Easy and Hard Sciences: A Comparison and a Suggested Program

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Observations and suggestions of a physicist—certain weakness for predictive modeling

Outline:

Study on ‘predicting terrorist events’ through JASON

- **Input**
- **Lessons**

Trend toward computational modeling

- **`Easy’ science modeling**
- **`Hard’ science modeling**

Global Goals—a suggestion for discussion

Predicting Terror Events

- **Scope**
  - Terror Scholarship
  - Terror Risk Assessment
  - Other disciplines where relevant
- **Formal questions**
  - Is it conceivable that a system to predict future acts could be developed?
  - What would prediction mean in such a system?
  - What inputs to the system would be needed?
  - How could a predictive system be tested?
- **What we tried to answer**
  - Do existing efforts in terror studies form the basis for valid and useful predictions of terrorist behavior?
  - What would a quantitative predictive system look like?

Terror Scholarship

- Narrative methods
  - News/Press releases
  - Bomber interviews
  - Recruiter interviews
  - Intel/Police info
  - Court records
  - Psychological profiling
  - Sociological analysis
- Quantitative methods
  - **Time series analysis**
  - Social networks analysis
  - Game theory
- Simulation methods
  - Red/Blue
  - **Agent-based computer simulation**

State-of-the-art quantitative method

- Walter Enders and Todd Sandler (2000)
- ITERATE Database - international terror incidents since 1970
- Series
  - Incidents
  - Casualties
  - Murders
- Time series analysis
  - Autoregressive modeling
  - Threshold autoregression
- Trends
  - Rate
  - Lethality
  - Number involved

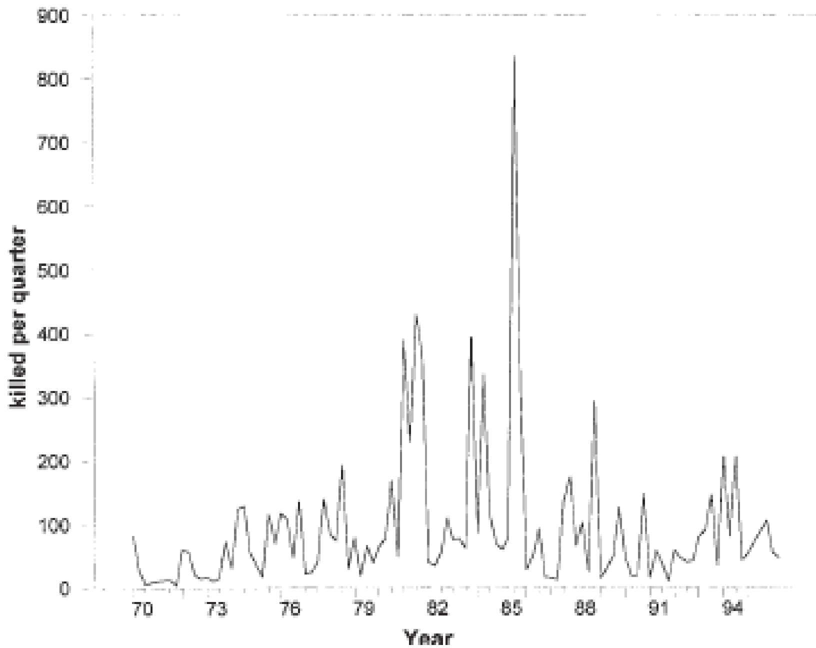
Journal of Conflict Resolution

NAS Award for Behavioral Research Relevant to the Prevention of Nuclear War

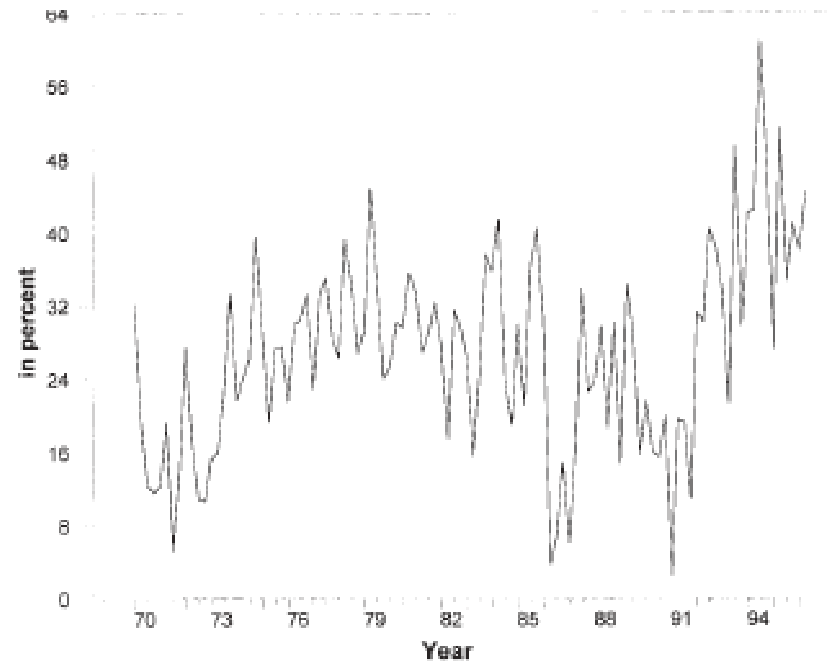
Awarded to recognize basic research in any field of cognitive or behavioral science that has employed rigorous formal or empirical methods, optimally a combination of these, to advance our understanding of problems or issues relating to the risk of nuclear war. Established by a gift of William and Katherine Estes.

Walter Enders and Todd Sandler (2003)
For their joint work on transnational terrorism using game theory and **time series analysis to document the cyclic and shifting nature of terrorist attacks** in response to defensive counteractions.

The View From 2000



igure 1: Number Killed



re 4: Proportion of Incidents With Casualties

What did E & S do?

TABLE 2

Trend Estimates for the INCIDENTS Series

Series	*Constant*	t	t^2	t^3	*F Statistics*	*ADF(4)*[a]
INCIDENTS	68.17	1.360	–0.010	—	2.90	–3.94
	(4.39)	(2.37)	(–2.34)		[0.060]	
CASUALTIES	6.49	1.43	–0.027	0.00016	7.16	–3.37
	(1.43)	(3.91)	(–3.45)	(3.19)	[0.0002]	
NONCASUALTIES	93.63	–2.58	0.071	–0.00049	20.03	–5.11
	(6.33)	(–2.17)	(2.76)	(–3.11)	[0.000]	
PROPORTION	7.24	1.69	–0.038	0.00024	18.59	–4.36
	(2.03)	(5.37)	(–6.06)	(6.26)	[0.000]	
DEATH EVENTS	1.91	0.94	–0.017	0.0010	10.53	–3.80
	(0.69)	(4.25)	(–3.56)	(3.22)	[0.000]	

Polynomial Trend

$a_0 + a_1 t + a_2 t^2 + a_3 t^3$

TABLE 3

Periodicities for CASUALTIES and PROPORTION Series

Series[a]	*Primary Frequency*	*Period in Quarters*	*Secondary Frequency*	*Period in Quarters*
CASUALTIES	0.338	18.57	0.822	7.65
PROPORTION[b]	0.338	18.57	0.870	7.22
DEATH EVENTS	0.108	58.18	0.262	23.98

Periodicity

$a_0 + a_1 \cos(\omega t + \phi)$

Methodological problems with E &S

- Database incomplete and heterogeneous
  - Does not include foiled or unpublicized exploits
  - Mixes geography and actors
- Polynomial fitting is, at best, interpolative
  - Extrapolation without an underlying mechanism is unjustified
- Fourier analysis without context has no value; same as above-- Extrapolation without an underlying mechanism is unjustified

E & S's unjustified conclusion

"The spectral analysis shows that incidents without casualties display no cycles, whereas those with casualties impart a long-term and a medium-term cycle to transnational terrorist incidents. Downturns in incidents with casualties have been followed at just less than 2.5 years by upturns. Authorities should apply time-series techniques to anticipate overall patterns to protect against new campaigns before they occur."

Enders & Sandler (2000)

One clear outcome of this study:

There are culture clashes in this arena:

Scientific

Political

Culture Clash, I

- **Short-term view**
  - “We need answers now”
  - "Let's do something now, even if imperfect”
  - “This model of social processes is controversial, but it might tell us something about terrorist thinking”
- **Long-term view**
  - This is a very hard problem!
  - Other experiences in science may play an important role
  - This may take decades
  - Must be done carefully, correctly and well
  - Premature efforts can doom a field

Culture Clash, II

	Desired Results	Common weaknesses
Prediction	**Fundamental basis**	**Often Ad Hoc**
	Recorded in Advance	**Perhaps a `recovered memory'**
	Committed to in Advance	**May be chosen post hoc**
	Fixed Scope/Event	**Scope/event chosen post facto**
	Validated	**Inherently nontestable**
	Uncertainty is Quantified	**No concept of uncertainty**
	Independently Judged	**``Looks good to me''**
	False predictions acknowledged	**False predictions ignored**
Model	**Scientific motivation**	**Just-so story**
	Known modeling errors	**Unknown modeling errors**
	Model entities correspond to real objects	**Model entities fanciful**
	Correct computational implementation	**Crude computational implementation**
	Accurate empirical calibration	**Unknowable calibration**

A positive sign in these culture clashes:

A desire for quantitative and predictive modeling is emerging

A growing trend:
Computational Modeling of Social Behavior

- Build interdisciplinary teams
  - Subject Matter scholars
  - Behavioral scientists
  - Computer scientists
- Compile knowledge of behavioral tendencies
  - Statistical tendencies
  - Narrative
- Build large computational models
  - Model general behaviorial properties
  - Model specific tasks issues
  - Agents, computational behaviors

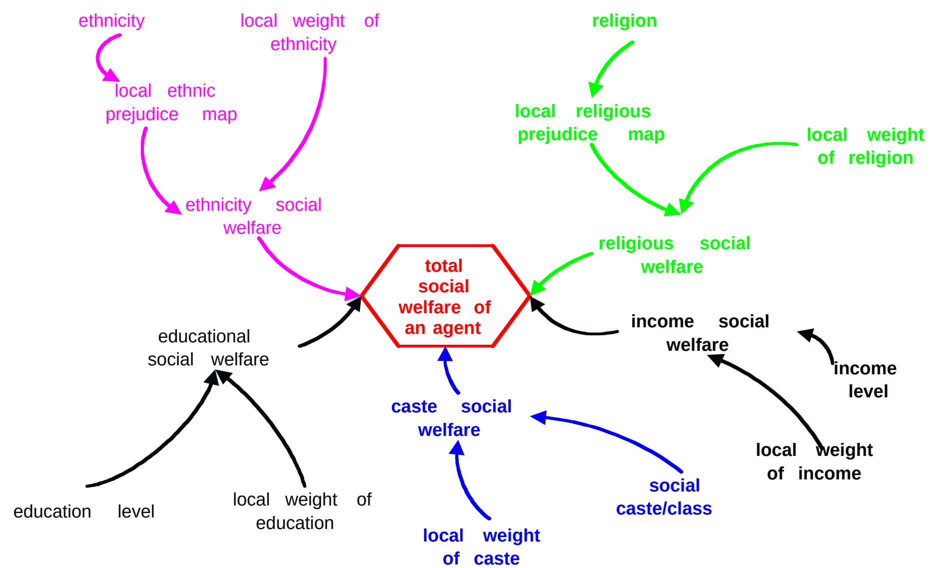
Some Agent-based Modeling Projects (Terror Prediction; JASON)

	Socioeconomic Model (MacKerrow)	DYNET (Carley)	Project Albert (USMC)	Biowar (Carley)	Seldon 2004 (SNL)
Simulation Type	MidEast Grievance	Disrupt. of Terror Orgs	Battlefield Tactics	U.S. Urban BioAttack	Terrorrists Enlistment
# of Agents	1000s	12	30 to 50	260,000	200 to 1000
Time Steps	Day	(Day)	Seconds	4 hrs	Day
Adaptation	Game Theory	(Yes)	No	No	No
Social Networks	Dynamic & Multiple	Dynamic	No	Static	Dynamic & Multiple
Clique Formation	(Yes)	No	No	No	Yes

Example of Simulation Approaches: TAPAS

- Developed by Edward MacKerrow, LANL
- Socio-economic, multi-agent simulation of Middle East, including terrorist groups
- Stochastic inputs based on empirical data
- Several interlocking micromodels, e.g. grievance, social welfare - based on social science theories
- Real-world object instantiation
- Can intervene, e.g. withdraw U.S. troops from Philippines or build McDonalds in Innsbruck
- Yields strategic-level outputs

TAPAS model:



$$
\begin{aligned}
S_{i,j}(t) = & \; w_{j,income} * A_i.income + w_{j,education} * A_i.education \\
& + w_{j,ethnicity} * A_i.ethnicity + w_{j,pedigree} * A_i.pedigree \\
& + w_{j,religion} * A_i.religion
\end{aligned}
$$

1. Local districts (defined GIS ADSM districts) have different weighting factors for each contribution to social welfare. For example in one district it is more important to have high income versus what religious group you belong to.

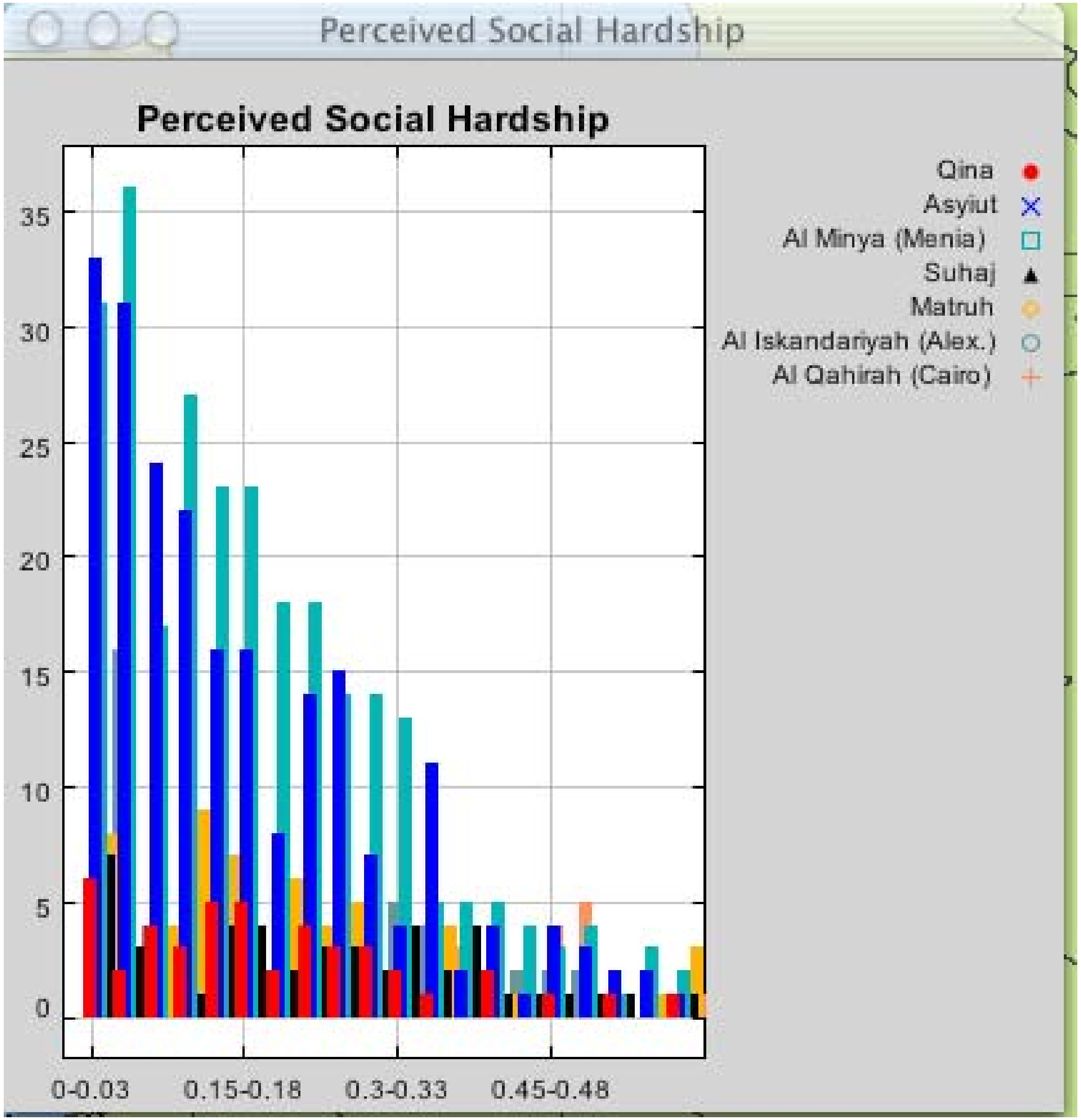
2. Religion and ethnic prejudices are defined as a *relative mapping* in each district. This mapping ranks the local prejudices based on religion and ethnicity.

3. If a social factor (e.g. caste) is not important in estimating social welfare for a particular district, then the weighting factor for that social factor in that district is set to zero.

4. Social welfare is a dyanmical quantity in the model, since income levels are dynamic. In later stages of the model development religious and ethnic prejudice mappings can change based on socio -political dynamics.

TAPAS Output:

As simulation runs, possible to watch key variables evolve



Fortunately, there is significant experience with ‘hard’ problems in computational modeling

Experiences with Computational Models

- Many past investments in computational modeling of complex systems:

Weather	Natural Hazards	Climate
Nuclear Weapons	Energy Production	Energy Consumption
Aeronautics	Cosmology	Traffic

•Common path of experience in modeling complex systems:

- At first, large claims but low validated progress
  - Science non-cumulative
  - Knowledge transfer not achieved
- Eventually, reforms in process
  - Data quality
  - Model documentation
  - Model validation
  - Model verification
- Later, steady progress

Example: Energy Resource and Consumption Modeling

After the first oil price shock in 1973/4, energy modeling was a US national research priority.

However, the second price shock 1978/9 showed the models were of low validity.

A new approach was needed.

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Doug Hale, Energy Information Administration (email to JASON):

In the early 1980's most energy models were poorly documented, their published results were impossible to replicate, and the models were highly sensitive to *ad hoc* adjustments/"parameter estimates" buried deep in the code. Ample scope for mischief!

Energy Resource and Consumption Modeling

We required models to be documented in a standard way, and we required all models and their published forecasts to be archived. The archival process included an independent party running the model and obtaining the published results.

Unless a sponsor is committed to rigorous documentation and replication, it is a waste of time and effort to talk about model integrity and quality.

- In the next three steps we to critically examined:
  - **the model's economic/physical foundations,**
  - **parameter estimation**
  - **forecast accuracy**
- When feasible, we also tried to estimate the distributions of forecast errors. To minimize intramural food fights we usually hired well known economists to evaluate the model's economic foundations, but my staff reviewed estimation, compiled histories of forecast errors and conducted sensitivity studies.
- Finally we wrote up our findings and made recommendations to the Administrator for fixes. The recommendations were usually acted on.

From discussions such as this, we suggest there are

‘Easy’ sciences where one is dealing with `dumb’ agents interacting to determine the state of an interesting system, and there are

`Hard’ sciences where one is dealing with ‘smart’ agents to determine the state of a system

`dumb’---no internal degrees of freedom

‘hard’—internal degrees of freedom, perhaps not observable

Many physical and biological sciences are ‘hard’

“Easy” sciences and “Hard” sciences

General goals:

<u>prediction</u> in time of results of interactions among “agents” with internal and public properties of state of agents and actions—choices of public state of an agent

$p_a(t) \rightarrow p_a(t+1)$ $a = 1, 2, \ldots, N$ rules for evolution

Require: rules of interaction, database of attributes, verification of attributes, database of observed outcomes, methods for comparison (metrics) for verification and validation of proposed interactions of attributes

Must have consistent and professional interaction and consistency among participants in building and testing rules—**<u>must talk to each other and have contests</u>**

Agent based interactions

as models for easy and hard sciences

Agents are actors who may inter-act

Agents may have many individual attributes, public and private

Interaction may change both public and private attributes

Outcome of interactions may be changed selection of attributes, maybe choices for further action:

Continued interaction; removal from interaction

Normative action

Other actions……

Easy Sciences

Physics of “dumb” agents

“Dumb” agent---

One quality—e.g. location

No internal degrees of freedom

Unable to change attributes on interaction

Easy Sciences

Physics of “dumb” agents

Masses interacting through forces dependent on distance

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One agent problem:

$$p(t) = \text{properties or attributes of agent}$$

$$\frac{dp(t)}{dt} = \text{Forces from other agents} = 0$$

$$p(t) = \text{constant}$$

Easy Sciences

Two agent problem:

$p_a(t) = \textit{public}$ attributes of the agents, $a = 1, 2$

$$\frac{dp_a(t)}{dt} = F_a(p_1(t), p_2(t))$$

$p_a(t) \neq$ constant

Forces inversely proportional to $(\text{distance})^{-2}$
leads to ellipitical motions - -simple

Forces inversely proportional to $(\text{distance})^{-3}$
leads to complicated motions - -not so simple

Easy Sciences

Three agent problem:

$p_a(t) = \textit{public}$ attributes of the agents, $a = 1, 2$

$$\frac{dp_a(t)}{dt} = F_a(p_1(t), p_2(t), p_3(t))$$

$p_a(t) \neq \text{constant}$

Essentially any forces lead to chaotic motions

Complexity from simplicity of statement on agent interaction;

Model is simple, outcomes are complex.

Easy Sciences

Here's an example of a three agent problem

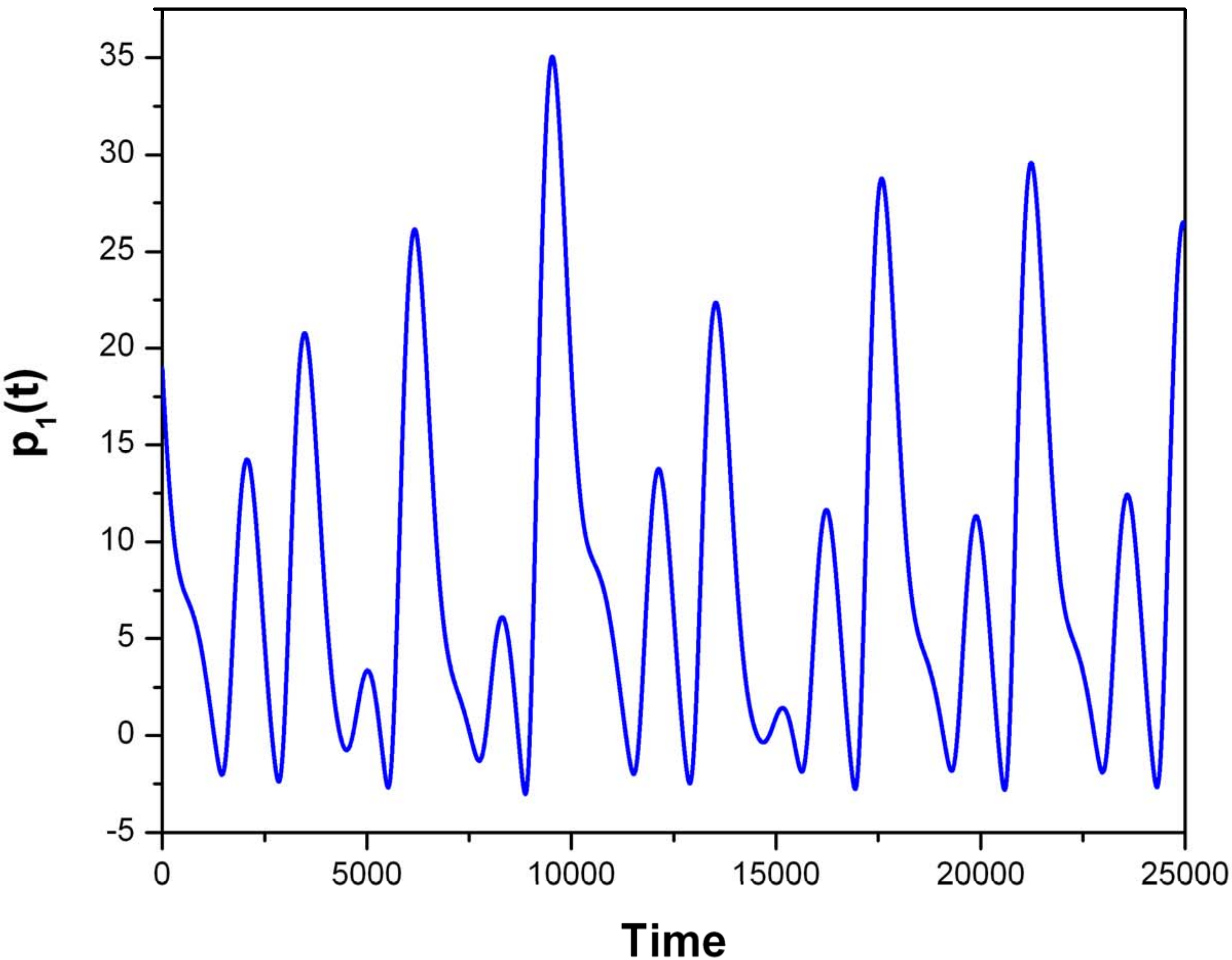
The <u>state of the system</u> is $(p_1(t),p_2(t)p_3(t))$ namely the properties of all agents at any time; give a rule for time development of the system.

I'll show

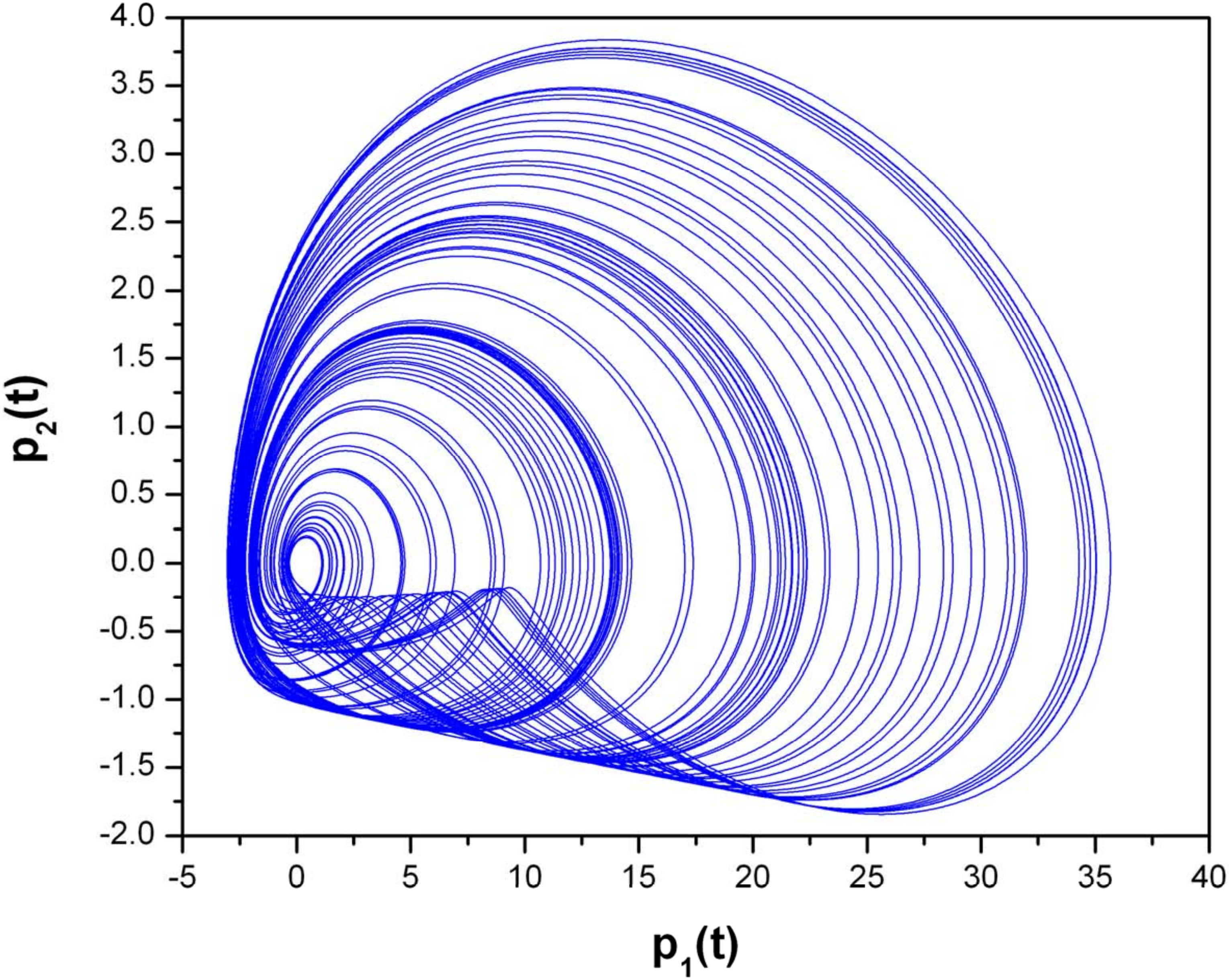
$p_1(t)$

and

$(p_1(t),p_2(t))$



35
30
25
20
15
10
5
0
-5
p1(t)
0
5000
10000
15000
20000
25000
Time



4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-5
0
5
10
15
20
25
30
35
40
$p_2(t)$
$p_1(t)$

Critical Lesson in ‘Easy’ Sciences:

Small numbers of dumb agents can be handled and understood

Networks of ‘dumb’ agents are dramatically harder---examples of hard computational problems

Weather	Natural Hazards	Climate
Nuclear Weapons	Energy Production	Energy Consumption
Aeronautics	Cosmology	Traffic

‘Hard’ Sciences

Dynamics of “smart” agents

“Smart” agent---

Many qualities—not all are observable

Many ‘internal’ (or private) degrees of freedom

Able to change on interaction

$p_a(t) \rightarrow p_a(\mathbf{S},t)$ where **S** is the state of the internal dynamics. As it is not observable, one needs a distribution of its values, and the state of the agent can only be known statistically.

Need dynamical rules: $p_a(\mathbf{S},t+1) = F_a(p(\mathbf{S},t))$

Truly, there is no distinct boundary between ‘easy’ and ‘hard’ sciences

Lessons from former blend into suggestions for latter

Here’s a challenging set of goals for guiding ‘hard’ science developments into a quantitative, predictive tool

Build Foundations for Quantitative, Predictive Studies

- Investments to promote the positive development of the field of social science studies
- Aim for a `hard' science enterprise that is:
  - **PROFESSIONAL**
  - **DATA DRIVEN**
  - **PREDICTIVE**
  - **CUMULATIVE**
  - **SELF-CRITICAL**
  - **GLOBAL**

Professional Enterprise

- **Encourage and support careful concept/language usage**
  - Prediction vs Anticipation vs Imagination
  - Modeling exercise versus Model validity and verification
  - Rhetorical outcome or Management Tool versus Scientific output

- **Support/Require awareness of best empirical/computational modeling efforts throughout science and technology**
- **Encourage competition and comparison on suite of selected problems—easy to, well, impossible**

Data Driven Enterprise

- Encourage broad awareness of difficulties of observational (as opposed to experimental) data

- Long term support to those who compile, edit, criticize, curate, manage, distribute, apply quality control to critical databases. Frankly, this is hard in `easy’ sciences—example of ARM program in US DOE

- Long term support for those who design experimental procedures, case control methods, double blind techniques, etc. that potentially enable valid inferences

Cumulative Enterprise

- Requirements and financial Incentives
  - Model sharing
  - Data sharing

  Embed behavior in contracts and grants clauses
- Address security concerns
  - sharing sensitive data within the sponsored research community

Predictive

- Reach for Quantitative, Predictive Models
  - Address problems selected for illustration of issues, not necessarily driven by short-term political or financial needs
  - Base modeling on shared data, common metrics of comparison
  - Community efforts at verification and validation

Critical and Self-Critical Enterprise

- Create broad awareness of
  - model criticism
  - model validation
- Recognize and Support
  - Surveys of empirical work
  - Surveys of computational modeling
  - Critical evaluations
- Sponsor criticism exercises, prediction exercises, challenge problems
- Competing centers of model development and data collection are <u>not</u> waste or redundant, but critical to development of valid, predictive efforts

Global Enterprise

- Fund research on attitudes and phenomena in many countries and cultures
- Fund research by scholars and law enforcement officials in key cultures and societies
- Encourage inputs about behavior using experiences from several cultures—comparison exercises, draw universal and “local” lessons.

Time for a little self-criticism

Speaker has no experience in social sciences

Speaker has no ‘worked example’ indicating his ideas might be feasible

Speaker leaves hard job of ‘hard’ sciences to others

Speaker is, however, (modestly) prepared for questions

Thank You!