Some Ideas on
Asynchronous Computation

[redacted]

- The concept of :
    - Temporal Precedence
    - Spatial Precedence

- Prior work in relaxing precedence

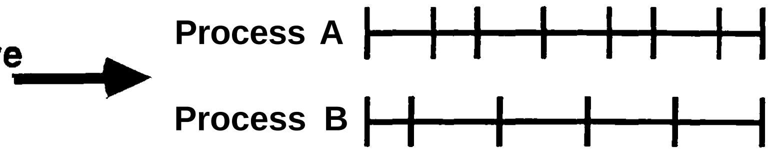
- Evidence for a conjecture:
  Quantum behavior is emergent.

- Why does it work this way?

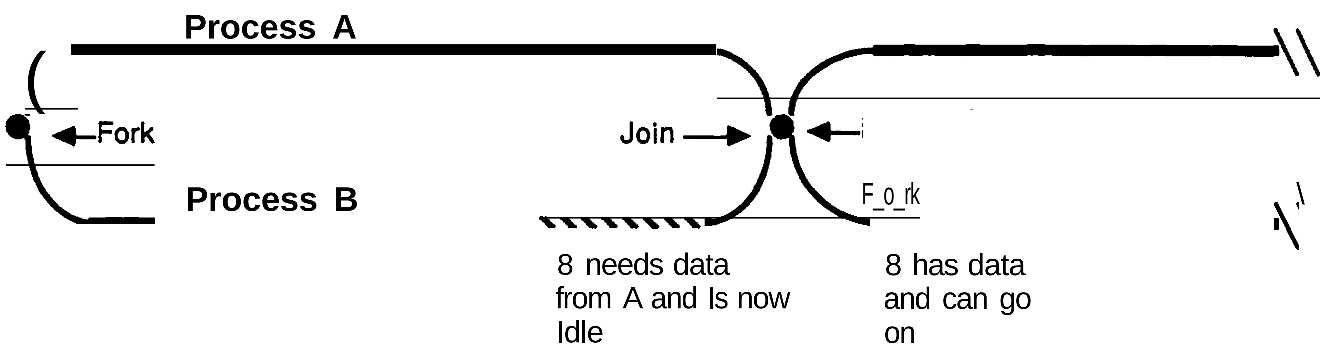
- Speculation:
  Does nature work this way?

The Concept of Temporal Precedence

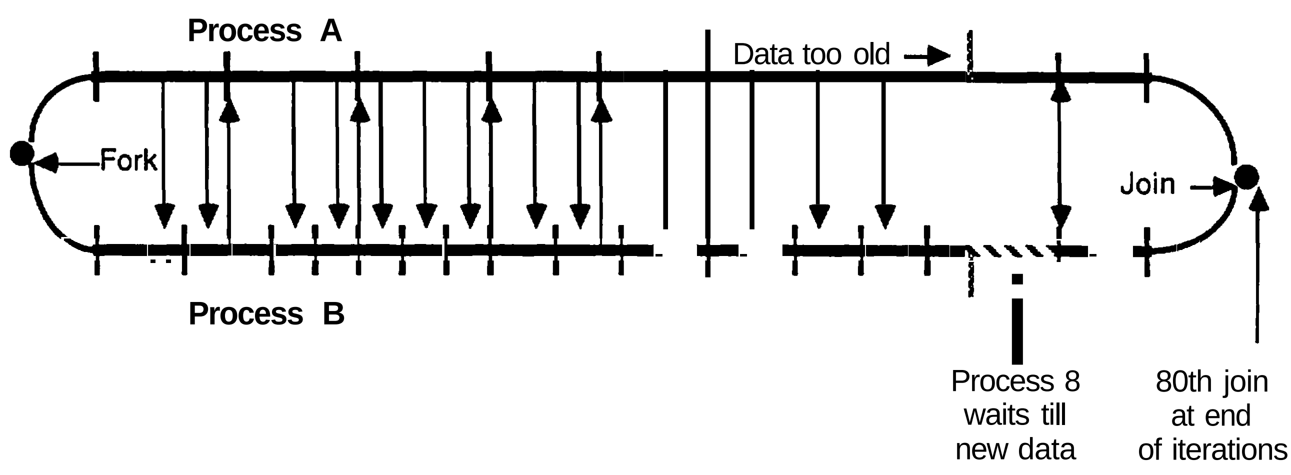
Note that Processes can have different cycle times:



Two Synchronized Processes:

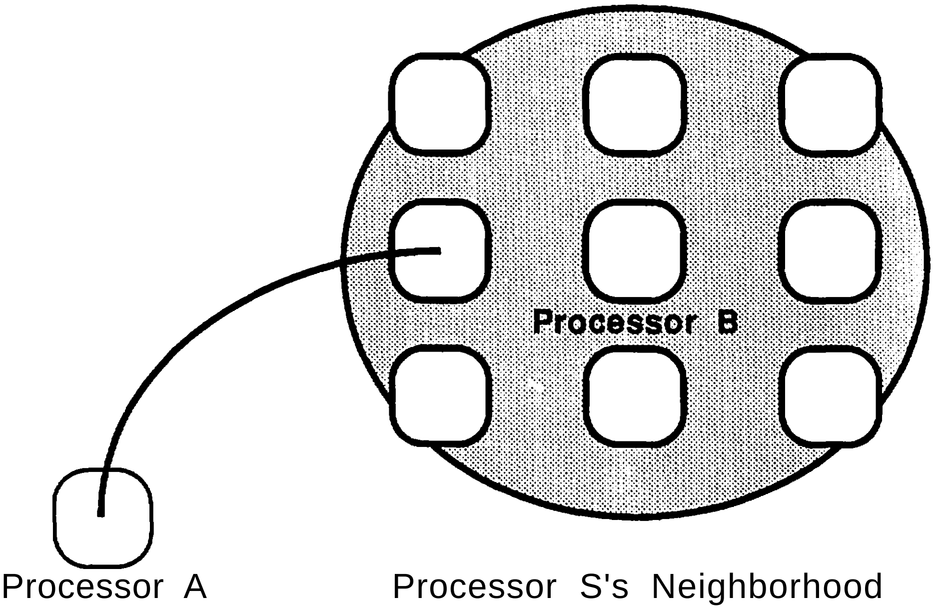


Two Asynchronous Processes:



The Concept of Spatial Precedence

Data are obtained from
a neighbor of processor B



·Prior Work in Relaxing Precedence: Asynchronous Iterative Algorithms

- Chazan and Miranker:
  "Chaotic Relaxation"
  Linear Algebra and Appl., 2, 1969

- Baudet:
  "Asynchronous Iterative Methods for Multiprocessors"
  JACM, April 1978

- Kung:
  "Synchronized and Asynchronous Parallel Algorithms for Multiprocessors"
  In *Algorithms and Complexity: New Directions and Recent Results*
  1976 Academic Press

- Lubachevsky and Mitra
  IIA Chaotic Asynchronous Algorithm for Computing the Fixed Point of a Nonnegative Matrix of Unit Spectral Radius"
  JACM, Jan. 1986

JACM Jan 86

A Chaotic Asynchronous Algorithm for Computing the Fixed Point of a Nonnegative Matrix of Unit Spectral Radius

BORIS LUBACHEVSKY AND DEBASIS MITRA

AT&T Bell Laboratories, Murray Hill, New Jersey

Abstract. Given a nonnegative, irreducible matrix P of spectral radius unity, there exists a positive vector π such that $\pi = \pi P$. If P also happens to be stochastic, then π gives the stationary distribution of the Markov chain that has state-transition probabilities given by the elements of P. This paper gives an algorithm for computing π that is particularly well suited for parallel processing. The main attraction of our algorithm is that the timing and sequencing restrictions on individual processors are almost entirely eliminated and. consequently, the necessary coordination between processors is negligible and the enforced idle time is also negligible.

Under certain mild and easily satisfied restrictions on P and on the implementation of the algorithm, $x(\cdot)$. the vectors of computed values are proved to converge to within a positive, finite constant of proportionality of π. It is also proved that a natural measure of the *projective* distance of $x(\cdot)$ from π vanishes geometrically fast. and at a rate for which a lower bound is given. We have conducted extensive experiments on random matrices P. and the results show that the improvement over the parallel implementation of the synchronous version of the algorithm is substantial, sometimes exceeding the synchronization penalty to which the latter is always subject.

Categories and Subject Descriptors: C.1.2 [Processor Architectures]: Multiple Data Stream Architectures (*Multiprocessors*)—*parallel processors*; F.2.1 [Analysis of Algorithms and Problem Complexity]: Numerical Algorithms and Problems—*computations on matrices*; G.1.0 [Numerical Analysis]: General—*parallel algorithms*

General Terms: Algorithms. Theory

Additional Key Words and Phrases: Asynchronous algorithm. chaotic algorithm, fixed point. Markov chains

JACM APRIL 78

Asynchronous Iterative Methods for Multiprocessors

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ABSTRACT. A class of asynchronous iterative methods is presented for solving a system of equations. Existing iterative methods are identified in terms of asynchronous iterations, and new schemes are introduced corresponding to a parallel implementation on a multiprocessor system with no synchronization between cooperating processes. A sufficient condition "is given to guarantee the convergence of any asynchronous iterations, and results are extended to include iterative methods with memory.

Asynchronous iterative methods are then evaluated from a computational point of view. and bounds are derived for the efficiency. The bounds are compared with actual measurements obtained by running various asynchronous iterations on a mulliprocessor, and the experimental results show clearly the advantage of purely asynchronous iterative methods.

KEY WORDS AND PHRASES: asynchronous algorithms. asynchronous multiprocessors, parallel algorithms. iterative methods, chaotic relaxation, analysis of algorithms

CR CATEGORIES: 5.14. 5.15, 5.25

1. I"troduction

In this paper we investigate the fixed point problem for an operator F from $\mathbb{R}^n$ into itself: We want to find a vector x in $\mathbb{R}^n$ which satisfies the system of equations represented by

$$x = F(x). \tag{1.1}$$

In (2) Chazan and Miranker introduced the *chaotic relaxation scltenle,* a class of iterativ.e methods for solving eq. (1.1) where F is a linear operator given by $F(x) = Ax + b$. They showed that iterations defined by a chaotic relaxation scheme converge to

IN Algorithms and complexity New Directions and Recent Resu/1
J.F. Traub (ED) 1976 A.P.

SYNCHRONIZED AND ASYNCHRONOUS PARALLEL ALGORITHMS FOR MULTIPROCESSORS

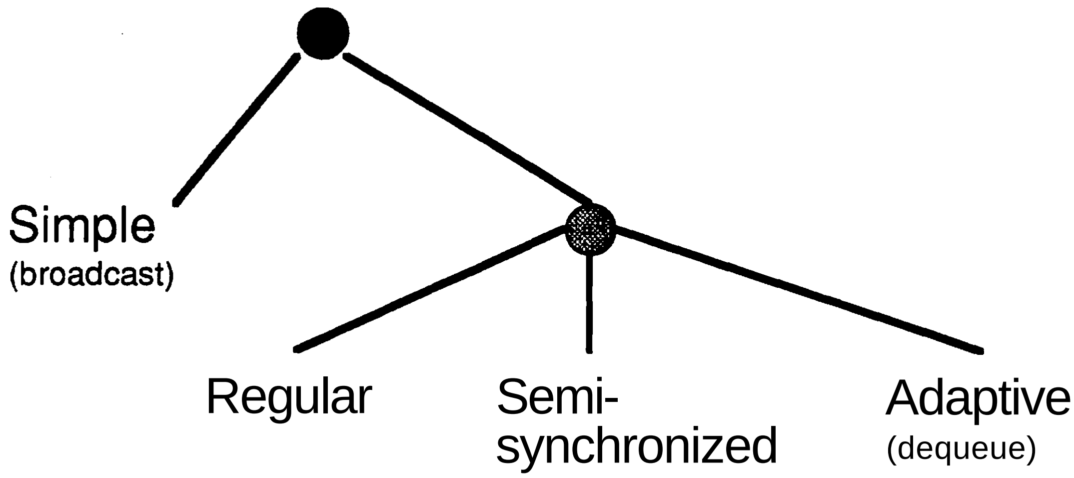
H. T. Kung·
Department of Computer Science
Carnegie-Mellon University
Pittsburgh, Pa.

Abstract

Parallel algorithms for multiprocessors are classified into synchronized and asynchronous. algorithms. Important characteristics with respect to the design and analysis of the two types of algorithms are identified and discussed. Several examples of the two types of algorithms are considered in depth.

· Prior Work in Relaxing Precedence: T.H. Kung

Types of asynchronous algorithms:



Sources for process speed fluctuations:

- Processors have different speeds
- Individual processors are asynchronous
- Process is delayed due to memory conflicts
- Operating system interference
- Multiple user interference

Prior Work in Relaxing Precedence: Hearsay Experience
Lesser & Erman

- They threw away the synchronization locks on the blackboard and the system still worked.

ARPA ORDER NO. 2223

23

ISI/RR-79-76

May 1979

V. R. Lesser
University of Massachusetts

L. D. Erman
USC Information Sciences Institute

An Experiment in Distributed Interpretation

ABSTRACT

The ... tic ... to distributed processing ... n.d effectively in ... t ... and this ... for distributed systems ... be ...

We present ... the ... system is able to function effectively even though ... inconsistent ... incomplete ... of the bases necessary for their ... ut ... This ... fers from ... in its emphasis on dealing with distribution-caused ...ainty and ... in ... data, and algorithm as an integral part of the network ... ...

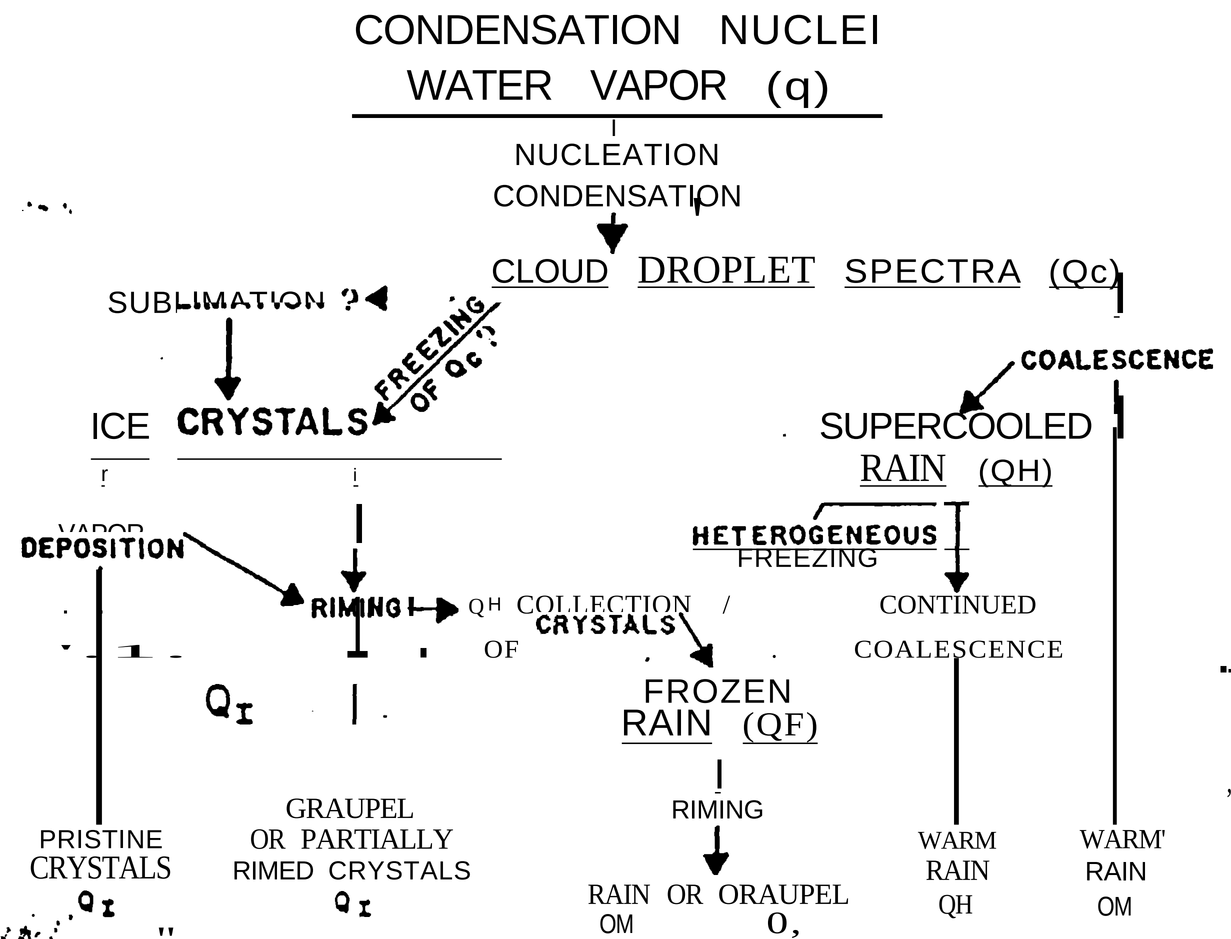
We ... how this new ... can be ... n.d t. the problem of distributed In'erpret ... Experimental result ... pre ... system ... upp art these ide...

This report is being publ... ...ously by USC/Information Sciences Institute (... RR-79-76) ... Carn... t ... y C... CMU-CS-79-120).

INFORMATION SCIENCES INSTITUTE
UNIVERSITY OF SOUTHERN CALIFORNIA
4676 Admiralty Way/ Marina del Rey/ California 90291

Prior Work in Relaxing Precedence: My hardware designs to support relaxing spatial and temporal precedence.

- Temporal precedence relaxation was supported with date-tagged data.
- Spatial precedence relaxation was supported with a bidder-buyer scheme.



Flow Chart of the Microphysics in Cotton's Model. (From Cotton 1975)

Evidence for a Conjecture:

Quantum Behavior is emergent.

- Classical Hamiltonian for an orbiting electron with temporal precedence relaxed.

- Quantum behavior in the Boltzmann Machine with time delays.

The Calculations for the Two Processes

(Messiah Vol I, Page 34, EON 1.15)

For an electron of mass m in 2d in a potential of:

$$\frac{e^2}{r}$$

The equations for the conjugate variables, position and momentum, in polar coordinates:

Classical Hamiltonian:

$$H = \frac{1}{2m}\left(p_r^2 + \frac{p_\phi^2}{r^2}\right) - \frac{e^2}{r}$$

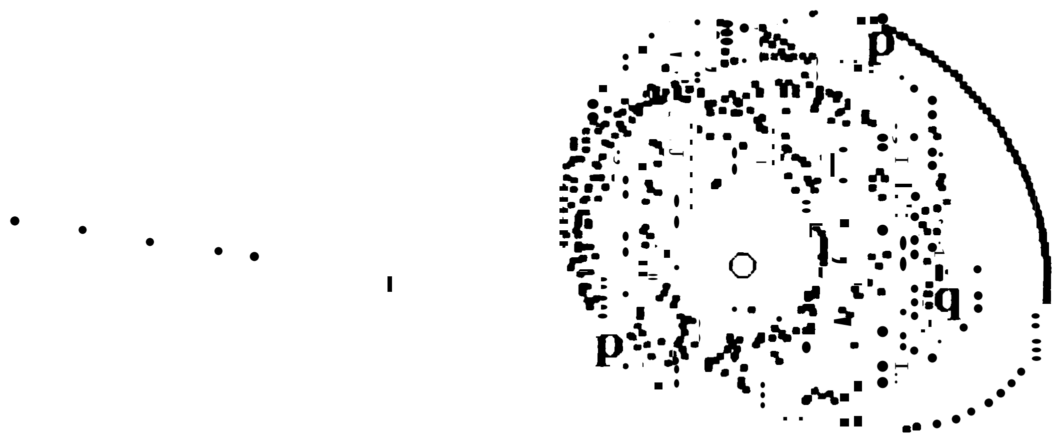
Momentum equations:

$$\frac{dp_\phi}{dt} = 0 \qquad \frac{dp_r}{dt} = \frac{p_\phi^2}{mr^3} - \frac{e^2}{r^2}$$

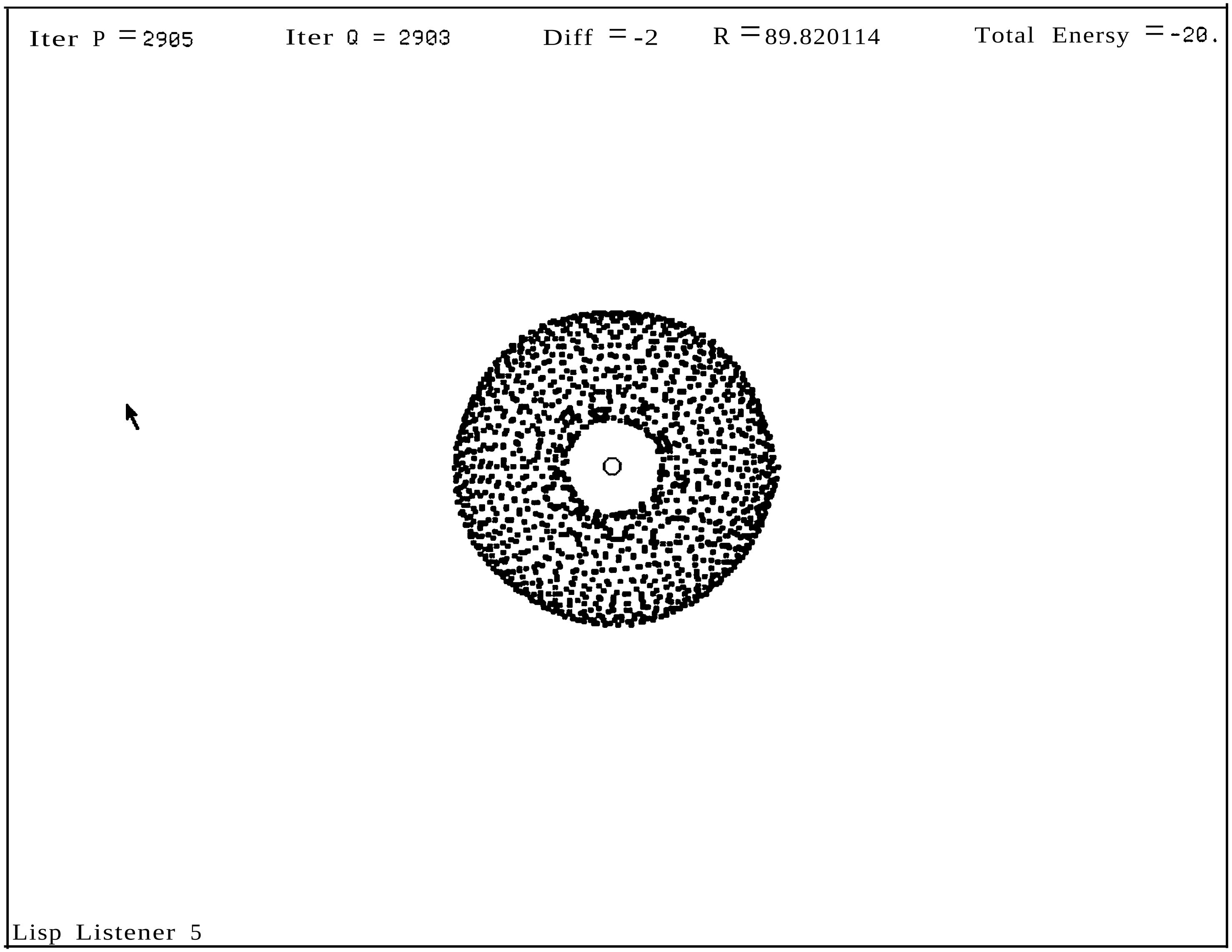
Position Equations:

$$\frac{d\phi}{dt} = \frac{p_\phi}{mr^2}, \qquad \frac{dr}{dt} = \frac{p_r}{m}$$

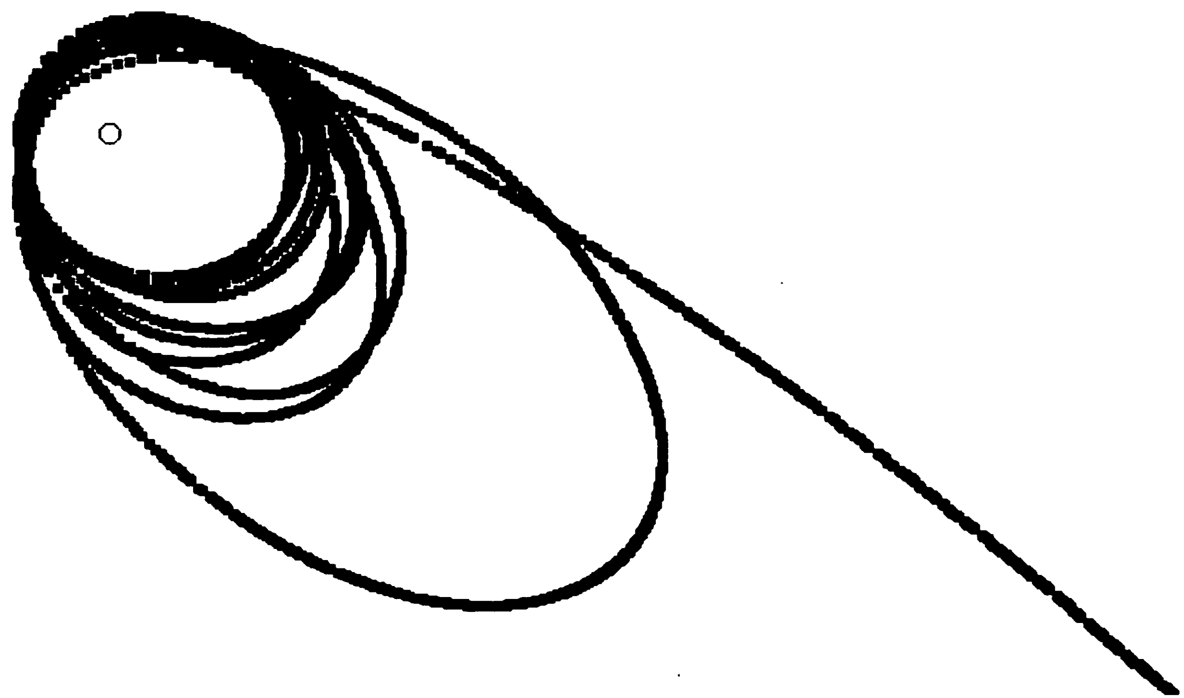
Iter P = Iter Q = Diff = R = 497.77988 Total Energy = 78



Lisp Listener 5

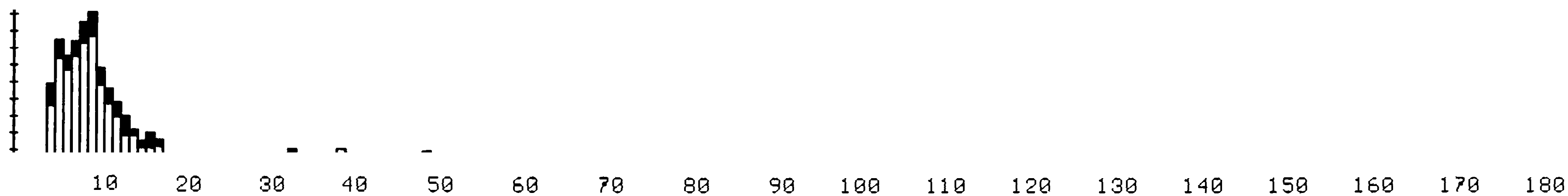

Iter P =2905
Iter Q = 2903
Diff =-2
R =89.820114
Total Enersy =-20.
Lisp Listener 5

NIL
COMMand:



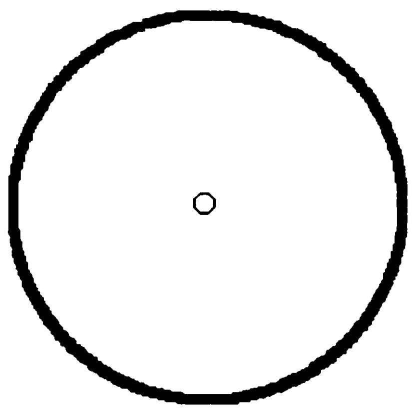
Lisp Listener 3

Density HistograM



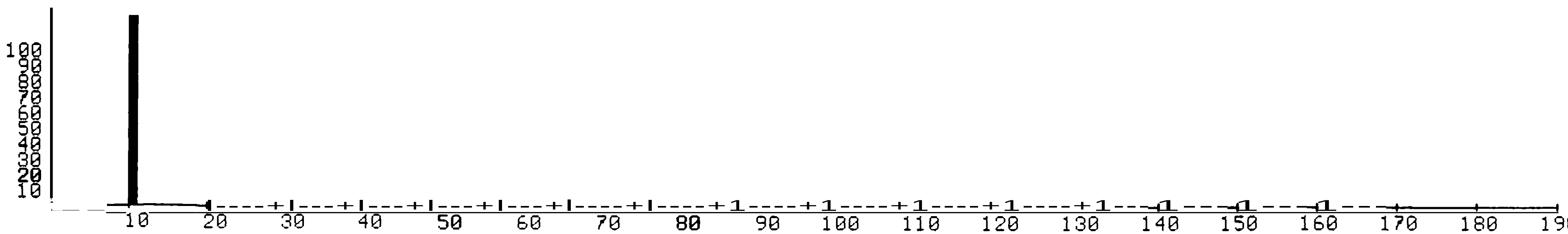
12/23/85 14:04:17 LISPM USER: Tyi 2 active servers

Iter P =559 Iter Q =460 R =100.0 Total Energy =-2.0



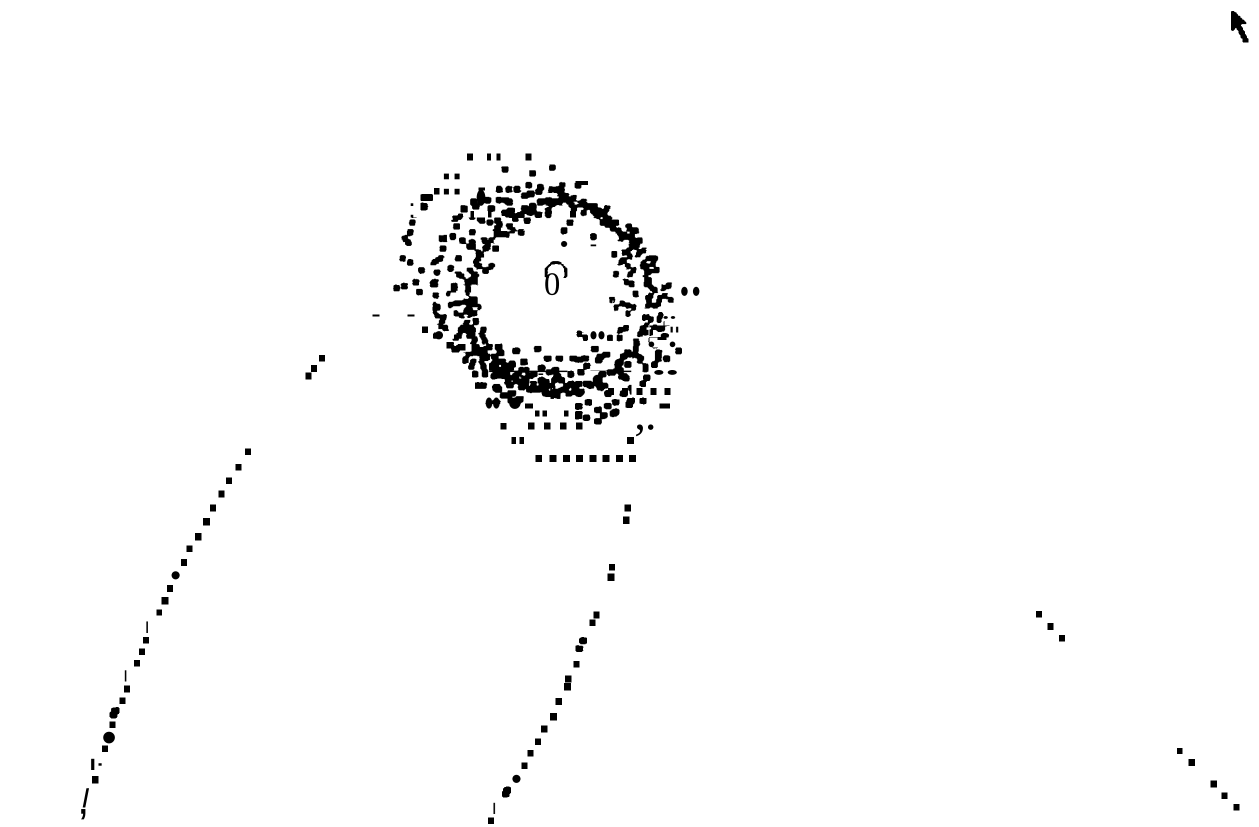
Lisp Listener 3

Density HistograM



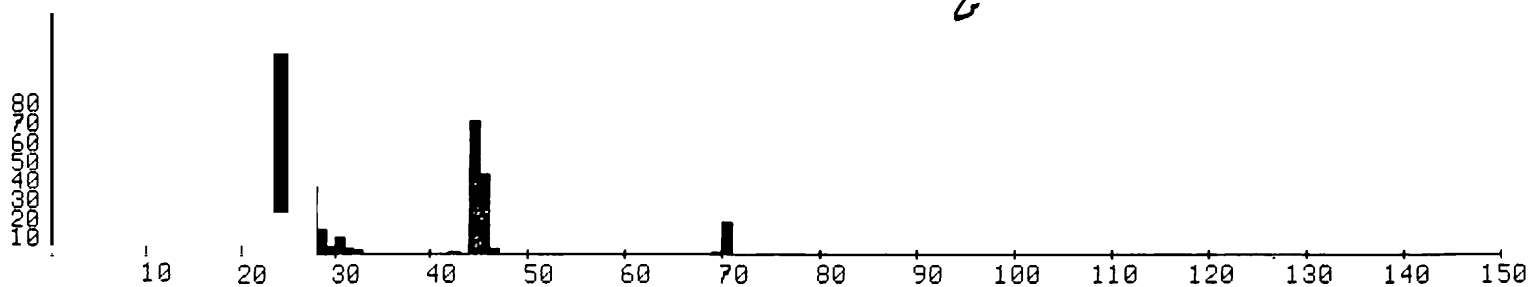
12/23/85 19:16:23 LISPM USER: Tyi Herring

Iter P =1533 Iter Q =1501 Diff =-32 R =626.85004 Total Energy 20.88393426

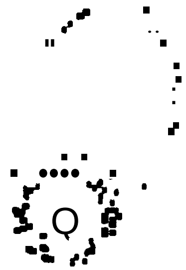


Lisp Listener 2

Density HistograM

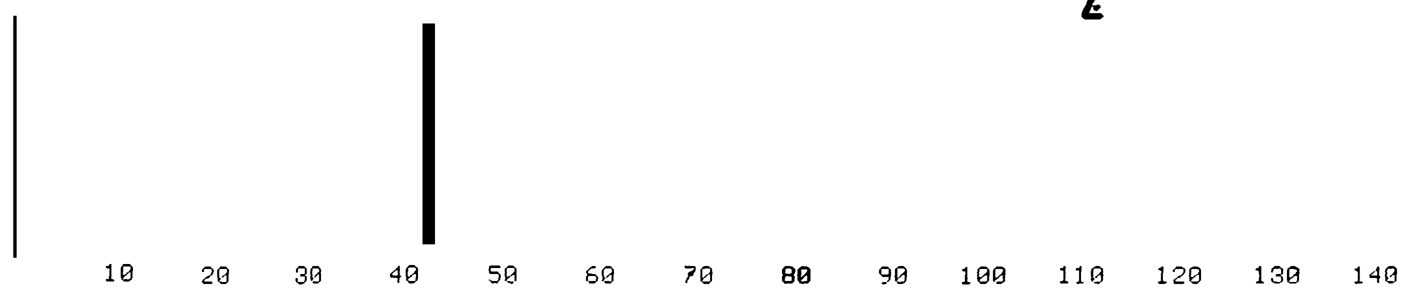


Iter P =211 Iter a =205 Diff =-6 R.= 6313.9985 Total Energy = 11617.53452

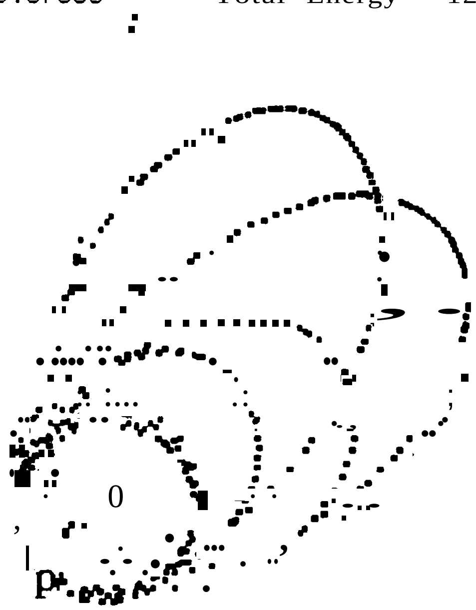


Lisp Listener 2

Density HistograM



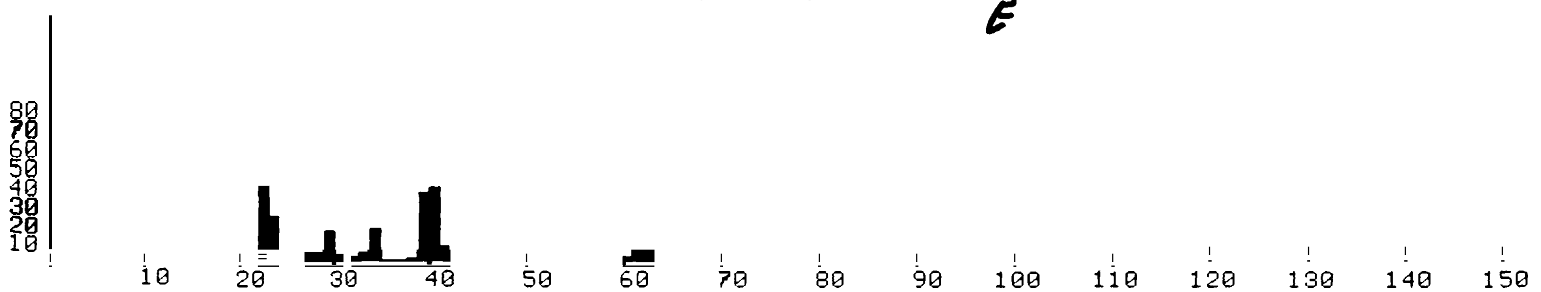
Iter P = 832 Iter Q = 872 Diff = 40 R = 799.37085 Total Energy = 12.23792525



Lisp Listener 2

Density HistograM

E



OU€:Lle Lengt.h: 0
Metering

Iter P = 687 Iter' 0 = 1108 Diff = 421 R = 619.903 Total Energy = -1.4

Open Connection Reset Console

[19:59:39 Process Remote Eval,got an error
Select Remote Eval Background Stream by typing Function-0-S.]

0

con Pane 1

Listener Pane 1

COMPUTATIONS IN STOCHASTIC PARALLEL NETWORKS ••••••

EFFECT OF COMMUNICATION TIME DELAYS

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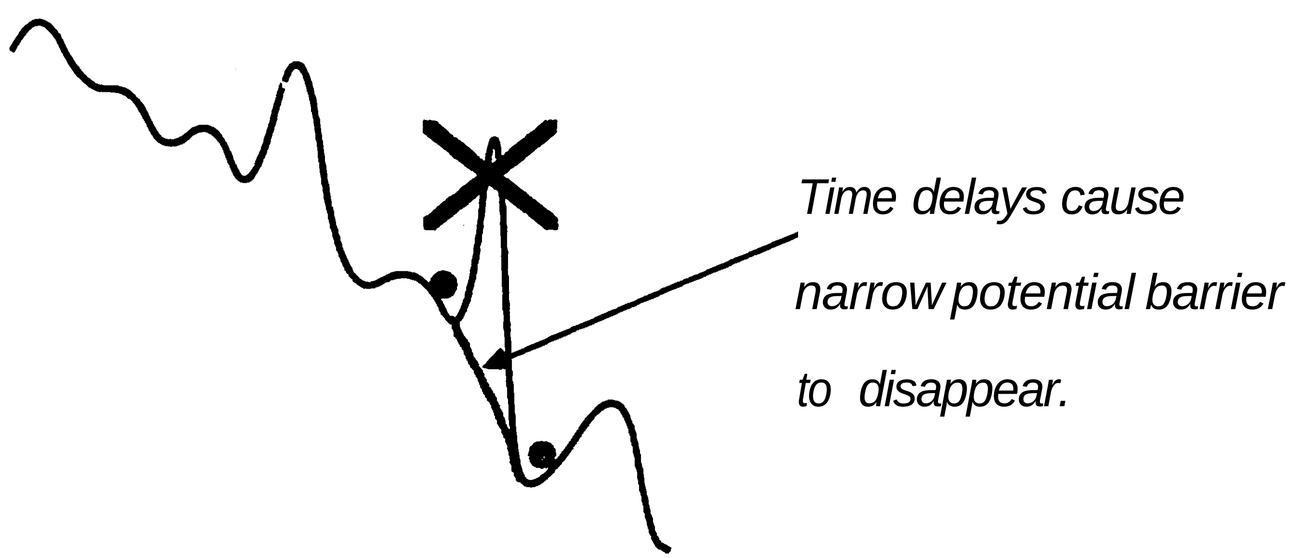
Quantum Behavior in the Boltzmann Machine: Tunneling



Why Does It Work This Way? -

New understanding from the work in
Complex Dynamical Systems

Physics Today April 1983

How random is a coin toss?

In examining the differences between orderly and chaotic behavior in the solutions of nonlinear dynamical problems, we are led to explore algorithmic complexity theory,' the computability of numbers and the measurability of the continuum.

Joseph Ford

We ought then to regard the present state of the Universe as the effect of its preceding state and as the cause of its succeeding state.
Laplace

The true logic of this world is the calculus of probabilities.
Maxwell

Probabilistic and deterministic descriptions of macroscopic phenomena have coexisted for centuries. During the period 1650-1750, for example, Newton developed his calculus of determinism for dynamics while the Bernoullis simultaneously constructed their calculus of probability for games of chance and various other many-body problems, In retrospect, it would appear strange indeed that no major confrontation ever arose between these seemingly contradictory world views were it not for the remarkable success of Laplace in elevating Newtonian determinism to the level of dogma in the scientific faith. Thereafter, probabilistic descriptions of classical systems were regarded as no more than useful conveniences to be invoked when, for one reason or another. the deterministic equations of motion were difficult or impossible to solve exactly. Moreover, these probabilistic descriptions were presumed derivable from the underlying determinism. Weather, human behavior and the stock market are, on the other hand, commonly regarded as strictly deterministic, notwithstanding their seemingly frivolous unpredictability. But perhaps nowhere in science does there exist greater confusion over the random-determinate question than that which arises for analytic Hamiltonian systems

$$H = H_0(q_k, p_k) + \lambda H_1(q_k, p_k) \qquad (1)$$

where H_0 describes an analytically exactly solvable system with N degrees of freedom, the small parameter λ determines. the strength of the perturbation H_1 and the argument (q_k, p_k) is shorthand for the full argument $(q_1, \ldots, q_N, p_1, \ldots, p_N)$. The traditional folklore of this topic asserts that Hamiltonians of this form are analytically solvable and determinate when the number of degrees of freedom N is small; when N is large, statistical mechanics and the law of large numbers are presumed valid. Doubts regarding this folklore immediately arise, however, when one recalls the notorious insolubility of the three-body problem or even the nonseparable two-body problem, when one considers ... for many decades, as if the Hamiltonian of equation 1 had an incurable disease unmentionable in polite society. But then around 1950, some three hundred years after the birth of Newton, a new multidisciplinary area, now called nonlinear dynamics, began a concerted effort to solve some of the deeper puzzles presented by these Hamiltonians. The following few paragraphs briefly discuss one new result of especial relevance to this paper. More comprehensive presentations appear in tutorial review papers by Joel Lebowitz and Oliver Penrose[3] and by Michael Berry.[4]

Contemporary results

The success of astronomical perturbation theory for the solar system and other few-body problems and the equal success of statistical mechanics for many-body problems is *prima facie* evidence supporting the existence of a transition from orderly to highly erratic orbital motion in Hamiltonian systems as particle number is increased. However, this evidence provides little insight into the root cause of the transition or into the detailed structure of the resulting erratic orbits. Al-

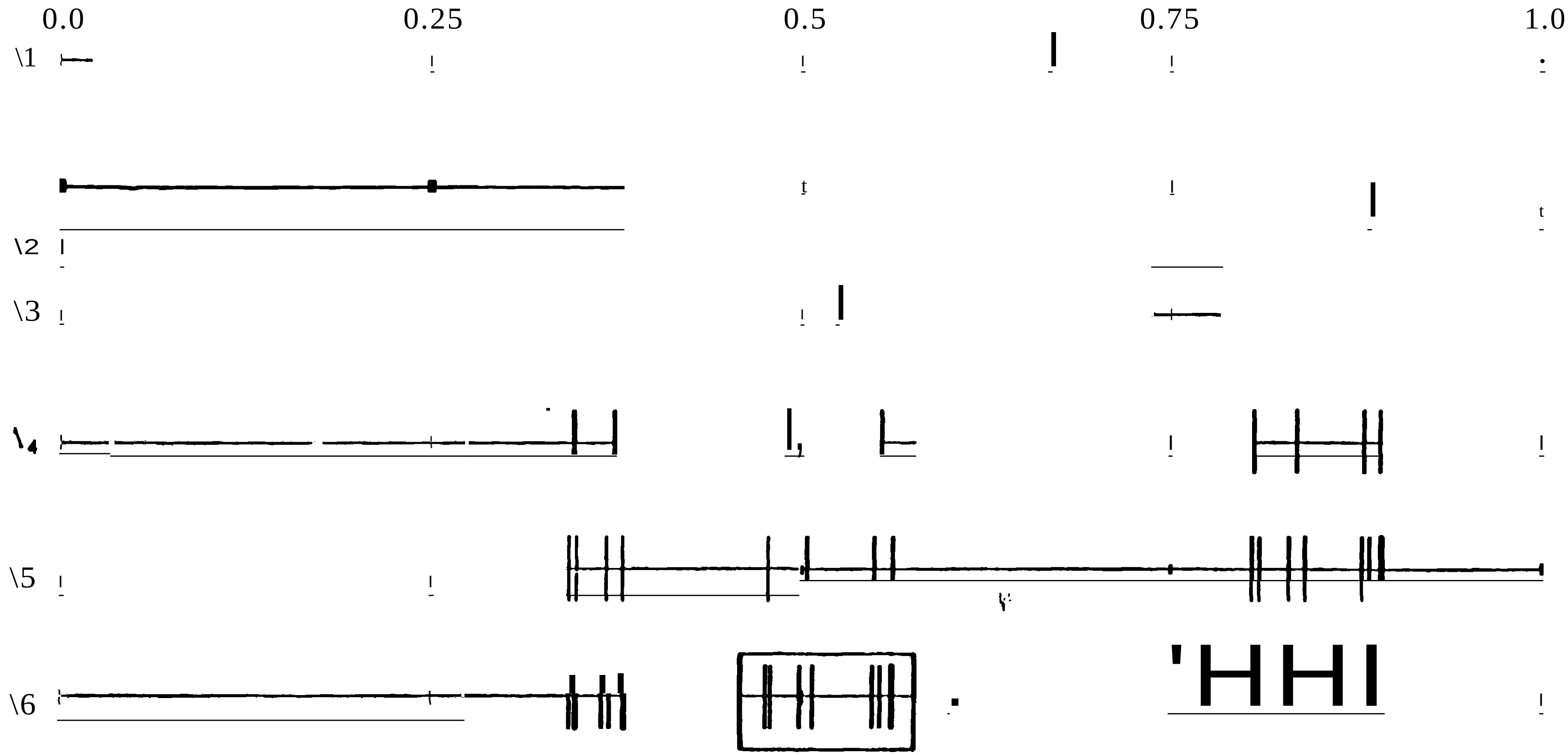


FIGURE 16-5. *Sllowing how stable attractors beC011le unstable and lllldelgo "fission" at a series of increasing A-values,' denoted* A n *for* 11 = *J,* 2, 3,..." *Note how the boxed subpattenl on tIle lowest line resembles the entire pattern tzuo lines above. Tltis l"eSelllblance becollles more a11d more accurate the larger* n *gets.*