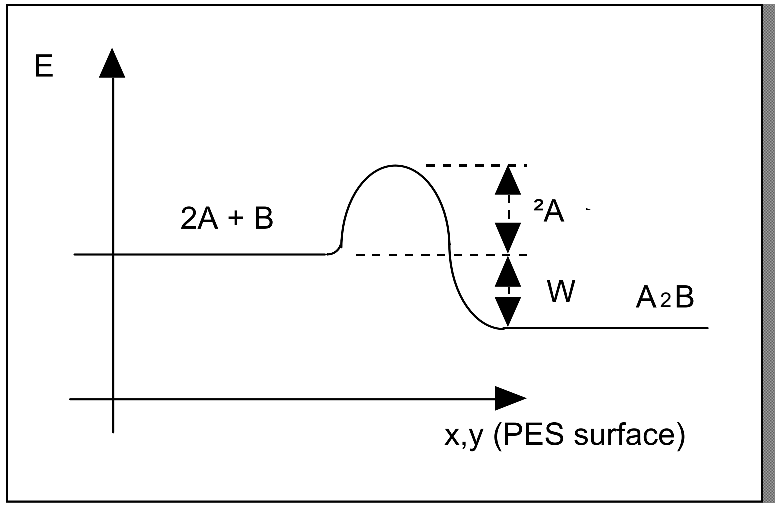
Conclusions:

- W/growth heterogenous island stresses reduce from Hi to Low (**terrorism**)
- Replaces Utility theory: $\Gamma_P = n_A n_B\, a\, \boldsymbol{\sigma}_{AB}\, exp\,(-\Delta A/k_B T)$ (5)
- **Interaction cross-section** $\boldsymbol{\sigma_{AB} = \alpha_\chi(\omega^4/(\omega^2-\omega_0^2)^2)}$ (6)
  - Friends ≈ vocal harmonic oscillators => **resonance** = HXS
  - terrorists cooperate to preclude warning observers = LXS

(Lawless & Chandrasekara, 2002)

$$E^{PES}(x,y) = min_{z,R\text{-}org}\ E^{TOT}(x,y,z,R_{org});$$

explains in g.t. why $\sum x_i \neq$ organization



(Lawless & Chandrasekara, 2002)

1. E_{min}:

- •Social Loafing (Latane, 1981)
- •Audience Skills enhancement (Zajonc, 1998)
- •Terror Mgt (Rosenblatt et al., 1990)
- •Health (House et al., 1988)

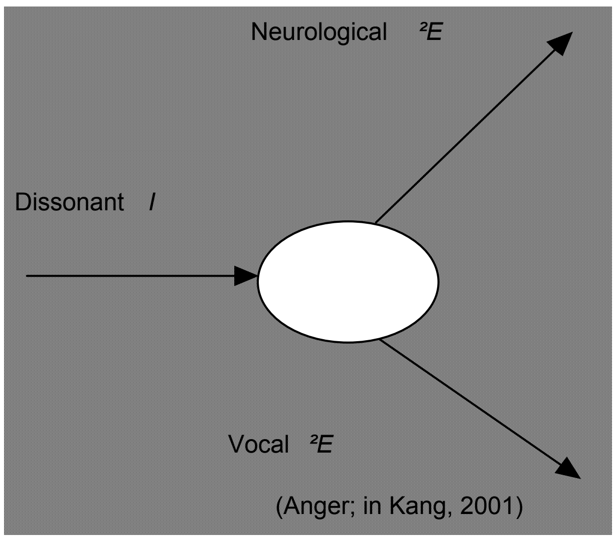
2. E_{min} **=> Perturbation Theory** (Lewin, 1951)

- •Attacks (cyber, business pricing, war)
- •**Only way to M(K_{EH})**

Future Research

Perturbations Theory (Picard's Liquid model of Emotion -> Spectrum)

$\Delta E \approx h * \Delta v$ (Penrose: 40 Hz, gamma)



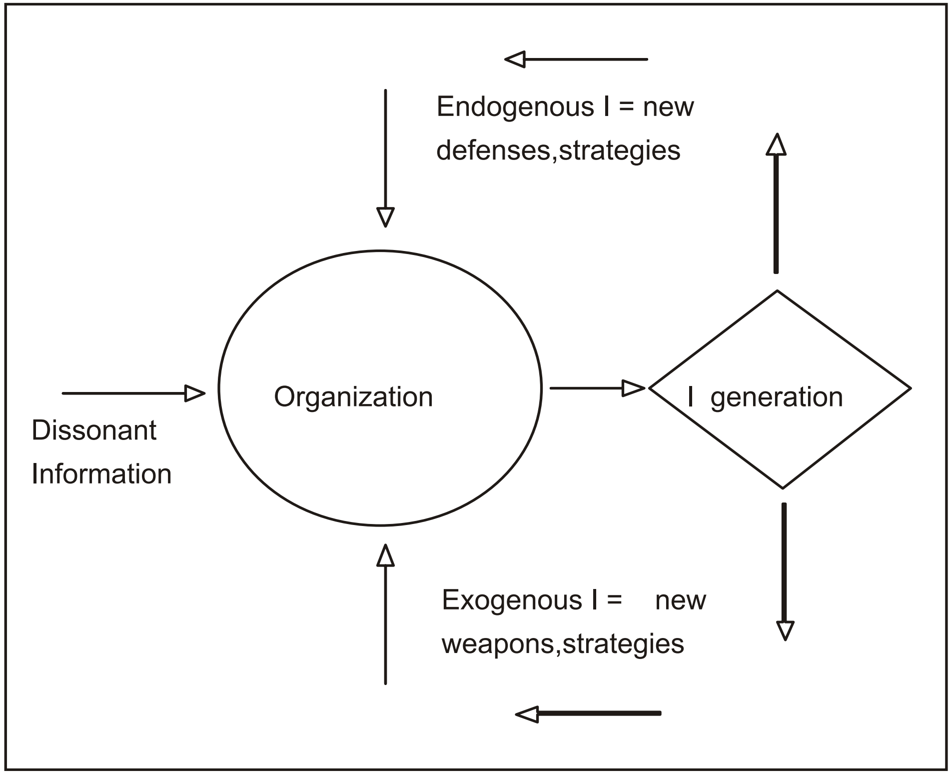
$\Delta E \approx h * \Delta v$

(Kang: Anger $\approx$ + 100 Hz)

Individual versus group Measures

1. Neurophysio-psych (SR's, qEEG's, fMRI's, EMG's, Lie Detectors, etc.)
2. Ground States (Single, Joint)
3. Anger (S, J)
4. Relationships (U-AZ, Foster)
5. D.M. (S, J)
6. Entanglement ***(interaction F's stronger than context F's => EPR test: entangled subjects separated: M(1) => State(2))***

Quantum Perturbation Theory

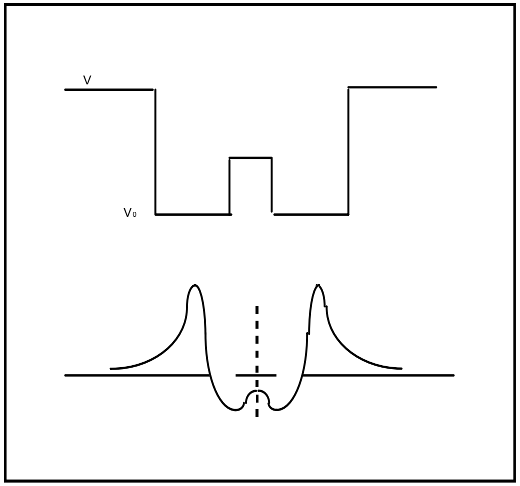


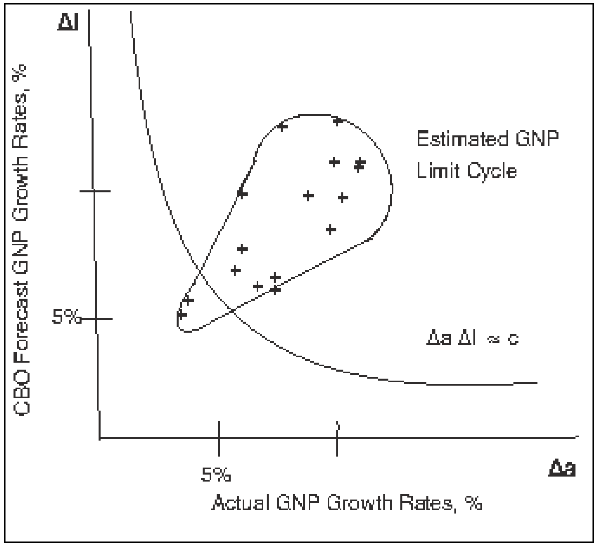
After perturbations, an organization uses endogenous feedback to defend itself. A competitor uses exogenous feedback to defeat the organization. In general, the quicker one wins; e.g., in 2003 in the war with Iraq, coalition decision-making and implementation of those decisions occurred faster than Iraq's Defense Forces, causing the latter to panic.

Current Research (links to Markovian Processes)

1. Predicted-Actual CBO two-year average growth rates for GNP (USA), 1976 to 1992 (CBO, 1999; in 1992, CBO switched to GDP). The estimated limit cycle is for GNP data; it contracts towards origin (increasing predictability), and expands away (increasing choice). (We have not calculated the dimensions of this phase space or attractor to see if chaotic, but in a contrast with a CDM economy, we expect a market economy to have a higher dimension; e.g., Nicolis & Prigogine, p. 281.)

2. For curve $\Delta a \Delta I \approx c$, the value for c is arbitrary, but predicated on no feedback.





1. Bifurcations: The double square well model represents *E* barrier between opponents and neutral middle, overcome in democracy by compromise or persuasion (e.g., even for BMW or GM to succeed, a company must appeal to neutral middle). Feedback $(\Delta I \rightarrow \infty) \approx$ fluctuations -> bifurcations when $\sum F \approx 0$, giving $\tau = exp(N\Delta V)$ => $\tau_{\text{majority rule}} << \tau_{\text{consensus}}$ -> regulation [**M(K_{EH})**]

2. *dI/dt* and *dX/dt* are Kolmogorov coupled nonlinear equations + $F_E(t)$ as forcing function is predicted stronger for CDM (dampening) than democracy (stochastic resonance) => K_{EH})

3. Regulatory Control (Lyapunov exponents => divergence from feedback) = f(environmental stability, **productivity, K_{EH}**)

4. λ = wave length ≈ organizational distances (no threat -> + cooperation w/less *I* dense, + K_{EH}; competition + *I* density, -K_{EH})

Conclusions

- Observation interacts with R (Pauli), collapsing State function (K of R) -> new K (Laurikainen, 1997)
- But K_{EH} cannot reconstruct R (Zeilinger)
- Org's under attack + E -> $-\lambda$ => tighter, closer groups
- C-SPT: If level of fluctuations are constant, given a stable env: => + diversity but w/- dyn stability (evolution wins); given an unstable env: - diversity but w/+ dyn stability (dynamics wins; e.g., survival mergers)
- Thus, while prediction may not be possible (deterministic chaos from density dependent signals), regulatory control or management of MAS is possible (i.e., limit cycles)

Additional Reading

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