STAT MECH & THERMO

STUDY SYSTEMS w/ LOTS OF PARTICLES:

- OPPOSITE OF USUAL PHYSICS ⇒ FIND SIMPLICITY, FUND. LAWS BY ISOLATING SMALL SYSTEMS GET RID OF EXTRANEOUS THINGS LIKE FRICTION

- HERE: MACROSCOPIC SYSTEMS ⇒
  FIND SIMPLICITY IN LARGE NUMBERS
  USE STATISTICAL REASONING & improves w/ large samples
  LAWS – STATED AS AVES
  VERY GENERAL APPLICATIONS

APPLICATIONS: ANYTHING WHERE WANT PROPERTIES OF MACRO OBJECTS (LOTS)

- EQNS OF STATE (RELN OF $P, V, T, E, S, \mu \cdots$)
  PHASE TRANSITIONS
  good to know if building something
- CHEM REACTIONS (why do some go, some not?)
- EFFICIENCY OF ENGINES, REFRIGERATORS
- LIMITS TO ELECTRONIC CIRCUITS (NOISE)
- HEAT FLOW
- TRANSPORT OF MATTER IN FLUIDS ----

FUNDAMENTAL

- FORMATION OF STARS, GALAXIES, ---
- AMONG 1ST CLUES FOR NEED FOR QM (FROM HEAT CAPACITY, B-BODY SPECTRUM)

skip (NOTE: CAN ALSO APPROACH SUBJECT W/OUT MENTIONING ATOMS → CLASSICAL THERMO ; CRAZY)

HAVE LARGE COMPUTERS. REALLY NECESSARY?

MICROSCOPIC CALCULATIONS:

2 PARTICLES:

EACH PARTICLE: TO SPECIFY NEED $\vec{r}$ (= (x, y, z)) & $\vec{v}$ (OR $\vec{p}$)
≡ 3 DOF (WAYS IT CAN MOVE)

$2 \times 3 = 6$ DEGREES OF FREEDOM (DOF) ~ 10

FAST COMPUTER: 1 GIGAFLOPS: 10^9 OPERATIONS/S
(FLOATING PT OPERATION PER SEC)

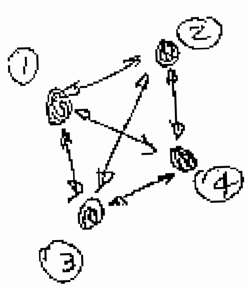
LET'S SUPPOSE IT TAKES 10 OPERATIONS (MULTIPLIES, DIVIDES, ETC) TO GET EACH DOF TO ITS NEXT VALUE AT $t + \Delta t$. { $\vec{v}$ calc $\Rightarrow \Delta\vec{r}$

$\Rightarrow$ 1 STEP: $(10\ \text{DOF})(10\ \text{OPS}/\text{DOF})(10^{-9}\ \text{s}/\text{OP}) \sim 10^{-7}\,\text{s}$

OR 10^7 STEPS/s

10 PARTICLES:

TO KNOW THE FORCE ON EACH, I COMPUTE THE FORCE ON IT DUE TO ALL OTHER PARTICLES. TO ESTIMATE HOW MUCH HARDER THIS IS, I NEED TO COUNT THE TOTAL NUMBER OF PAIRS:



PARTICLE 1 HAS PAIRS W/ 9 OTHERS.
" 2 " " " 8 "
(NOT COUNTING 1, SINCE WE HAVE THAT ONE ALREADY.)
" 3 " " " 7 "

OR TOTAL = $9 + 8 + 7 + \cdots + 1 = 45$
~ 50

(OR FOR N PARTICLES

$$\text{TOTAL} = \sum_{i=1}^{N-1} i = \frac{N(N-1)}{2} \sim \frac{1}{2}N^2 \text{ PAIRS})$$

(for each of the N particles I can make N−1 pairs but this over-counts by exactly 2 ⇒ 1/2

1 STEP: 50 TIMES LONGER:

$$(50) \times 10^{-7}\,s = 5 \times 10^{-6}\,s$$

100 PARTICLES:

$$\sim \frac{1}{2}(100)^2 \text{ PAIRS} = 5 \times 10^3 \text{ PAIRS}$$

1 STEP: $(5 \times 10^3) \times 10^{-7} = 5 \times 10^{-4}\,s$

(NOT TOO BAD: 2000 STEPS/s)

⇒ INSERT: TYPICAL MACRO SYS ⇐

10^{24} PARTICLES: (A REALISTIC MACRO SYSTEM)

$$\sim \frac{1}{2}\left(10^{24}\right)^2 \sim 10^{48} \quad (\text{IGNORING THE } \tfrac{1}{2})$$

1 STEP:

$$10^{48} \times 10^{-7}\,s = 10^{41}\,s$$

COMPARE TO T_{UNIV} (AGE OF UNIVERSE):

$$T_{UNIV} \sim 15 \text{ BILLION YRS} \sim 10^{17}\,s$$

SO 1 STEP $\sim 10^{24}\,T_{UNIV}$

ON A TERAFLOP COMPUTER? (1000 TIMES FASTER)

$$\Rightarrow \text{ ONLY } 10^{21}\,T_{UNIV}$$

m 3
0.5

T, insert

TYPICAL MACROSCOPIC SYSTEMS

ATOMIC MASS UNITS $\sim$ # p+n

(DEFN: ^{12}C MASS $\equiv$ 12 AMU)

1 MOLE: ENOUGH ATOMS/MOLECULES TO MAKE ATOMIC MASS IN GRAMS (ie 12 g OF ^{12}C)

AVOGADRO'S NUMBER: # MOLECULES IN 1 MOLE

$$N_A = 6.02 \times 10^{23} \text{ MOLECULES/MOLE}$$

{ NOTE ON UNITS: WILL FOLLOW CHEMISTS & TEXT USE cgs (CENT, GRAMS, SECS)

ENERGY: 1 ERG = 1 $g\,cm^2/s^2$ }

$\Rightarrow$ TYPICAL # PARTICLES $\sim 10^{24}$

PROSPECTS FOR MINDLESS MICROS CALCS:
UNSPEAKABLY BAD

one other good reason: no one cares what each molecule is doing

TREAT STATISTICALLY:

(a) (VERY) FEW ASSUMPTIONS; ROUGHLY: AS RANDOM AS POSSIBLE

(b) MEASURE & PREDICT AVE QTYS & MAGN.
$\Rightarrow$ MACROSCOPIC VARIABLES (P, V, E, T, μ, ...)

(c) LARGE N:
STATISTICS SIMPLER, MORE ACCURATE

GAS w/ N IDENTICAL MOLECULES

- DEMONSTRATE STATISTICAL TREATMENT OF MACRO PROPERTIES vs COMPLETE MICRO DESCRIPTION
- WILL DEFINE SIMPLE MACRO QTY, MAKE STATISTICAL PREDICTIONS, SEE HOW DEP. ON # MOLS, N AND t; WILL GIVE FLAVOR OF TYPICAL STAT MECH CALC

ASSUME:

(1) ISOLATED

(2) DILUTE : LARGE DIST / SMALL FORCE BETWEEN ~ ONLY WHEN COLLIDE (RARE) ≡ IDEAL GAS (THEN ELASTIC; NO INTERNAL STRUCTURE)

skip CAN IGNORE Q.M.

MICROSCOPIC PICTURE:

- LABEL INDIVID. MOLECULES
- IN PRINCIPLE, COULD CALC. IF KNEW INIT CONDS ⇒ GIVE $\vec{x}$, $\vec{v}$ (or $\vec{p}$) FOR EACH { don't need $\vec{a}$: not new info; fixed by laws of mech

say { ANOTHER PROBLEM:

(a) SPECIFYING 10^{24} IC's

(b) HAVE TO DO IT ACCURATELY OR AFTER SUFFICIENT # COLLISIONS, ERRORS PROPAGATE

⇒ { too hard; don't care; won't ever see those ICs again; satisfied knowing what typical ICs would give ⇒ statistical treatment

EXTREME: CHAOTIC SYSTEMS

skip CAN BE FEW DOF, BUT SO SENSITIVE TO IC'S, EFFECTIVELY RANDOM }

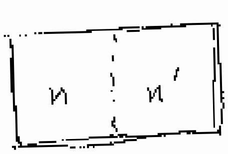
MACROSCOPIC TREATMENT:

MACRO VARIABLES:

- CHARACTERIZE GROSS FEATURES (AVE OVER PARTICLES)

(like density)

EXAMPLE:



$n + n' = N$

CHARACTERIZE w/ n = # PARTICLES ON LHS

MACRO (CONT'D)

QUESTIONS:

- AVE n ($\equiv \bar{n}$)?
- $\bar{n}$ vs N?
- $\bar{n}$ vs t?

APPROACH:

- WHAT CAN MY SYS. DO?
  - ⇒ LIST POSSIBLE MICRO CONFIGURATIONS OR STATES
- HOW LIKELY IS EACH?
  - ⇒ MAKE REASONABLE ASSUMPTIONS, USE TO COMPUTE AVES

⇒ CAN SAY A LOT

START SIMPLE:

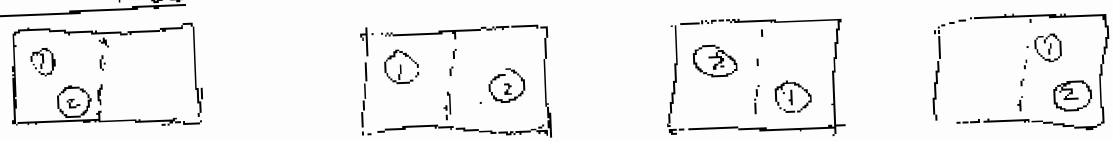
2 PARTICLES:

POSSIBLE CONFIGURATIONS: ~~OR STATES~~ FOR SYS

MOST SPECIFIC: POSSIBLE $\bar{x}$, $\bar{v}$ FOR EACH

HERE: ONLY MEAS. n $\Rightarrow$ ONLY NEED KEEP TRACK OF WHICH SIDE (a cheating a little)

4 CONFIGS:



n: 2 1 1 0

each one represents (same) large number of truly micro configs

EXPECT PARTICLES TO BOUNCE AROUND 4 CONFIGS w/ EQUAL LIKELIHOOD (nothing special about either side; particles small, don't take up much space)

PROB. $P(n=2)$ (BOTH IN LHS): $1/4$

MOST PROB: $P(1) = \frac{1}{2}$

(emphasize that computing probs easy here since all 4 are eq. likely; harder if  1/3 2/3)

BASIC ASSUMPTION:

ALL POSSIBLE CONFIGS ARE EQUALLY LIKELY

POSSIBLE $\equiv$ CONSISTENT w/ CONSTRAINTS.

HERE: $N = 2$ (CONST)

$\rightarrow$

PREDICTING W/ PROBS:

- CAN'T PREDICT 1 MEAS. PRECISELY

- CAN SAY:

(a) PREPARE SET OF "IDENTICAL" SYSTEMS
(FROM MACRO VIEWPT; ie W/ SAME CONSTRAINTS BUT W/OUT CONTROL OF MICRO VARIABLES)

"STATISTICAL ENSEMBLE"

THEN:

$\approx \frac{1}{2}$ OF SYSTEMS HAVE $n=1$, $\frac{1}{4}$ HAVE $n=2$ etc

LARGER THE ENS., MORE PRECISE IS STATEMENT

(b) or SAME SYSTEM MEASURED REPEATEDLY

$\approx \frac{1}{2}$ OF MEAS. FIND $n=1$ ...

(IF WAIT LONG ENOUGH BETWEEN FOR SEVERAL BOUNCES)

(c) CAN SOMETIMES SAY SOMETHING USEFUL ABOUT 1 MEAS

- SOMETIMES SO UNLIKELY CAN SAY WON'T HAPPEN

- CAN SAY WILL BE CLOSE TO AVE IF STD DEV. SMALL

4 PARTICLES:

(hand out) (again, only paying attn to which side)

\# CONFIGS: 2 CHOICES FOR EACH PARTICLE ⇒ EACH DIFF CONF

4 PARTICLES

$2^4 = 16$ CONFIGS

⇒ N PARTICLES : 2^N CONFIGS

ENUMERATE:

PARTICLE 1	2	3	4	n	n'	$C(n)$ = # CONFIGS FOR n
L	L	L	L	4	0	1
L	L	L	R	3	1	
L	L	R	L			4
L	R	L	L			
R	L	L	L			
L	L	R	R	2	2	
L	R	L	R			
L	R	R	L			6
R	L	L	R			
R	L	R	L			
R	R	L	L			
L	R	R	R	1	3	
R	L	R	R			4
R	R	L	R			
R	R	R	L			
R	R	R	R	0	4	1

1	2	3	4	n	n'	$C(n)$
L	L	L	L	4	0	1
L	L	L	R	3	1	4
L	L	R	L	3	1	
L	R	L	L	3	1	
R	L	L	L	3	1	
L	L	R	R	2	2	6
L	R	L	R	2	2	
L	R	R	L	2	2	
R	L	L	R	2	2	
R	L	R	L	2	2	
R	R	L	L	2	2	
L	R	R	R	1	3	4
R	L	R	R	1	3	
R	R	L	R	1	3	
R	R	R	L	1	3	
R	R	R	R	0	4	1

Table 1.1 Enumeration of the 16 possible ways in which $N = 4$ molecules (denoted by 1, 2, 3, 4) can be distributed between two halves of a box. The letter L indicates that the particular molecule is in the left half of the box, the letter R that it is in the right half. The number of molecules in each of the halves is denoted by n and n', respectively. The symbol $C(n)$ denotes the number of possible configurations of the molecules when n of them are in the left half of the box.

q.e.1

PROBABILITIES:

$$C_{TOT} = \sum_{n=0}^{4} C(n) = 16$$

$$P(2) \equiv \text{PROB. } n=2 = \frac{C(2)}{C_{TOT}} = \frac{6}{16}$$ USING: EACH CONFIG EQ. LIKELY

$$P(4) = \frac{C(4)}{C_{TOT}} = \frac{1}{16} \Rightarrow P(n) = \frac{C(n)}{C_{TOT}}$$

(DISTRIBUTION: MORE MEAS. YOU DO, CLOSER YOUR SET MATCHES THESE)

SUMMARY:

USUALLY: $n = N/2$ } why? lots of ways this can happen

SOMETIMES: n FLUCTUATES BY 1

RARELY: $n = 0$ OR N (ALL ON 1 SIDE)

OR: ORDERED, ~~STRUCTURED~~ SITUATIONS ARE RARE (ex $n=0$)
RANDOM, DISORDERED " " COMMON ($n \sim N/2$)
(will discuss in more detail soon)

N LARGE: MORE PRONOUNCED. (HAPPENS QUICKLY IN N)

ex PROB. ALL ON LEFT:

N	$P(n=N)$
2	$1/4$
4	$1/16$
60	$1/2^{60} = e^{-60\ln 2} \cong e^{-42}$

$\{C_{TOT} = 2^N\}$

ALREADY: 60 PARTICLES, MEAS EVERY 1 s
WAIT (ON AVE) $\sim 5 \cdot T_{UNIV}$ BEFORE ALL ON 1 SIDE

N = 40

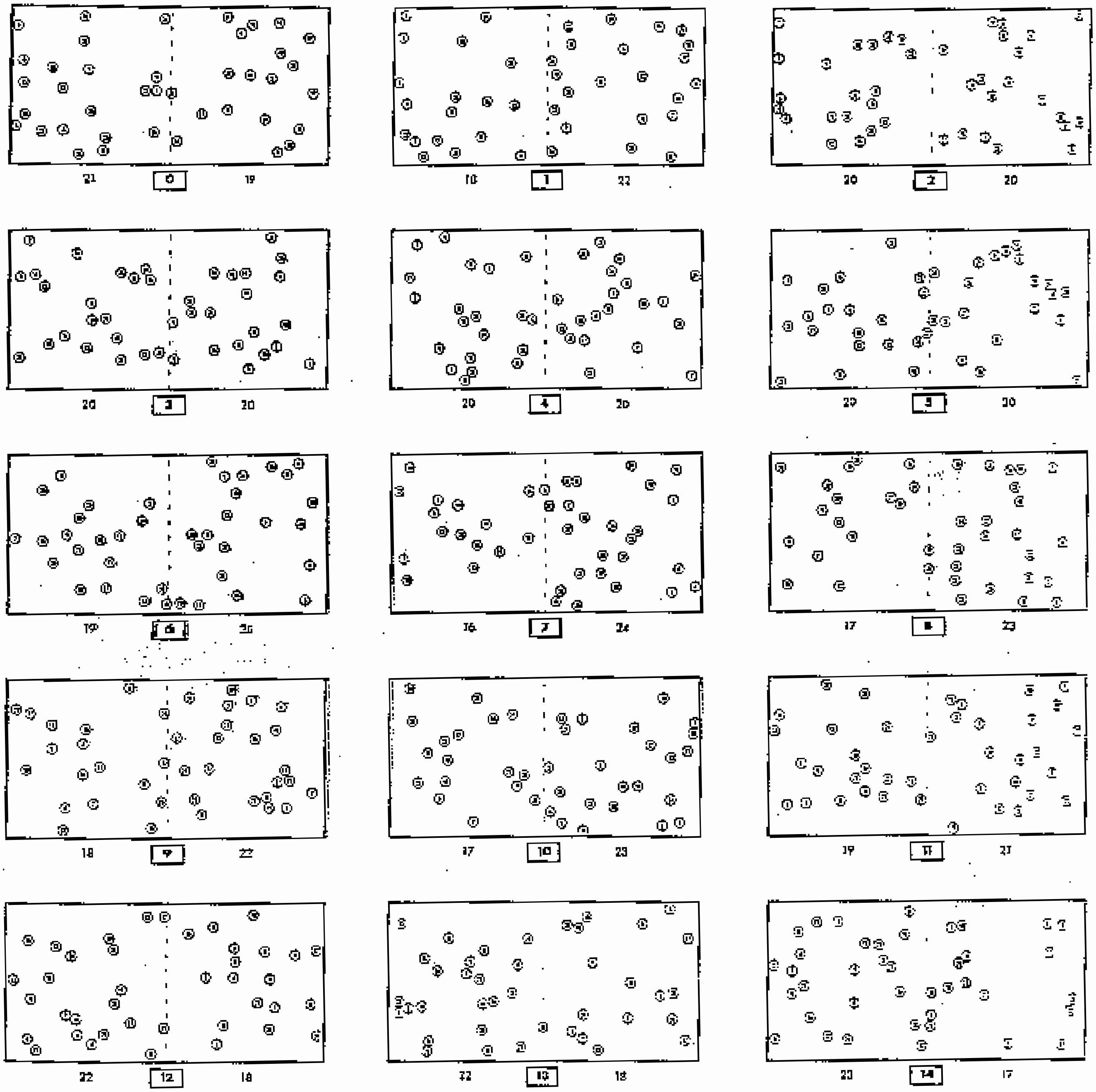


Fig. 1.4 Computer-made pictures showing 40 particles in a box. The fifteen successive frames (labeled by $j = 0, 1, 2, \ldots, 14$) are pictures taken a long time after the beginning of the computation with assumed initial conditions. The number of particles located in each half of the box is printed directly beneath that half. The velocities of the particles are not indicated.

0.10.1

WHAT ABOUT $N = 10^{24}$?

skip

LARGE # THMS:

0. FACTORIALS ARE EXPONENTIALS
1. EXP.'s > THAN THINK
2. EXP. OF EXP's > COMPREHENSION
3. LARGE #'s NOT LIKE SMALL #'s

(COULD GUESS THAT CAN GET STEAM + WATER + ICE FROM WATCHING H_2O ? OR HUMANS ?)

LAW: NEVER FIND ALL 60 ON LEFT,

- PRETTY GOOD
- NATURE OF ONE OF MAIN LAWS OF THERMO: INCREASE OF ENTROPY

⇒ SHOW $N = 40$ PICTURES; (JUST BOUNCING OFF WALLS & OTHERS)

- 15 SNAPSHOTS OF 1 SYS; SIMILAR TO ENS. OF 15
- $n = \frac{N}{2} \pm 3 = 20 \pm 3$

- LOOK RANDOM, DISORDERED, AVE, SAME

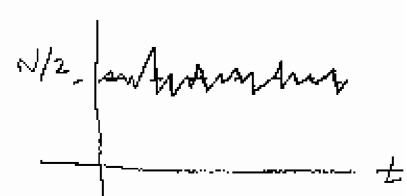
t BEHAVIOR OF $n(t)$: (M measurements)

AVE: $\bar{n} = \frac{1}{M}\left[n(t_1) + n(t_2) + \cdots n(t_M)\right]$

$$= \frac{1}{M}\sum_{i=1}^{M} n(t_i) \cong \frac{N}{2}$$

MORE DETAIL:

(1) $n(t) \approx \frac{N}{2}$ + FLUCTUATIONS



EQUILIBRIUM: MACRO VARIABLES ~ CONST

(2) RELATIVE FLUCTUATIONS DECREASE W/ N { ~density rather than abs. #

⇒ SHOW PICTURE OF t DEVELOPMENT

ABSOLUTE #

FRACTION

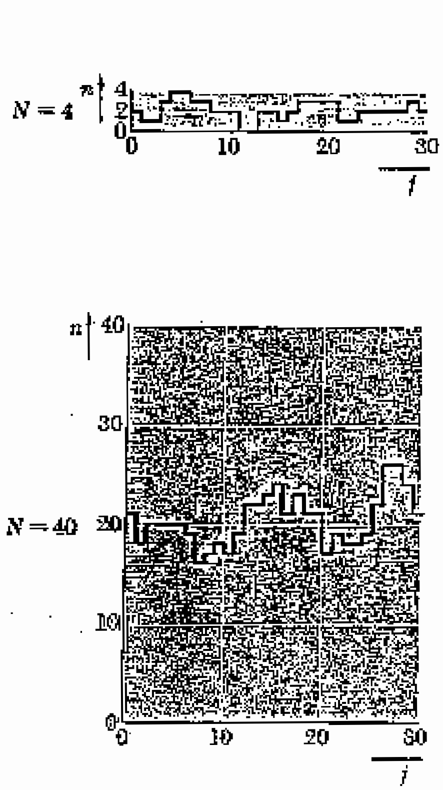


Fig. 1.5 The number n of particles in the left half of the box as a function of the frame index j or the elapsed time $t = j\tau_0$. The number n in the jth frame is indicated by a horizontal line extending from j to $j + 1$. The graphs describe Fig. 1.3 for $N = 4$ particles and Fig. 1.4 for $N = 40$ particles, but contain information about more frames than were shown there.

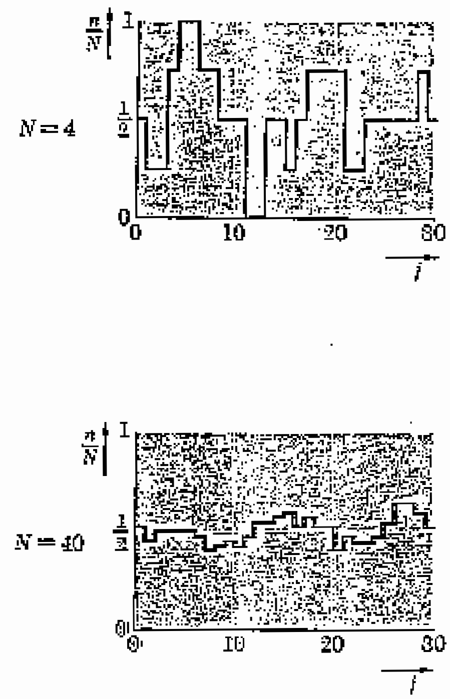


Fig. 1.6 The *relative* number n/N of particles in the left half of the box as a function of the frame index j or the elapsed time $t = j\tau_0$. The information presented is otherwise the same as that in Fig. 1.5.

a.10.2

PARADOX: (cf N = 40 PICTURE)

MACRO PICTURE:

ALL COMPLETELY RANDOM, AVE, UNEXCEPTIONAL

BUT

MICRO PICTURE:

FRAME 5: 7, 13, 6, 20, ... ON LHS

38, 26, 29, ... ON RHS

AS IMPROBABLE AS ALL ON RHS (1 SPECIFIC CONFIG OUT OF LARGE # OF CONFIGS EITHER WAY)

⇒ WILL NEVER RECUR

WHAT MEAN BY RANDOM?

ex LICENSE PLATES

SEE [7B2 33A1W], THEN [URA MORON]

WOULD DESCRIBE 1ST AS RANDOM, 2ND AS DELIBERATE (ORDERED),
LIKELY UNLIKELY

BUT ODDS OF GETTING EXACTLY 7B2 etc

AS SMALL AS GETTING 2ND BY CHANCE

RESOLUTION:

- RANDOMNESS DETERMINED BY WHICH SET PUT IN:

1ST: SET OF 8 MEANINGLESS #'S / LETTERS

2ND: " " MEANINGFUL STATEMENTS } MUCH SMALLER SET

→ SEEING SETS, NOT INDIVIDUALS (when look at picture of 40, think naturally of it in macro terms → cover one & ask how they'd describe it)

→ RANDIMNESS IS MACRO CONCEPT

- in Mongolia, would describe both as random
- like difference between winning a lottery (care about micro details; seems exceptional) vs watching w/out a ticket

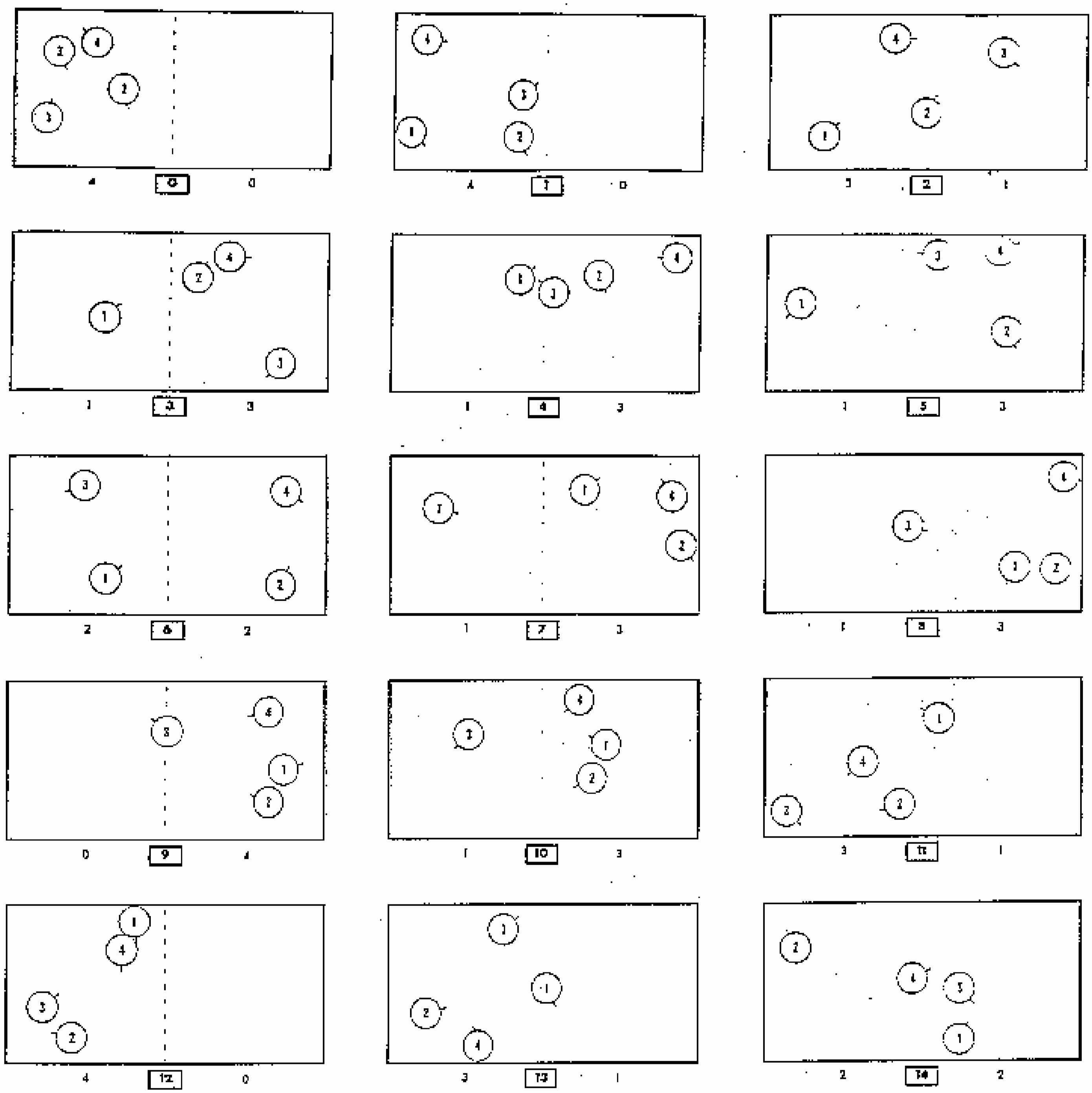


Fig. 1.16 Computer-made pictures showing 4 particles in a box. The pictures were constructed by starting with the special situation where all the particles are in the left half of the box in the positions shown in the frame $j = 0$ and are given some arbitrary assumed velocities. The resulting evolution of the system in time is then shown by the sequence of frames $j = 0, 1, 2, \ldots, 14$. The number of particles located in each half of the box is printed directly beneath that half. The short line segment emanating from each particle indicates the direction of the particle's velocity.

D.12-1

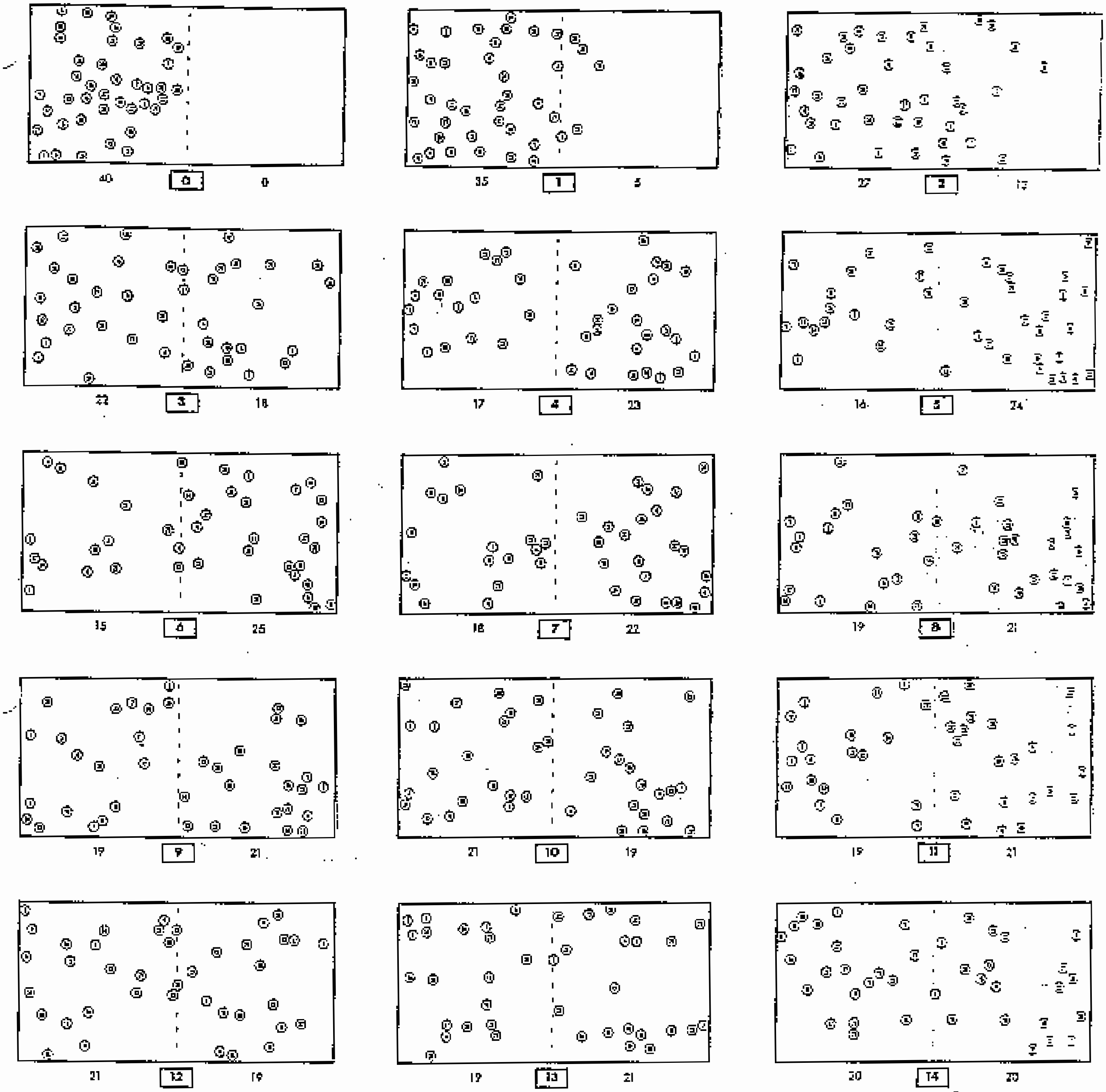


Fig. 1.18 Computer-made pictures showing 40 particles in a box. The pictures were constructed by starting with the special situation where all the particles are in the left half of the box in the positions shown in the frame $j = 0$ and are given some arbitrary assumed velocities. The resulting evolution of the system in time is then shown by the sequence of frames $j = 0, 1, 2, \ldots, 14$. The number of particles located in each half of the box is printed directly beneath that half. No velocities are indicated.

0.12.2

BACK TO PARTICLES:

- N = 40 : NATURALLY SEE GENERAL PROPERTIES
  (TOO TEDIOUS TO LOOK AT EACH PARTICLE)

  ex DENSITY ⇒ SEE FRAME 5 AS MEMBER OF SET W/N UNIFORM DENSITY

  ⇒ MACRO PERSPECTIVE

  ⇒ THIS SET >> THAN SET W/ $n = 0$.

- FRAME 5 NEVER RECURS, BUT VERY LIKELY NEXT FRAME IS ALSO IN THIS SET

SEE PARADOX IN t DEVELOPMENT:

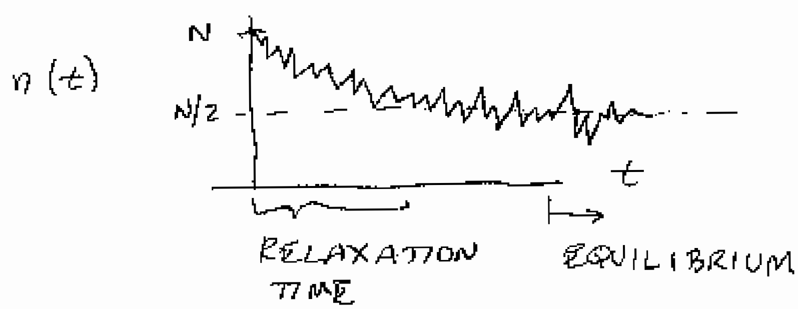
(⇒ SHOW 4 PARTICLE PICT!)

START W/ ALL ON ONE SIDE (WALL); REMOVE

- RUN t BACKWARDS: NOT UNUSUAL

  WHY? MICRO LAWS SAME (IN ALL CASES WE USE)

(⇒ SHOW 40 PARTICLES!)



GOES FROM ORDERED TO RANDOM CONFIG; STAYS THERE

- RUN t BACK: VERY ODD ⇒ CAN TELL t DIRECTION

PARADOX: PERFECTLY OK FROM LAWS OF PHYSICS → JUST START ALL IN REVERSE.

LOOK AT INDIVID. PARTICLES → COULDN'T TELL

- as unlikely that it ends in frame 14 as in frame 0 if start randomly

RESOLUTION:

LARGE N → MACRO VIEW (too tedious for micro)

(a) 1^{ST} FRAME IN SET w/ $n = N$

(b) LAST " IN SET w/ $n \approx \frac{N}{2}$

$C(n=N) \lll C\left(n \approx \frac{N}{2}\right)$

IN FACT $\frac{C(n=N)}{C_{TOT}} = \frac{1}{2^{40}}$

REMOVE WALL: $n \to N/2$ (ALWAYS)

- SET OF CONFIGS MUCH LARGER (2^40 larger)
- ALL CONFIGS EQUALLY LIKELY
  - ⇒ ASTRONOMICALLY MORE LIKELY TO END IN BIG SET

FROM PT OF VIEW OF INIT. CONDS: ORIGINALLY: - KNOW SOMEONE SET IT UP w/ ALL ON LEFT; JUST LIKE LICENSES

TO RUN IN REVERSE:
- CAN SET UP $\vec{r}$'s & $\vec{v}$'s SO RUNS BACK TO $n = N$
- SET OF IC's " "
  - $\lll$ SET OF IC's WHERE STAYS IN RANDOM SET

IRREVERSIBLE PROCESS (REMOVING WALL)

- WON'T UNDO ITSELF (BUT YOU CAN w/ WORK)
- HAS t DIRECTION
- HAPPENS WHEN MANY NEW CONFIGS AVAIL.
- MACRO CONCEPT (LIKE EQUIL.)

(no process is irrev. from micro viewpt)

(wouldn't make sense for $N=4$ ⇒ # new configs not very large)

ET

0.

ENERGY DISTRIBUTION:

- PLAYS LARGE ROLE IN HOW SYSTEMS ACT { & IN THIS COURSE - IT'S THE "THERMO" }
- DETERMINES HOW MUCH USEFUL WORK CAN GET FROM ENGINES, EFFICIENCY OF REFRIGS, ETC
- CAN STUDY W/ SAME APPROACH

TOY EXAMPLE { CLOSED SYSTEM OF 4 PARTICLES

N UNITS OF ENERGY (WILL ASSUME COMES IN INTEGER AMTS FOR SIMPLICITY)

CONSERVED: N CONST

LET INTERACT: E CAN BE EXCHANGED ⇒ CAN REDISTR.

DON'T KNOW DYNAMICS (OR TOO HARD)

ASSUMPTION: (AFTER EQUIL) ANY UNIT of E IS AS LIKELY TO BE FOUND W/ ANY PARTICLE

DISTRIBUTIONS.

ie 1 particle w/ 1 unit, 3 w/ 0

E	DISTR	# CONFIGS	TOTAL CONFIGS
1	0 0 0 1	4	4
2	0 0 0 2	4	16
	0 0 1 1	12	

COUNTING

1^{ST} UNIT 0 0 0 1 4

NEXT: EITHER ON SAME PARTICLE: 0 0 0 2 4×1

OR ON DIFF: 0 0 1 1 4×3

E	DISTR	# EL	TOTAL
3	0 0 0 3	4	
	0 0 1 2	36	
	0 1 1 1	24	64

COUNTING : eg 2ND CASE

1ST	0 0 0 1	4			
2ND	0 0 0 2	4 × 1	OR	0 0 1 1	4 × 3
3RD	0 0 1 2	4 × 1 × 3	OR	0 0 1 2	4 × 3 × 2

skip

4	0 0 0 4	4	
	0 0 1 3	48	
	0 0 2 2	36	
	0 1 1 2	144	
	1 1 1 1	24	256

IN GENERAL ; TOTAL # CONFIGS:

N UNITS, 4 CHOICES EACH $\Rightarrow$ $4^N = e^{N \ln 4}$

SPS M PARTICLES: $M^N = e^{N \ln M}$

PROB THAT 1 PART HAS ALL N : $\frac{4}{4^N} = 4^{-N+1} = e^{-(N-1)\ln 4}$

M PARTICLES : $M^{-N+1} = e^{-(N-1)\ln M}$

1/6/97

LARGE N OR M $\longrightarrow$ EXPONENTIALLY UNLIKELY

e3
O..

OBSERVATIONS

(2) ON AVE, E WILL BE DISTRIBUTED ROUGHLY EQUALLY OR RANDOMLY. (THO NOTE PROB. THAT ALL HAVE EXACTLY SAME IS SMALLER ~ ORDERED). ? skip
MORE WAYS THAT COULD HAPPEN.
EQUIL: $\mathcal{E}_i$ FOR EACH PARTICLE SAME ($\sim E/N$), W/ FLUCTUATIONS

(4) VERY ENERGETIC PARTICLE (EITHER FROM INIT COND OR FLUCTUATION) TENDS TO GIVE UP E TO OTHERS.
VERY RARE FOR IT TO KEEP PICKING UP E.

(1) TOTAL # CONFIGS (POSSIBLE STATES) GROWS EXPONENTIALLY W/ AVAILABLE E.

(3) AVE $\mathcal{E}_i$ (OVER t) FOR EACH PARTICLE ~ SAME.
(WOULD SEE IN OUR CALC IF LISTED INDIVID. PART.)
MOST PROB. SITUATIONS HAVE EACH $\mathcal{E}_i$ FLUCT. NEAR $\mathcal{E}_i = E/N$.

WHY? GIVING TOO MUCH TO ONE LIMITS POSSIBILITIES FOR OTHERS

GOVERNS FLOW OF HEAT ≡ TRANSFER OF ENERGY

SYSTEMS 1 & 2:

INSULATED TO OUTSIDE, BUT IN THERMAL CONTACT.
WHAT DETERMINES IF HEAT IS TRANSF?

KNOW IF $T_1 > T_2$, HEAT FLOWS FROM S_1 TO S_2

WHY?

ROUGHLY :

(1) $T_1 \sim E_1$ (MORE CAREFUL LATER)

(2) AVAIL. CONFIGS GROWS EXP. W/ E

COLD → FEW AVAIL. CONFIGS

HOT → LOTS TO GIVE UP

- IF TRANSFERING E FROM S_1 TO S_2 INCREASES AVAIL. CONFIGS, IT WILL (ON AVE)

- SAME AS SINGLE FAST PARTICLE GIVING UP E INSIDE SYS

<u>EQUIL</u>: AT MOST RANDOM CONDITION

AVE E SAME ON BOTH SIDES

$1/T \approx$ HOW QUICKLY AVAIL. CONFIGS GROWS W/ E

(a) large T ⇒ incr. E doesn't change # configs much
(b) small T " " does " " "
} gain of E flows from high T to low

(CAN USE METHODS OF COURSE TO GET BOTH EQUIL TEMP & HOW FAST IT EQUILIBRATES)

skip

END OF GENERAL INTRO