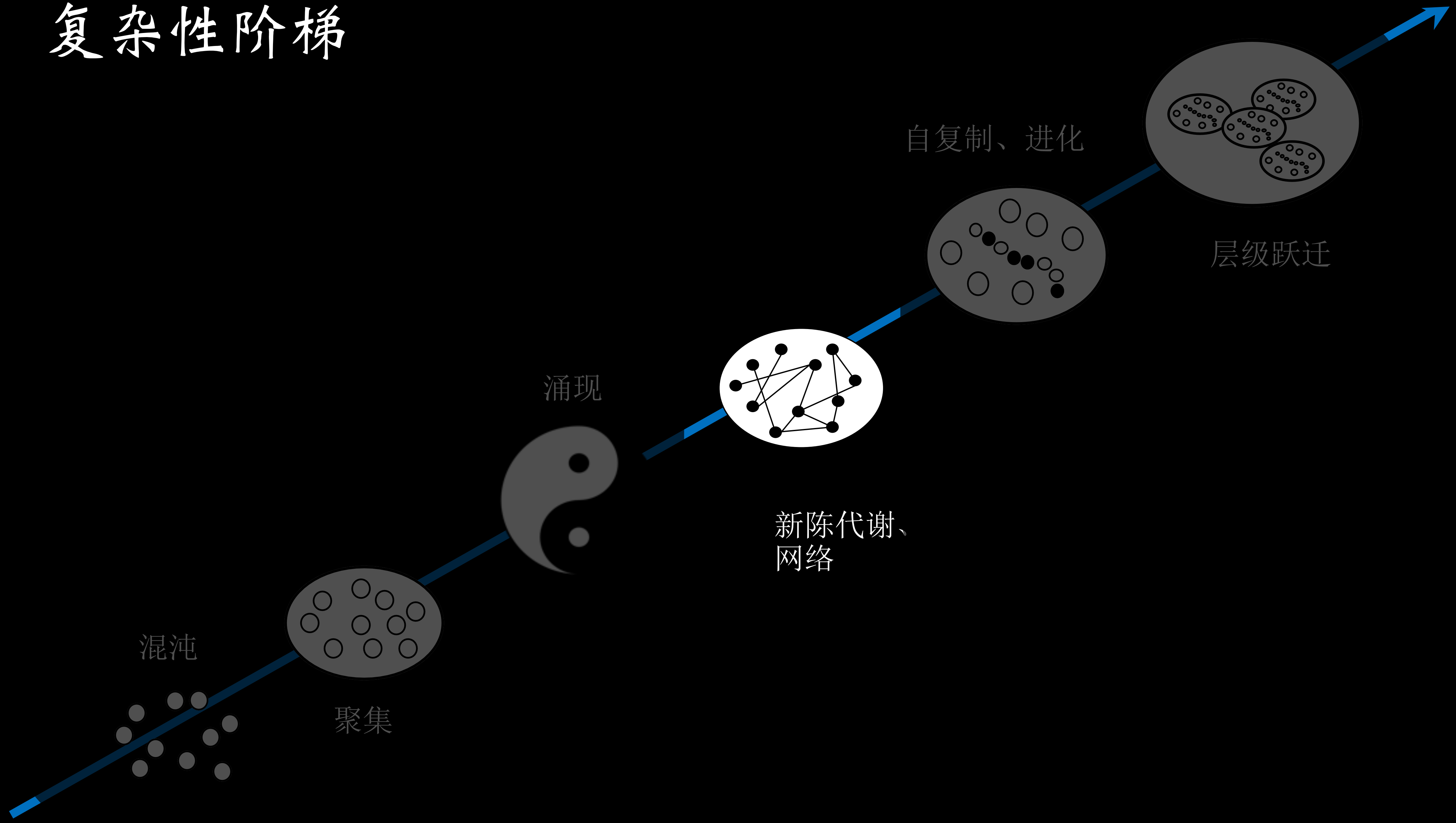
熵增与耗散结构

张江

北京师范大学系统科学学院
集智俱乐部
集智学园

复杂性阶梯



今日内容

- 热力学熵
- 统计力学熵
- 什么是耗散结构？

时间的问题

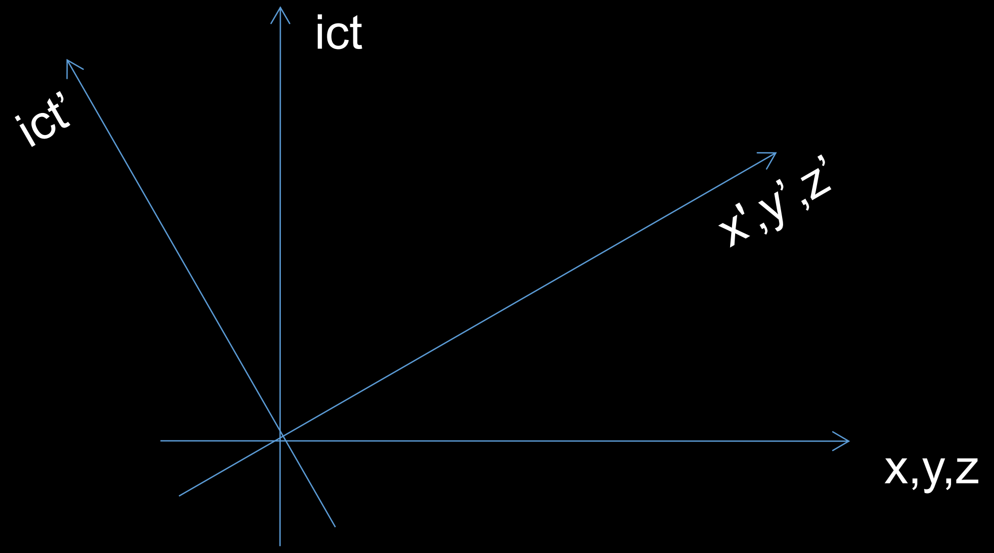
- 物理学中的时间
  - 牛顿时间
  - 相对论时间
  - 热力学时间
- 复杂系统的时间
  - 进化的时间

牛顿力学中的时间观

- 时间对称：t←→-t

相对论中的时间观

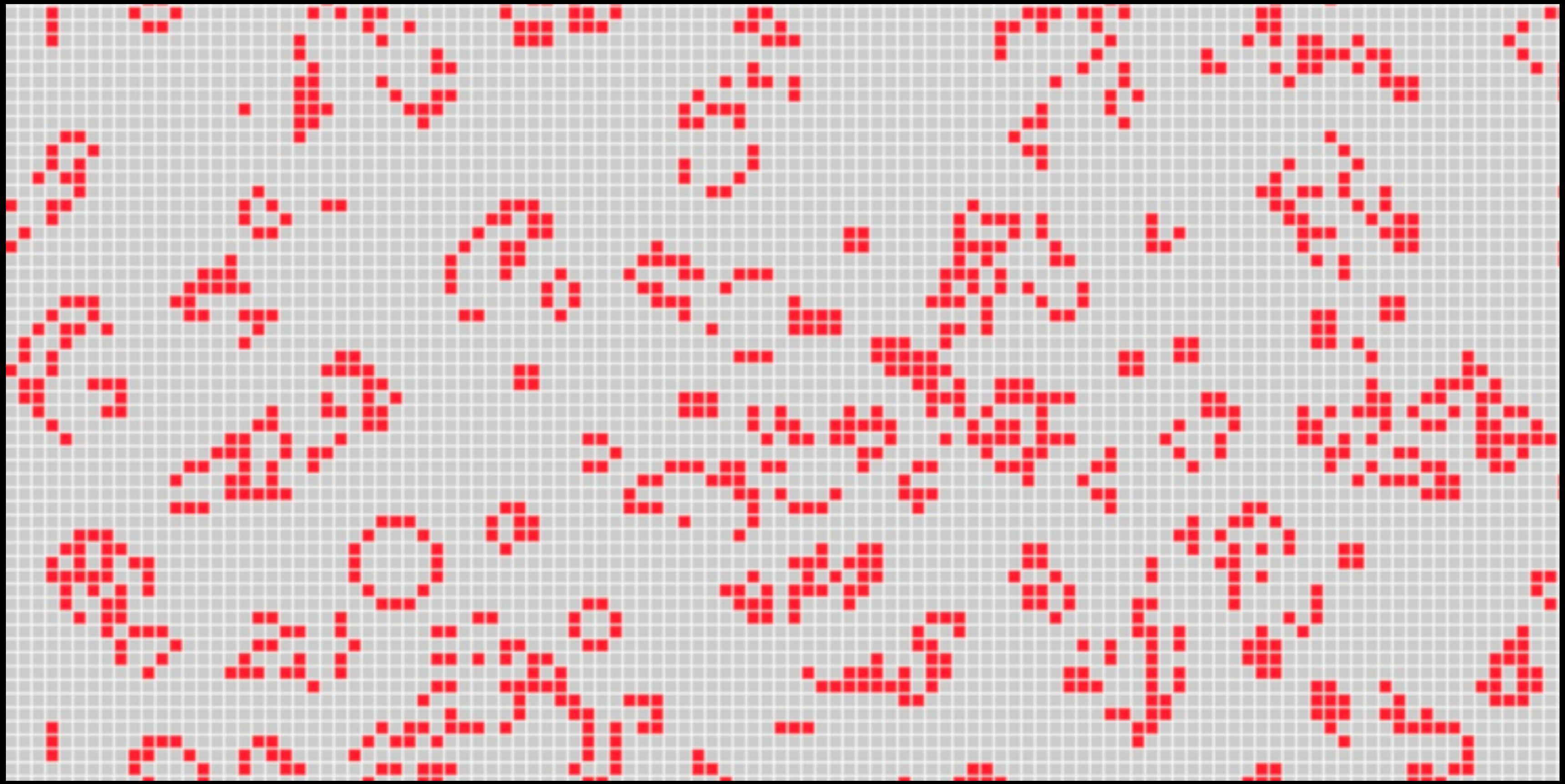
- 时间作为一种同空间等价的标度
- 天上一日，地上一年
- 狭义相对论的本质



热力学时间

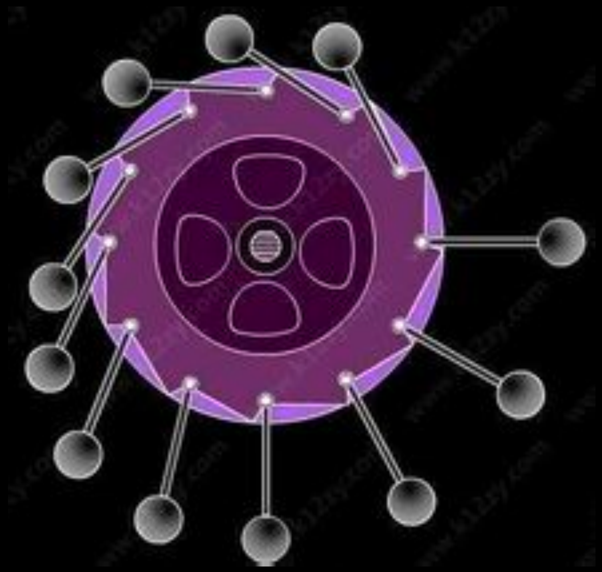
熵（无序度）增加

从斑图的角度理解时间之箭



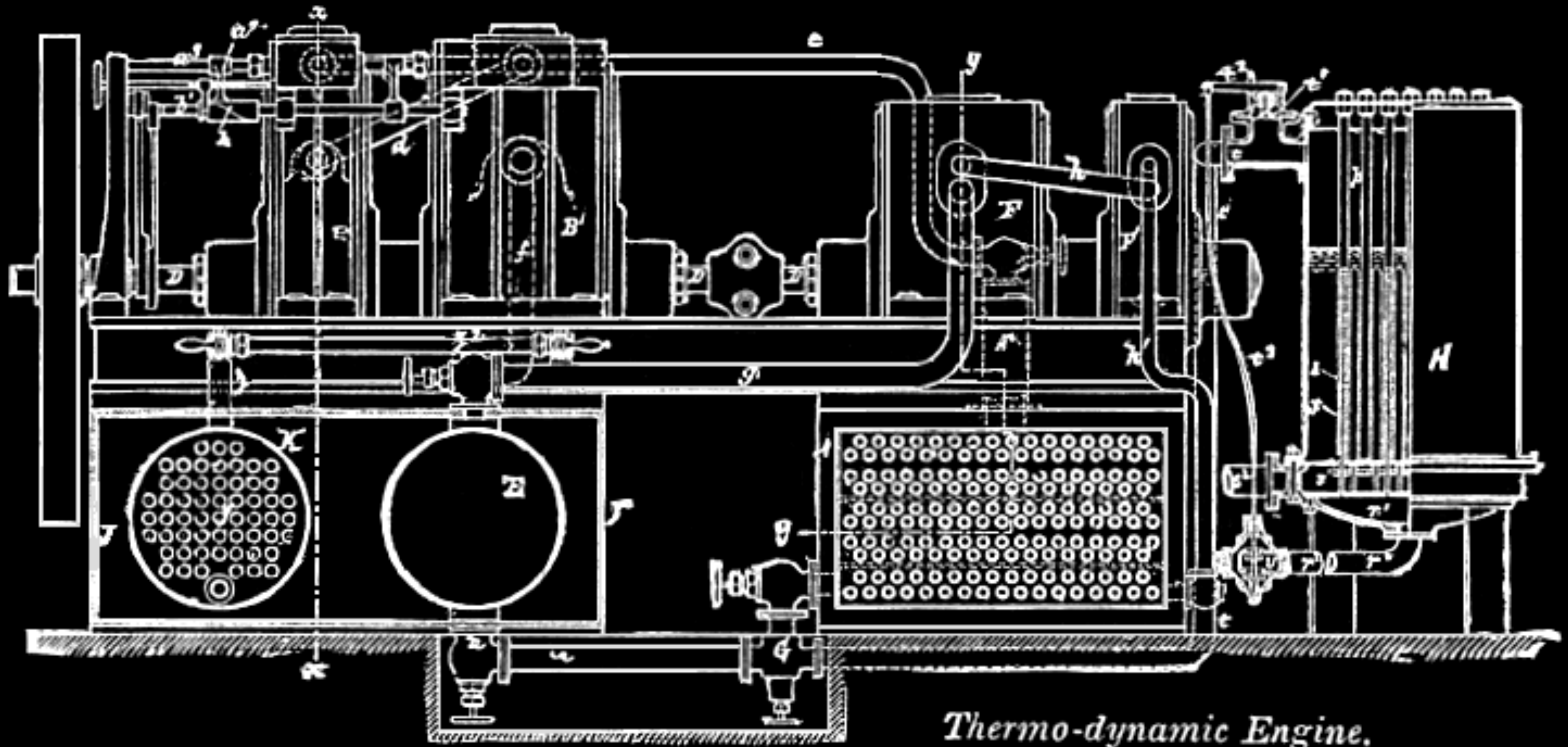
所有的斑图都倾向
于自然消散掉

永动机与热力学



第一类永动机 v.s. 热力学第一定律

永动机与热力学



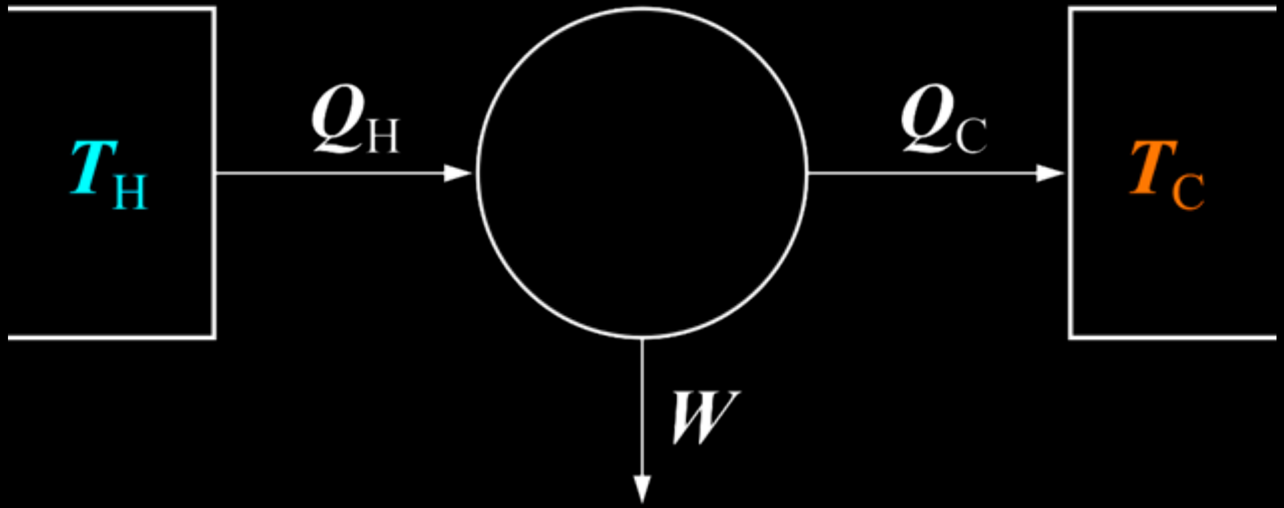
Thermo-dynamic Engine.

第二类永动机 v.s. 热力学第二定律

热力学第二定律的三种表述

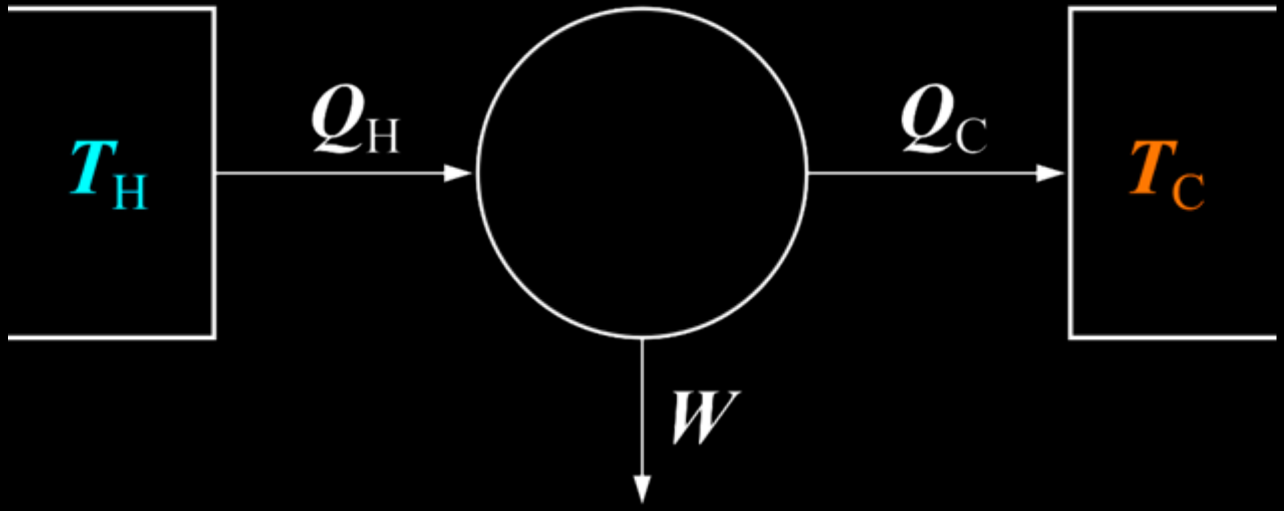
- 不可能从单一热源吸收能量，使之完全变为有用功而不产生其他影响。 (开尔文表述)
- 不可能把热量从低温物体传递到高温物体而不产生其他影响。 (克劳修斯表述)
- 孤立系统的熵只能单调增加

卡诺热机



Nicolas Léonard Sadi Carnot

卡诺热机

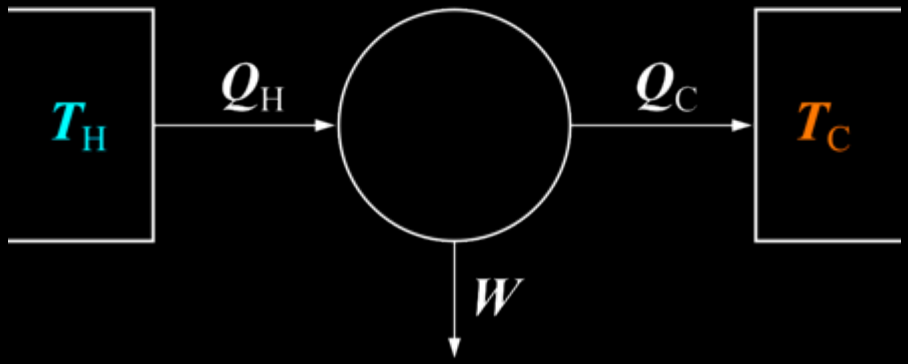


Nicolas Léonard Sadi Carnot

$$\frac{W}{Q_H} \leq \eta = \frac{T_H - T_C}{T_H}$$

要想达到这一热机效率，整个过程刚好可逆

卡诺热机



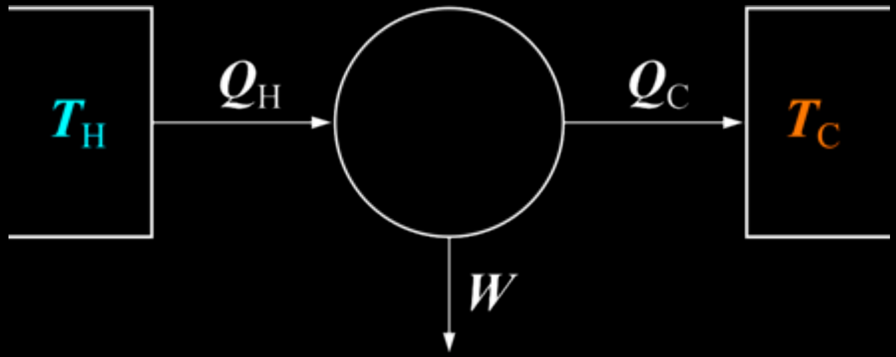
卡诺热机

=

可逆性

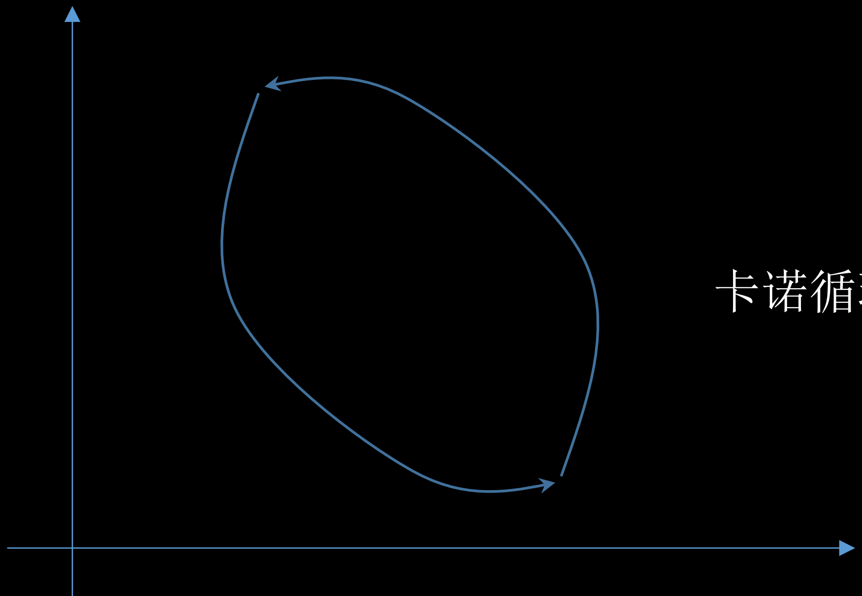
时间之箭

热力学熵（克劳修斯熵）



$$S(x) \Longrightarrow \Delta S = 0$$

$$\frac{Q_H - Q_L}{Q_H} = \frac{T_H - T_L}{T_H} \Longrightarrow \frac{Q_H}{T_H} - \frac{Q_L}{T_L} = 0$$



卡诺循环

$$\Delta S = \sum_i \frac{\Delta Q_i}{T_i} = 0 \quad \Rightarrow \quad \Delta S = \oint \frac{dQ}{T} = 0$$

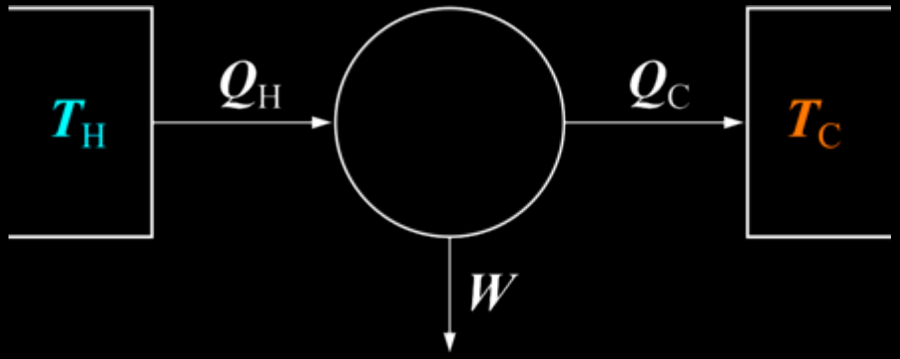
怎么理解热力学熵（克劳修斯熵）？

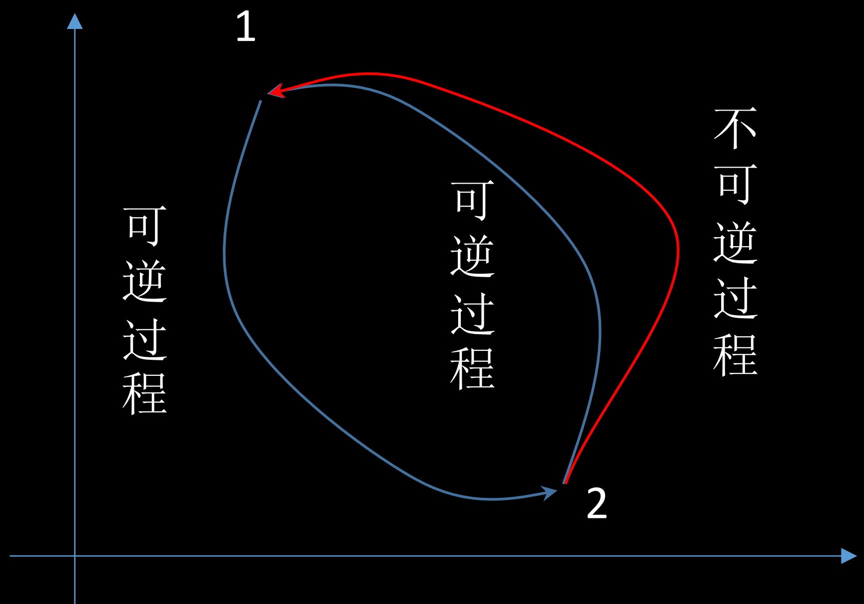
对于可逆过程来说：

$$\Delta S = \frac{\Delta Q}{T}$$

- 在不同温度下，吸收同等的热量效果完全不同，高温下熵增低，低温下熵增高
- 能量具有不同的品质，高温下能量的品质低，低温下能量品质高

热力学熵（克劳修斯熵）





$$\frac{Q_H - Q_L}{Q_H} < \frac{T_H - T_L}{T_H} \Rightarrow \frac{Q_H}{T_H} - \frac{Q_L}{T_L} < 0$$

$$S_2 - S_1 = \frac{Q_H}{T_H} \qquad S_1 - S_2 > \frac{-Q_L}{T_L}$$

$$\Delta S > \sum_i \frac{\Delta Q_i}{T_i} \Rightarrow \Delta S > \oint \frac{dQ}{T}$$

孤立系统的热力学第二定律

$$\Delta S > \sum_i \frac{\Delta Q_i}{T_i} \Rightarrow \quad \Delta S > \oint \frac{dQ}{T}$$

孤立系统： $dQ = 0$

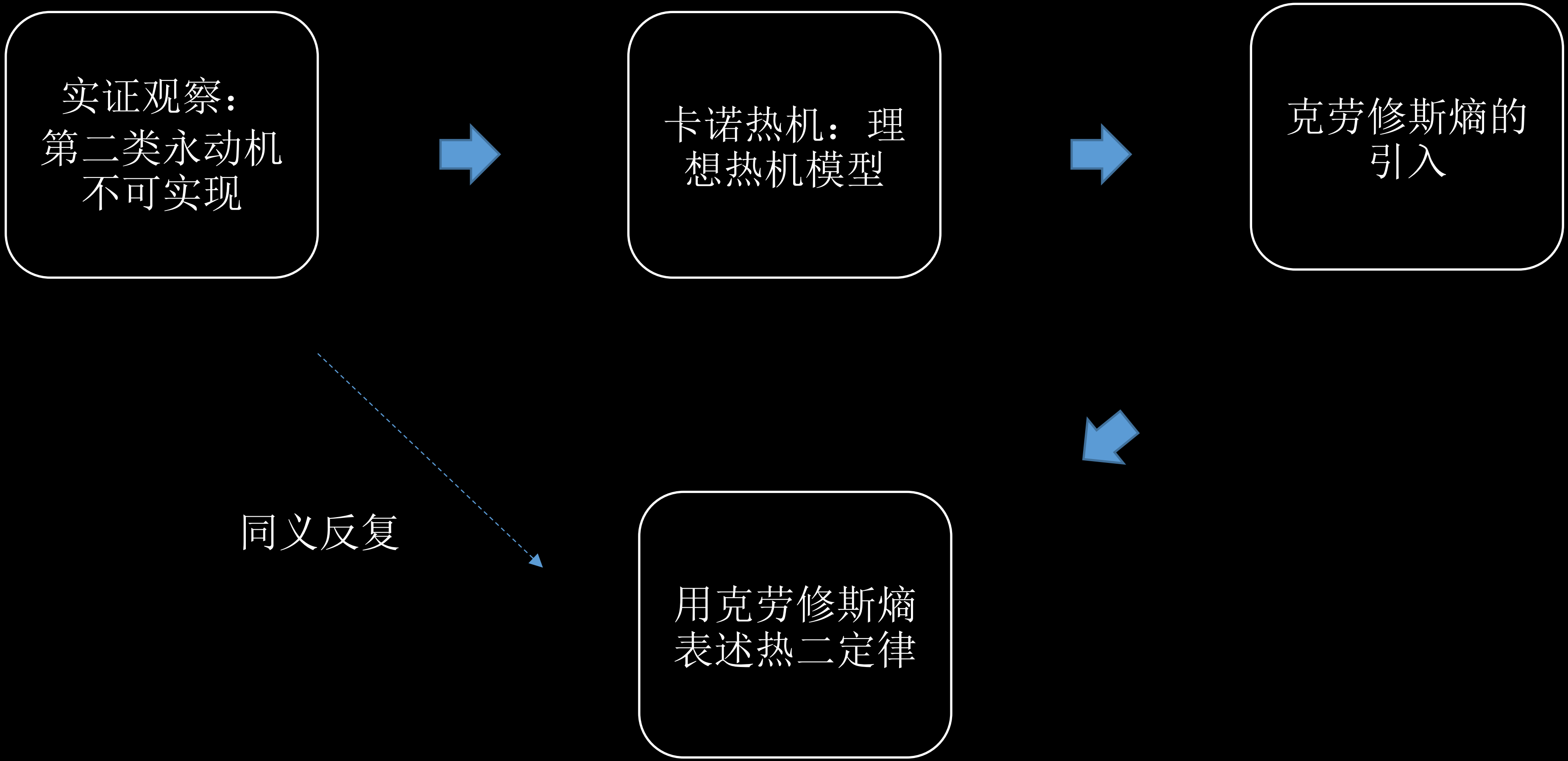
$$\Delta S > 0$$

孤立系统的热力学第二定律

$$\Delta S > 0$$

孤立系统的熵只能单调增加

熵增定律推导路线图



今日内容

- 热力学熵
- 统计力学熵
- 什么是耗散结构？

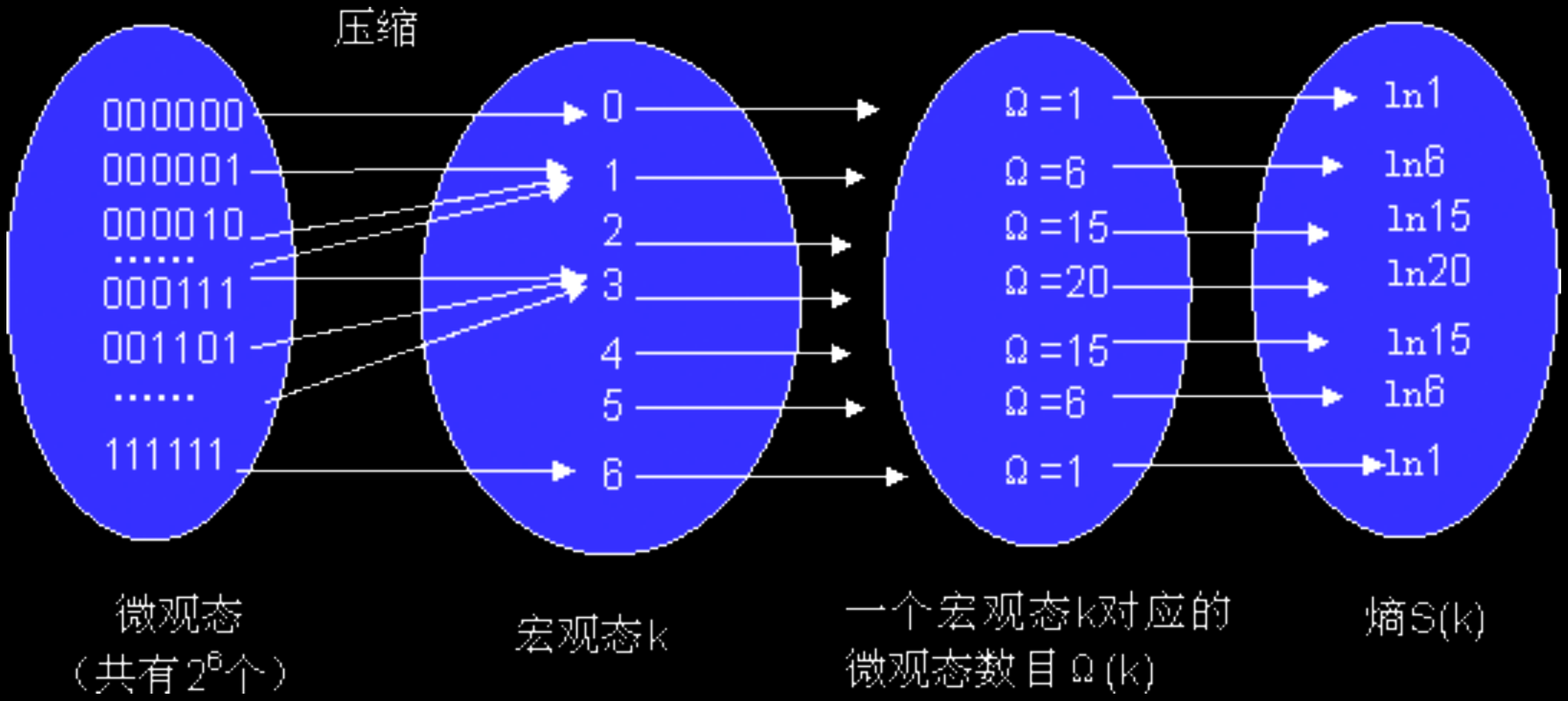
刻在墓碑上的公式

S = k. log W
LVDWIG
BOLTZMANN
1844 - 1906
HENRIETTE
BOLTZMANN
Dr PHIL. PAULA
BOLTZMANN
GEB. CHIARI
ARTHUR
BOLTZMANN
LVDWIG
BOLTZMANN
1923 - 1943

一个简单的实验

- 随机产生大量个0-1二进制串 (N位长)
- 在屏幕上打印出N位数字累加的结果
- 你最能看到什么数字?

一个简单的实验



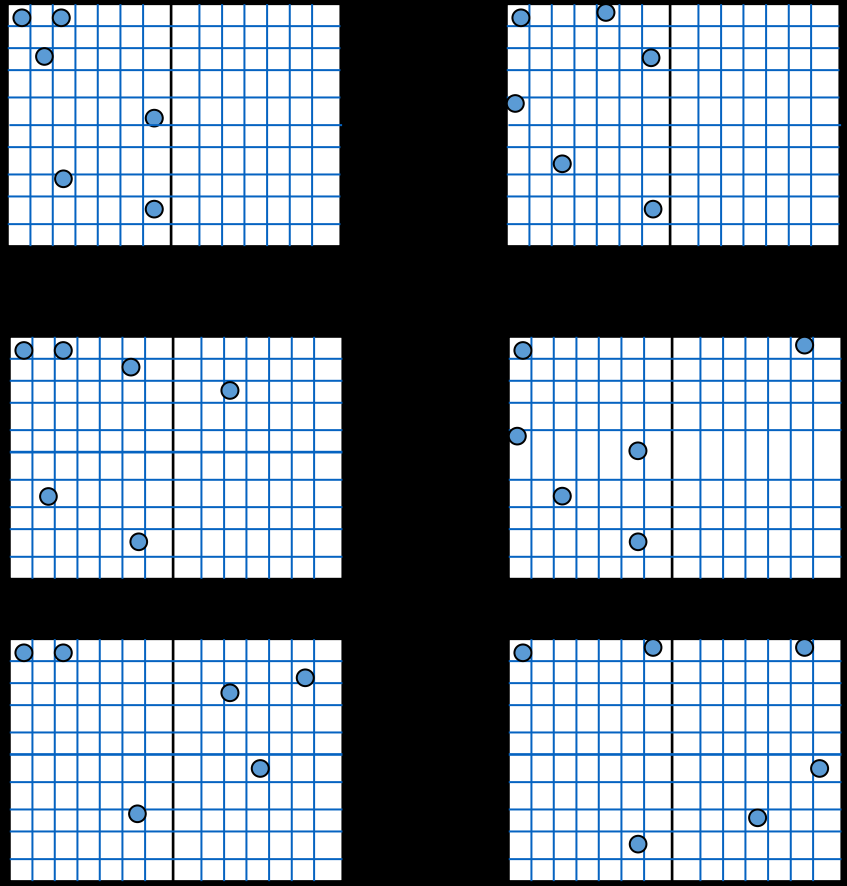
压缩
000000
000001
000010
……
000111
001101
……
111111
0
1
2
3
4
5
6
Ω=1
Ω=6
Ω=15
Ω=20
Ω=15
Ω=6
Ω=1
ln1
ln6
ln15
ln20
ln15
ln6
ln1
微观态
(共有2⁶个)
宏观态k
一个宏观态k对应的
微观态数目Ω(k)
熵S(k)

熵是什么？

- 由于我们无法追踪忽略的信息量就称之为熵

小球模型

宏观态	微观态1	微观态2	微观态个数
6 | 0			…… $W=C(6,6)70^6=70^6$个
5 | 1			…… $W=C(6,5)70^6=8*70^6$个
……			
3 | 3			…… $W=C(6,3)70^6=20*70^6$个



小球模型

$$S = k \ln W$$

宏观态	微观态1	微观态2	微观态个数
6 | 0			…… $W=C(6,6)70^6=70^6$个
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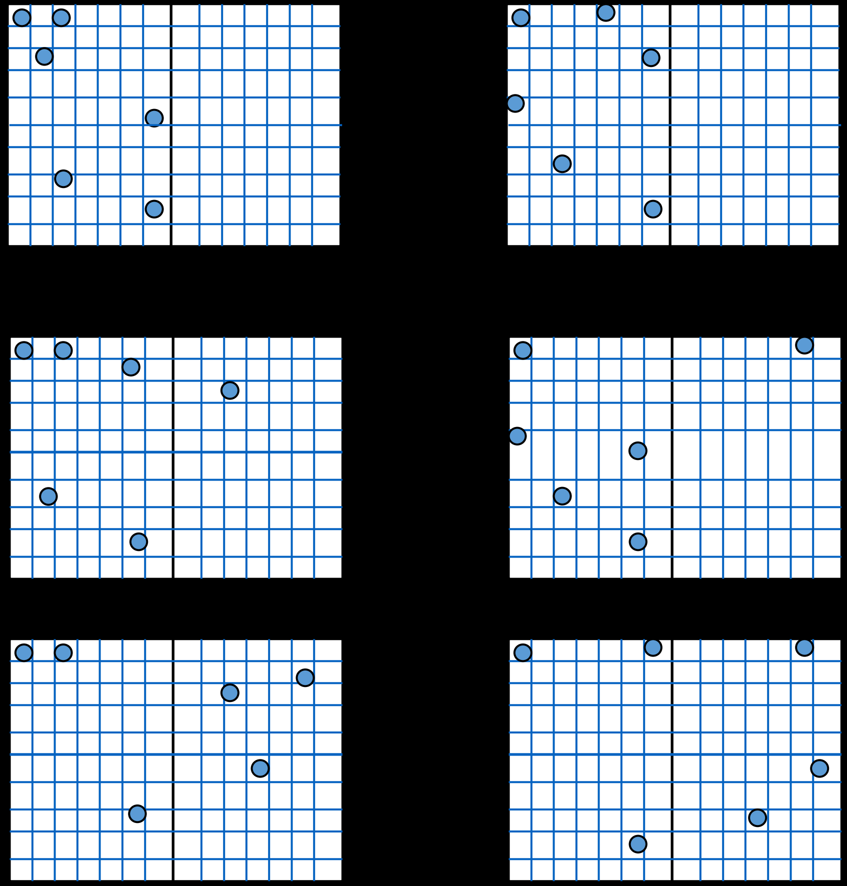
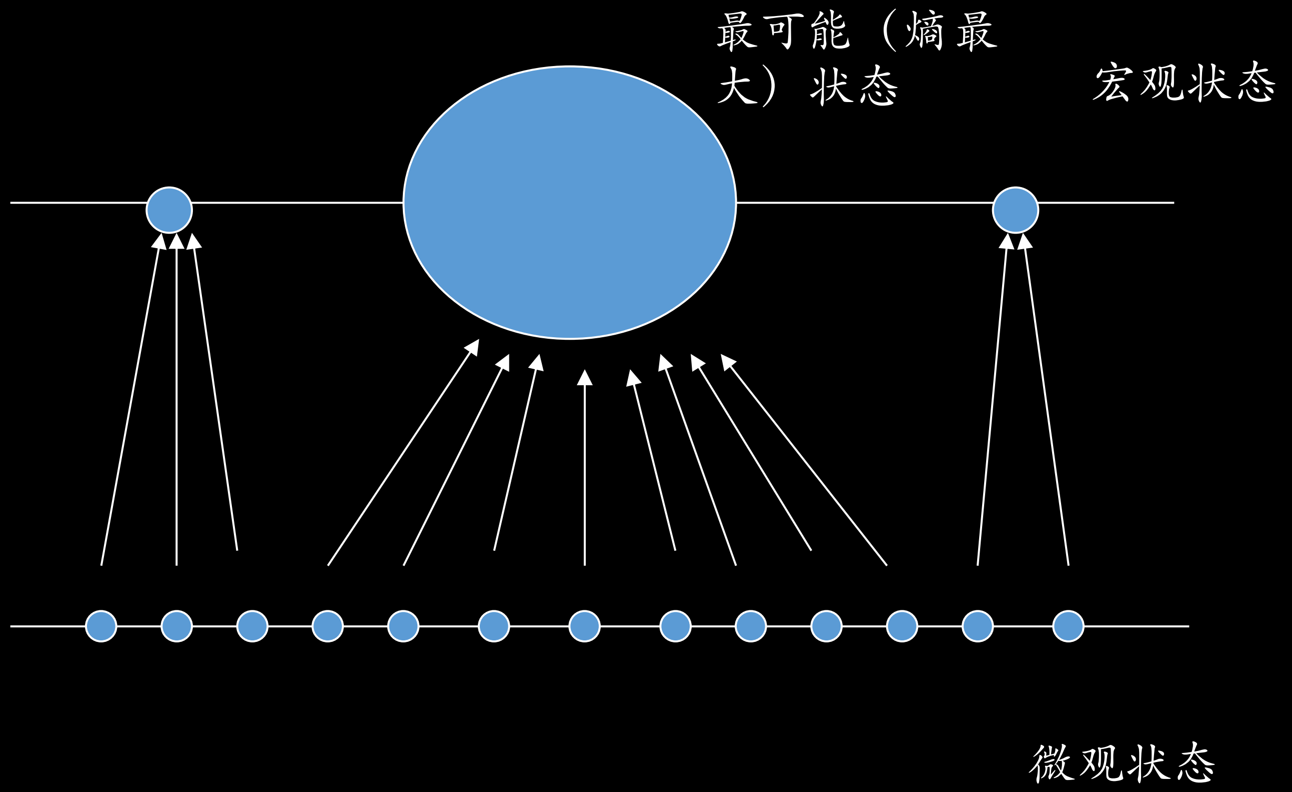
……			
3 | 3			…… $W=C(6,3)70^6=20*70^6$个



玻尔兹曼熵

$$S = k \ln W$$

热力学第二定律的“解释”



用玻尔兹曼熵重新推导热力学

熵、温度、压强、自由能、……的微观统计定义 → 热力学定律/经验公式 → 热力学定律/经验公式

$$dS \geq \int \frac{dQ}{T}$$

$$PV = nRT$$

香农熵

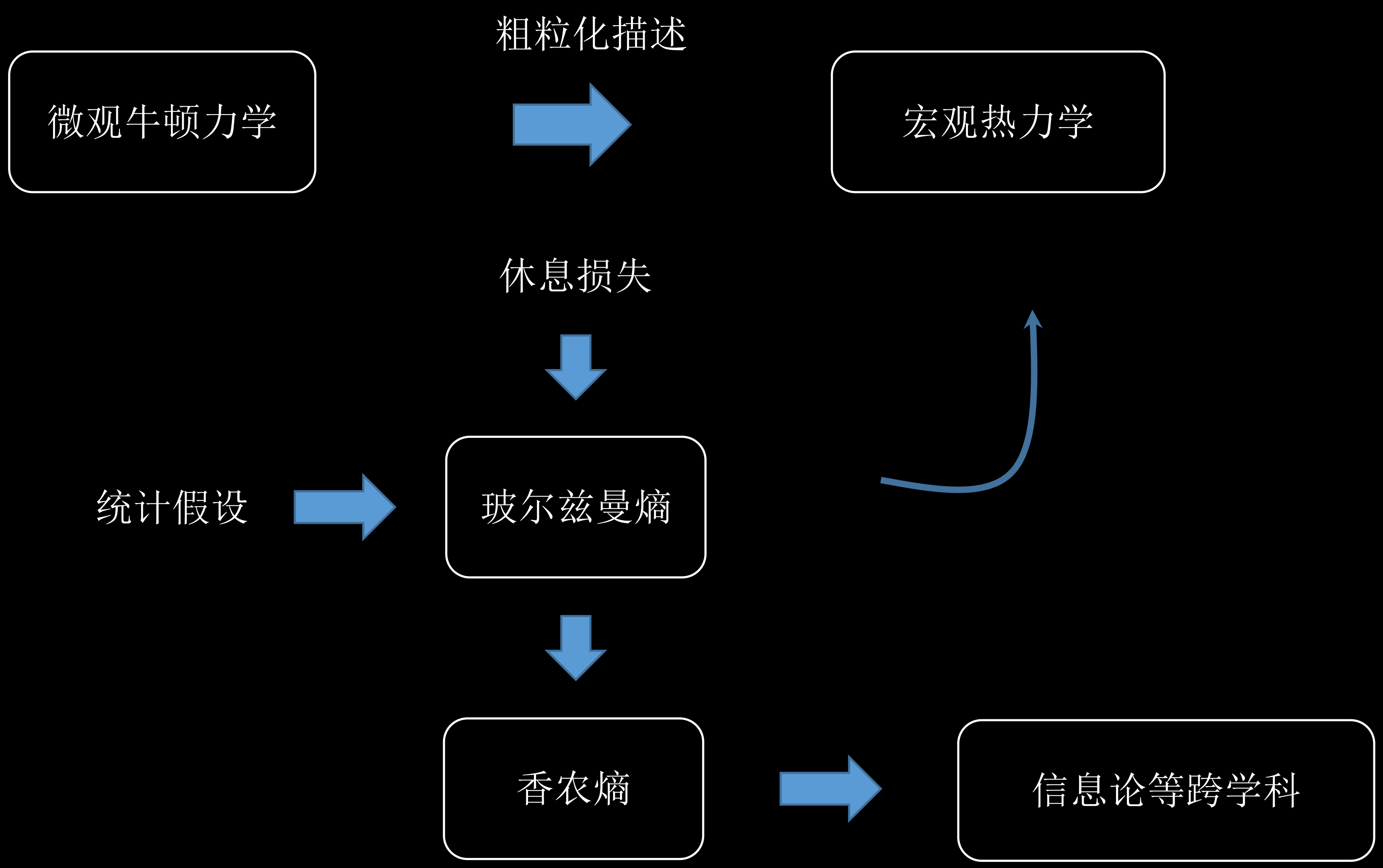
宏观态		概率分布	
6	0	1	0
5	1	5/6	1/6
……		……	
3	3	1/2	1/2

$$S = k \ln W$$

⬇

$$S = -\sum_i p_i \ln p_i$$

统计物理框架



今日内容

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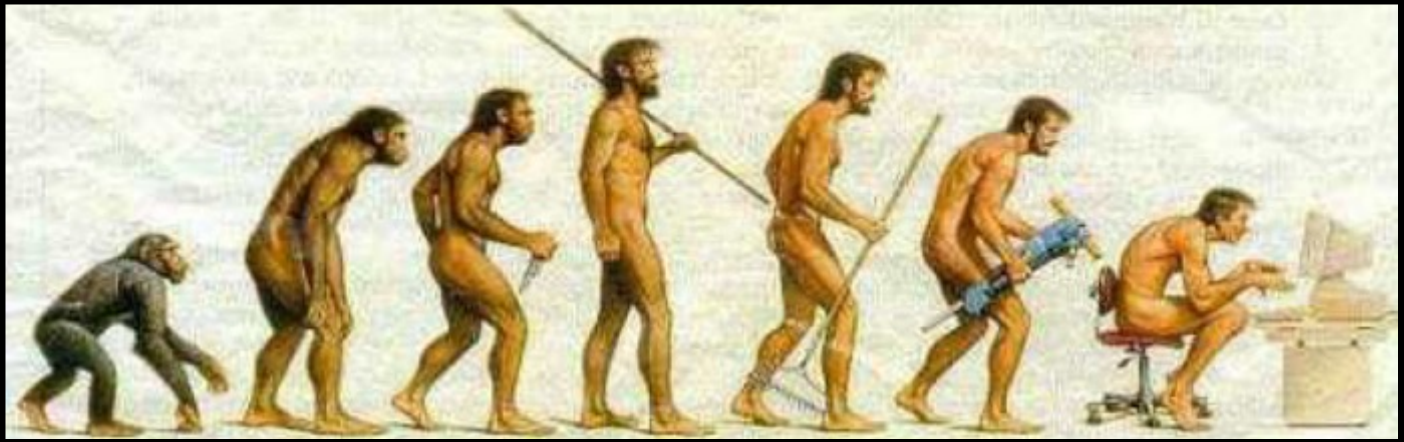
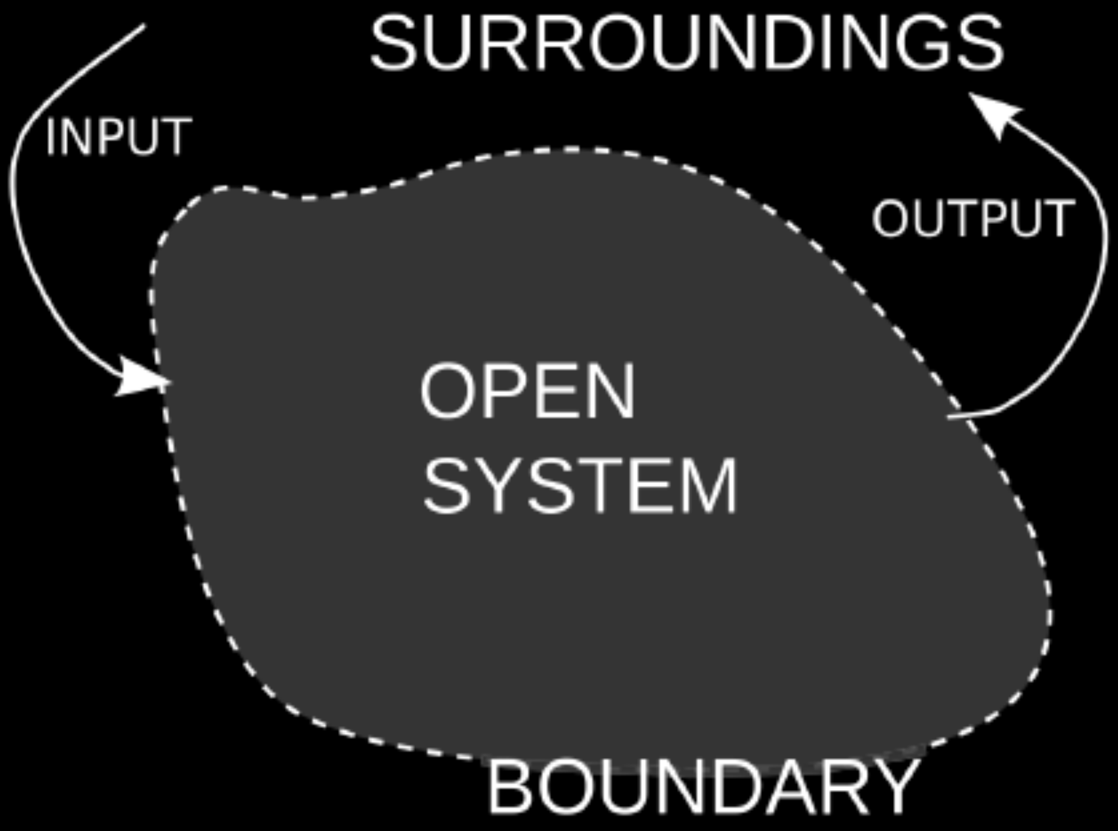
- 统计力学熵
- 什么是耗散结构？

第二种时间之箭



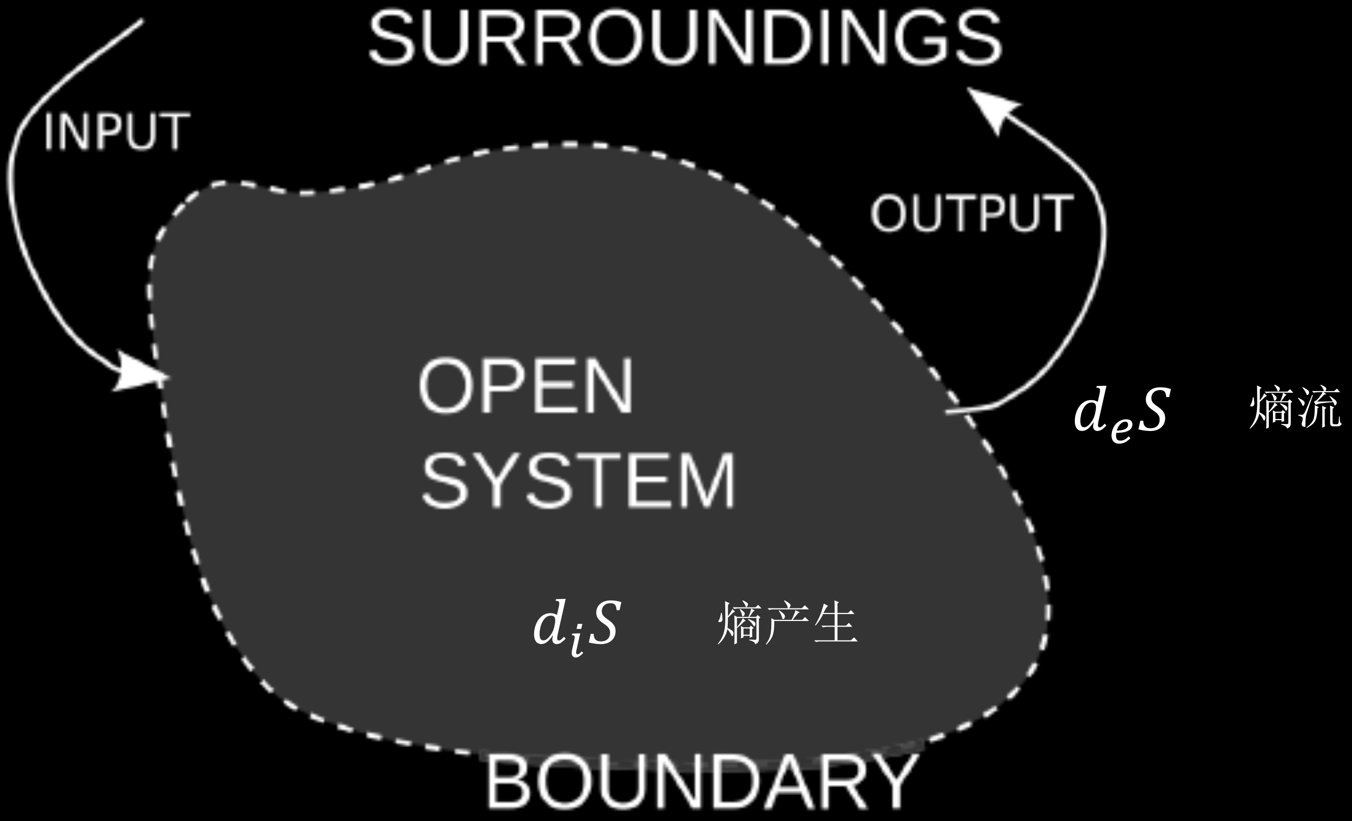
复杂度和有序性不断增加

开放带来有序



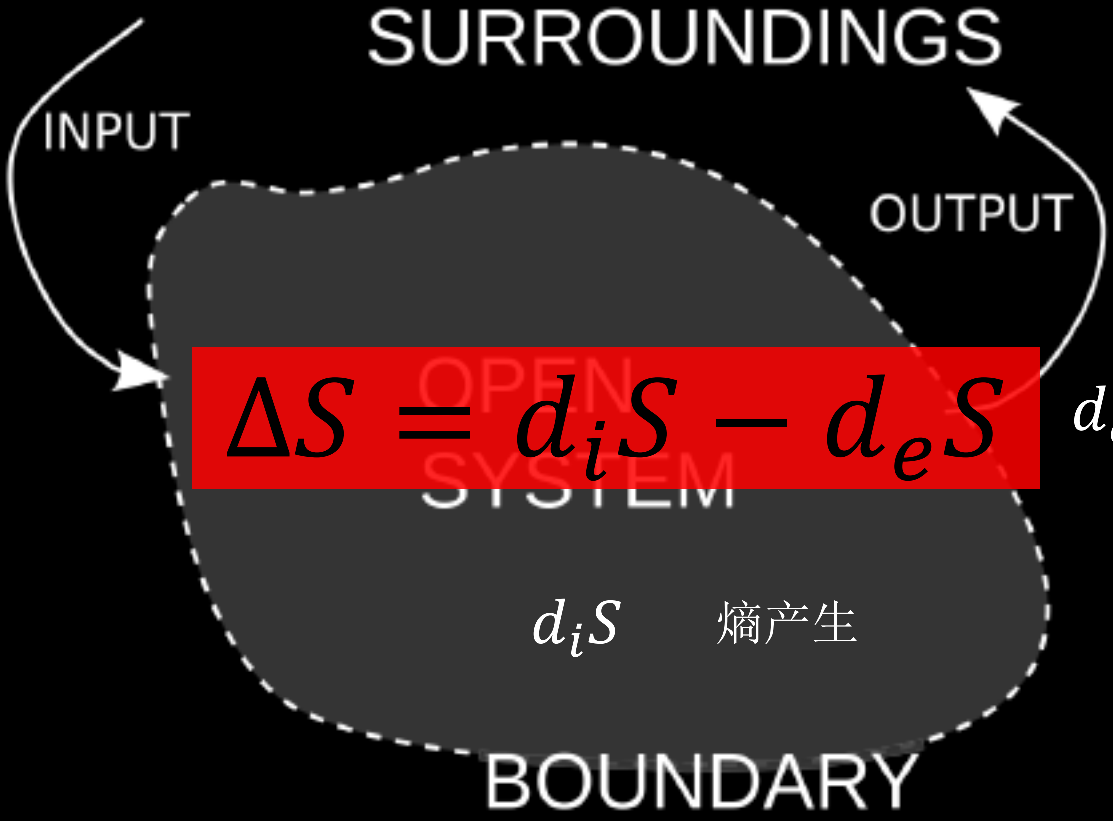
开放带来有序

Ilya Prigogine



秩序为何自发出现?

Ilya Prigogine

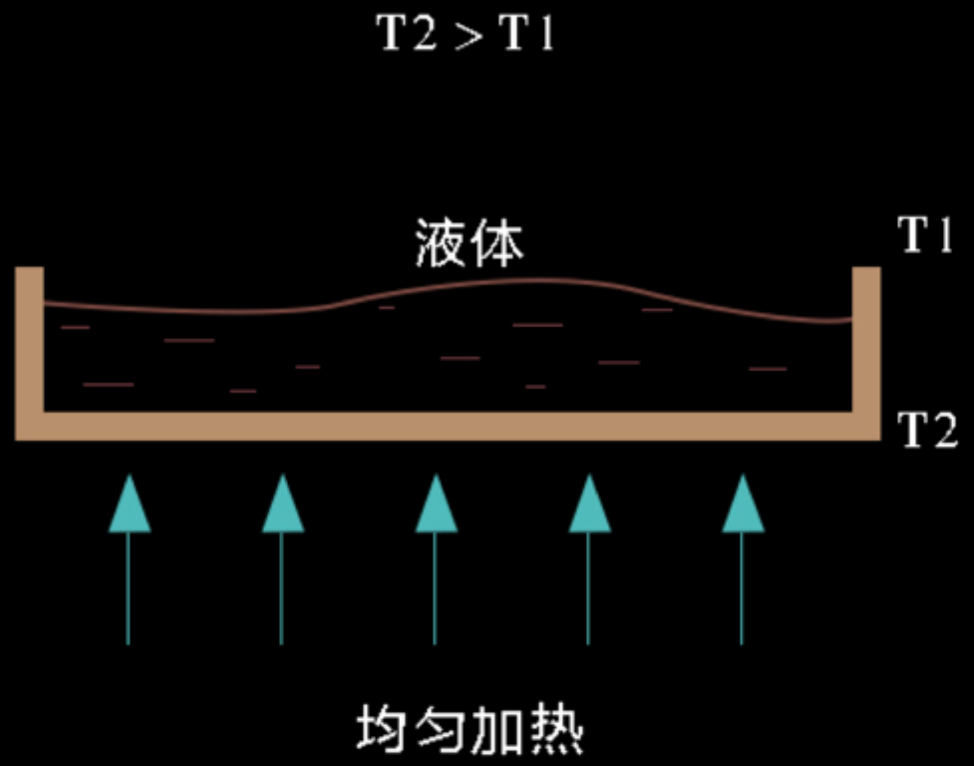


$$\Delta S = d_i S - d_e S$$

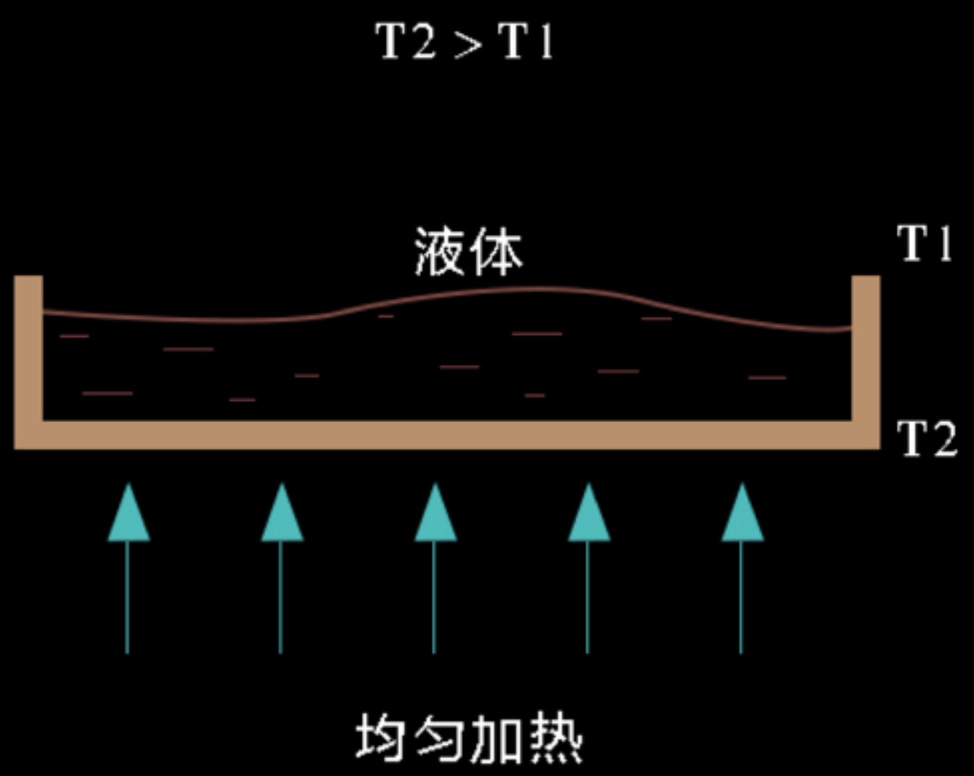
$d_e S$ 熵流

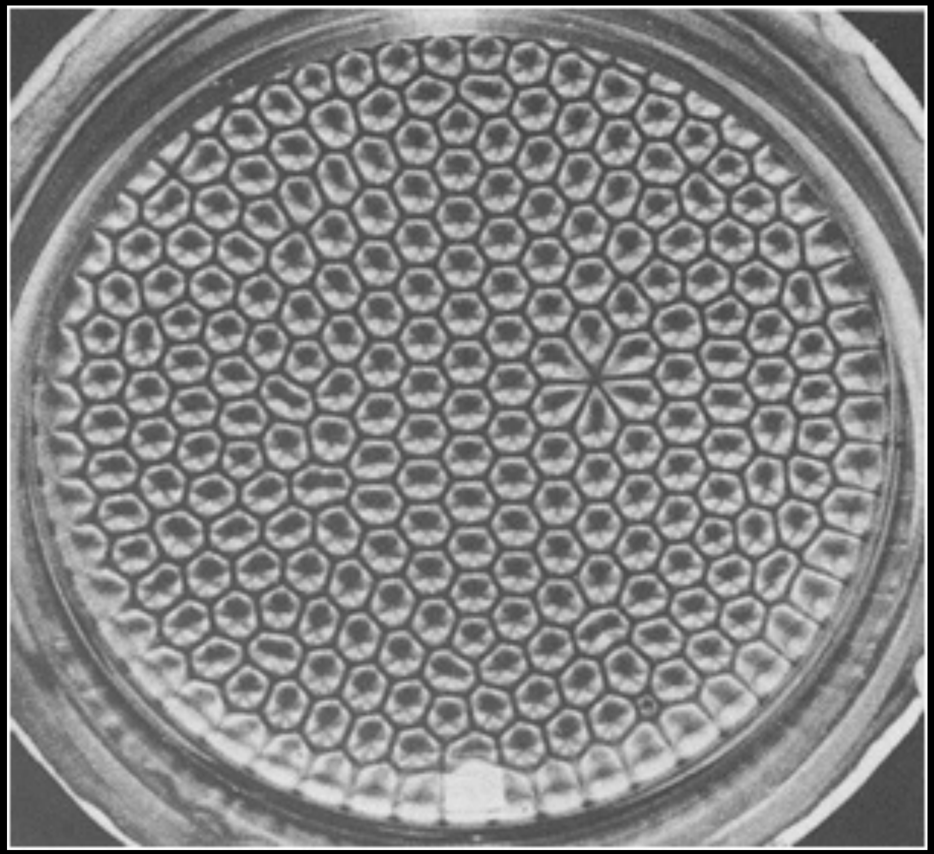
$d_i S$ 熵产生

贝纳德对流实验



贝纳德对流实验

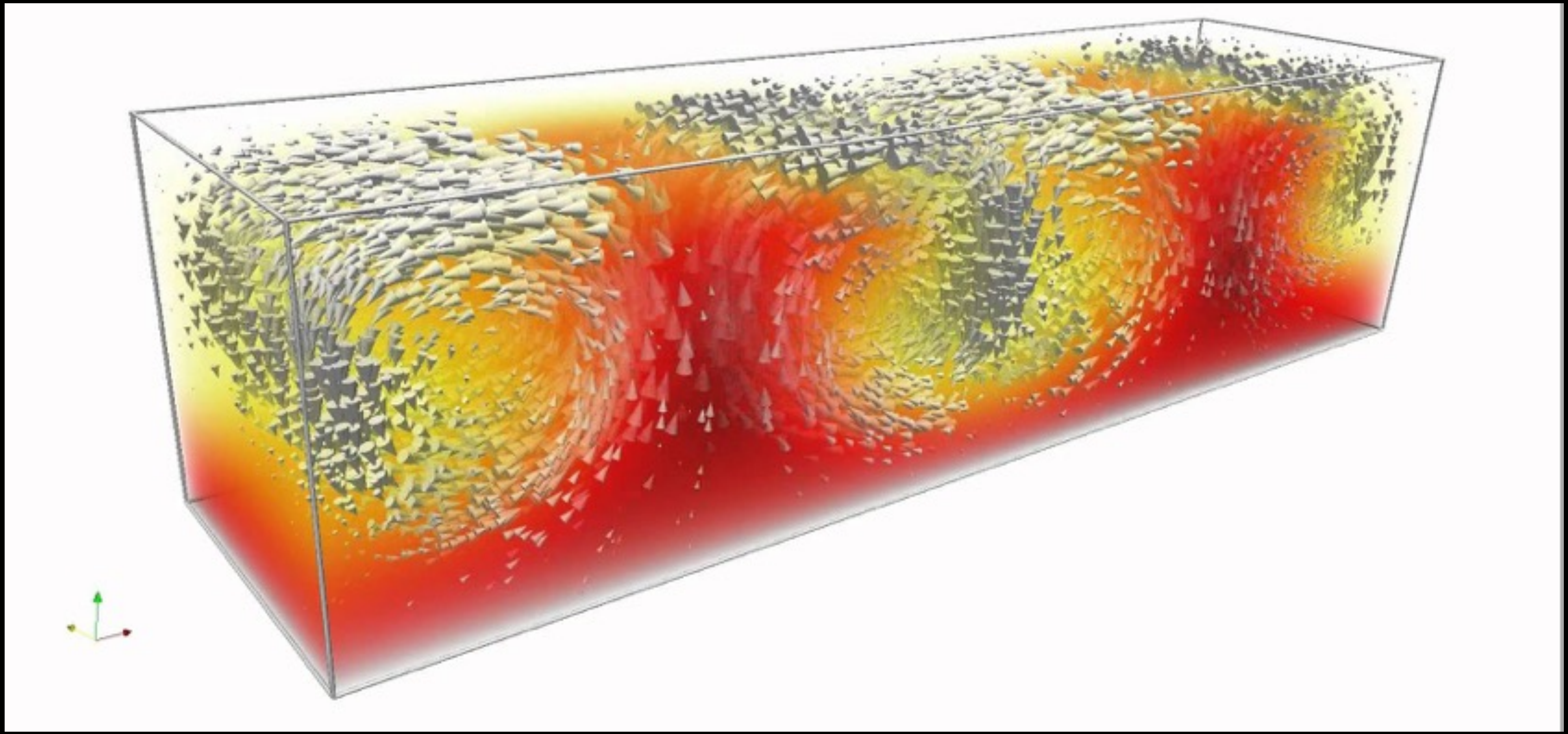




贝纳德对流试验

贝纳德对流实验

- 局部相互作用产生集体运动
- 集体运动导致长程关联
- 长程关联导致宏观秩序结构（Pattern）的涌现

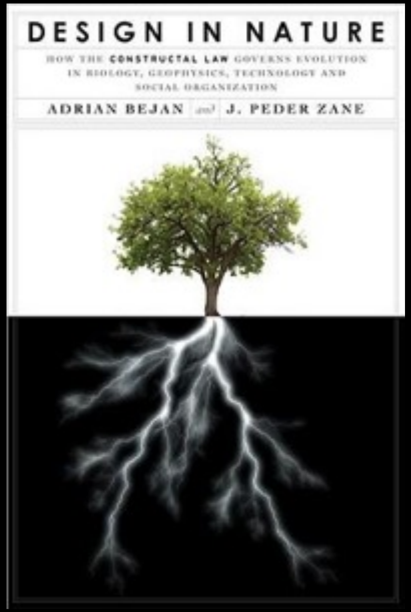


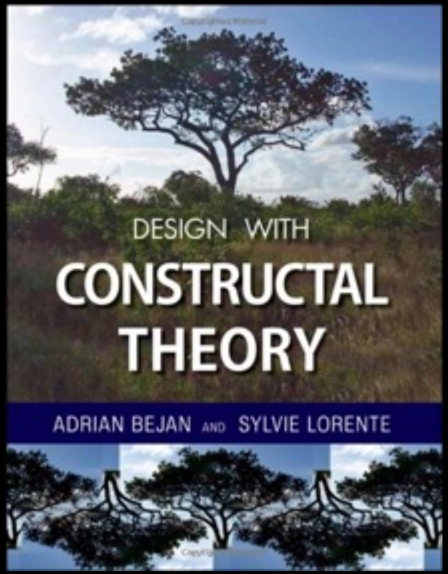
耗散结构

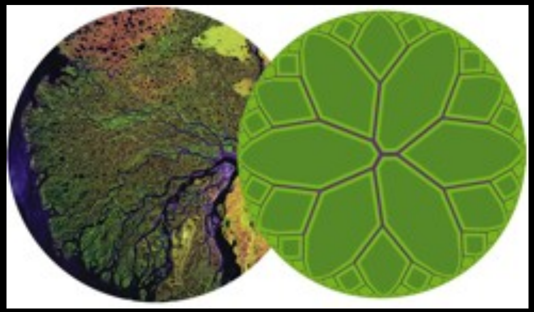
静态Pattern

动态Pattern

热力学第四定律?







A. Bejan

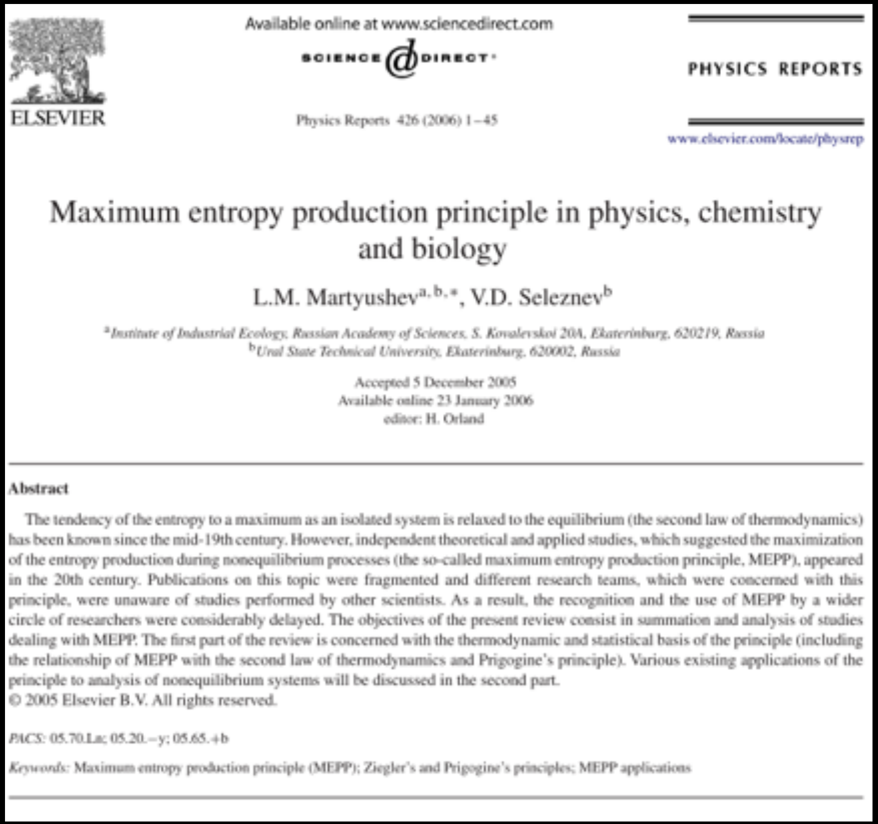
For a finite-size system to persist in time (to live), it must evolve in such a way that it provides easier access to the imposed currents that flow through it

---- Bejan

生态目标

- 最大功率原理Maximum Power Principle
- 最大内涵能量原理Maximum Empower Principle
- 最大外显能量Maximum Exergy
- 最大优越性Maximum Ascendency

最大熵产生原理



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Maximum entropy production principle in physics, chemistry and biology

L.M. Martyushev[a,b,*], V.D. Seleznev[b]

[a] Institute of Industrial Ecology, Russian Academy of Sciences, S. Kovalevskoi 20A, Ekaterinburg, 620219, Russia
[b] Ural State Technical University, Ekaterinburg, 620002, Russia

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Abstract

The tendency of the entropy to a maximum as an isolated system is relaxed to the equilibrium (the second law of thermodynamics) has been known since the mid-19th century. However, independent theoretical and applied studies, which suggested the maximization of the entropy production during nonequilibrium processes (the so-called maximum entropy production principle, MEPP), appeared in the 20th century. Publications on this topic were fragmented and different research teams, which were concerned with this principle, were unaware of studies performed by other scientists. As a result, the recognition and the use of MEPP by a wider circle of researchers were considerably delayed. The objectives of the present review consist in summation and analysis of studies dealing with MEPP. The first part of the review is concerned with the thermodynamic and statistical basis of the principle (including the relationship of MEPP with the second law of thermodynamics and Prigogine's principle). Various existing applications of the principle to analysis of nonequilibrium systems will be discussed in the second part.

PACS: 05.70.Ln; 05.20.–y; 05.65.+b

Keywords: Maximum entropy production principle (MEPP); Ziegler's and Prigogine's principles; MEPP applications

这意味着什么？

对更秩序的追求 → 更快速地向环境释放熵

向外扩张的本性是深深根植在热力学定律之中的

今日内容

- 热力学第二定律是公理
- 熵来源于我们对系统微观信息的忽略
- 开放可能导致熵减的出现