Dynamics of Cooperation in Spatial Prisoner's Dilemma of Memory-Based Players

基于记忆模式下的空间囚徒困境的动态合作

Abstract In a population of extremely primitive players with no memory, interaction with local neighbors in a spatial array can promote the coexistence of cooperators and defectors, which is not possible in the well mixed case (Nowak, Bonhoeffer, and May, 1994). However, the applicability of this insight is unclear in the context of a social system where memory plays a significant role in the conscious decision-making of the members. In this paper, the problem of cooperation is analyzed in a population of players with the memory model embodied in the ACT-R cognitive architecture (Anderson and Lebiere, 1998). Using agent-based simulations, it is shown that in a population of memory-based agents, spatial structure supports higher levels of cooperation in comparison to the well mixed paradigm.

摘要：
在一个没有记忆的极度原始的玩家群体中，在空间阵列中与附近邻居的交互可以促进合作者和背叛者的共存，这在完全混合（不存在空间结构）的情况下是不可能的（Nowak,Bonhoeffer,andMay,1994)。然而，还不清楚这种观点在成员高度依赖记忆做出决策的系统中的适用性。
本文在ACT-R认知结构中加入记忆模型，分析了玩家群体中的合作问题（Anderson and Lebiere，1998)。通过基于玩家个体（agent）的模拟，表明了在一个基于记忆的个体群体中，空间结构支持比完全混合模式更高层次的合作。

ity [4, 16]. Even though, the PD offers an invaluable framework to study the problem of cooperation in the context of two self-regarding players, realistic investigation of cooperation problems at societal level involves a population of more than two players [18]. Consideration of a population of more than two interacting players leads

囚徒困境模型局限：
囚徒困境研究两个自私个体的合作，但是现实中往往要研究有多个这样的个体的情况。

structure of the interaction

引出重点：互动的结构

to the further assumptions concerning the structure of the interaction. Mean-field approximation and rigid spatial structures are often considered as the two limiting

两种互动结构的极限情况：
MFA（均场近似）：所有人的策略被均一化（等效于完全混合情况）
RSS（网格空间结构）：个体被放在网格里只与周围的个体互动
（以下好像都是讲RSS）

topologies observed in the real world could be used to explain the emergence and maintenance of cooperation in a population of extremely simple players with no memory. Nowak and May [16] have employed a spatial version of evolutionary PD,

证实：RSS没记忆情况下合作的出现和维持

tionary models. Moreover, some researchers argue that the evolutionary template may not be an appropriate framework to study learning and adaptation processes at the cognitive level [3]. This paper studies the problem of cooperation in a spatial

无记忆模型的缺陷：没有重复决策下的学习和适应
这也就是本文所要用记忆模型所要解决的

The paper is organized as follows: Section 2 presents the representational details of the decision-making model of players in the model. Section 3 presents details about computational simulations with SPD involving memory-based players described in Section 2 and corresponding results about the dynamics of cooperation in such a framework. A discussion about the decision-making process of players in the model and some perspectives for future research is given Section 4. Finally, concluding remarks are pointed out in Section 5.

文章结构：
1. 引言
2. 玩家决策模型的相关细节
3. 模拟过程&框架下的动态决策
4. 讨论和未来研究方向
5. Remarks

higher level decision-making is embodied in the declarative memory of facts and the procedural memory of production rules []Taatgen2006. The production rules in the

ACT-R:
更高层次的决策依据:
1. 事实的陈述性记忆：知识的结构化编码+label（chunk）
2. 生产规则的程序性记忆：编码在满足某些条件时可能采取的动作

configurations of labeled slots. Each chunk has a level of activation that depends on its previous usage, its relevance to the current context, and a noise component.

chunk的激活等级取决于:
1. 以前的使用情况
2. 与当前上下文的相关性
3. 噪声

ACT-R memory model retrieves the chunk with highest activation and applies the relevant production rule to achieve a goal [19].

ACT-R模型两步:
1. 选出相关chunk中有最高激活等级的
2. 运用生产规则实现目标

from two-person game playing context to the spatial game, the procedural component of the player is kept intact: a player looks at its two possible moves, determines

程序性部分和2人PD一样：选择最有可能获得最高回报outcome的决策
pi=argmax_(policy){argmax_(outcome){Pr(outcome)}}

C-*k*C

outcome格式：C/D-kC
意味着个体选择合作/背叛，周围n个人中k个选择合作

C-*n*C

outcome（局势）

p-move C

个体选择：C合作

N-config *k*C

邻居配置：k个合作

OutcomeC

从（n-1）个chunks中检索一个自己选择C的outcome

OutcomeD

从（n-1）个chunks中检索一个自己选择D的outcome

$\boxed{B}$

上述检索是搜索有最大激活程度的chunks
激活程度的计算函数B

payoff nS	回报： 个体选择合作的回报计算： 1. 每个选择合作的邻居贡献R(eward) 2. 每个选择背叛的邻居贡献S(ucker) 个体选择背叛的回报计算： 1. 每个选择合作的邻居贡献T(emptation) 2. 每个选择背叛的邻居贡献P(unishment)
p-move	个体的决策：决定于两个outcome中谁回报更高
$\ln\left[\sum_{i=1}^{k} t_i^{-d} + \frac{(n-k)(t_n^{1-d} - t_k^{1-d})}{(1-d)(t_n - t_k)}\right]$	神经学实验得出的人的记忆项（基础水平激活） t_{j}=自第j次引用后的时间 n=总的被引用次数 d=遗忘率
$N\left(0, \frac{\pi.s}{\sqrt{3}}\right)$	噪音 s=噪音参数
in Anderson and Schooler [2] is due to Petrov [17]. Petrov has shown that by keeping the most recent k references, the base level activation can be approximated with great accuracy. In the actual implementation we used $k = 1$ for computational effi-	文献论证：不必保留所有记忆，保留最近的k次记忆就可以达到一定的让人满意的近似度
$R = 3, S = 0, T = 5$, and $P = 1$	各种回报项的设置： R, S, T, P = 3, 0, 5, 1
we used $k = 1$	本文取k=1来增大运算效率
ues are considered as in Lebiere et al. [13] for the forgetting rate of $d = 0.5$, and the activation noise parameter of $s = 0.25$. The initial references of declarative chunks are uniformly distributed such that on average each chunk would get 100 references. It has been observed from computational experiments that results are qualitatively unchanged when we varied the number of initial references from 10 to 100.	超参数设置： k=1 d=0.5 s=0.25 每个chunks初始被引用量=100（实测10~100实验结果没明显变化）
The first computational experiment is carried out on a square lattice of the size 50×50 with periodic boundary conditions. Memory-based players with the procedural and declarative memory components described in the previous section are	实验1：在50*50的正方形周期网格上，与自己的von Neumann邻居交互，无自交互
As such the underlying dynamics of the model are synchronous	模型的底层动态是同步的（各个个体同时决定、同时获得回报、更新记忆等）
To characterize the macroscopic dynamics of the model, the fraction of cooperators (f_C) in the population at each generation is considered. Since the model involves	模型在每一代的动态指标： f_{c}=每一代中选择合作的个体比例

and some statistical treatment would be more appropriate. The simulation is carried out 30 times with a different random seed each time to ensure statistical indepen-

30次重复实验（run），每次更换随机数种子，减小偶然误差

totically stabilizes and fluctuates around a constant after some number of generations. The model is considered to be asymptotically stable in a given run when the

观察到每次f_{c}都在一定代数后在某常数附近波动
模型渐进稳定：在两个连续的10^4代的窗口内均值之差小于10^-3数量级。
在模型渐近稳定后的10^4代的均值被认为是模型的渐近值。

In this run

实测结果：
渐近稳定：12*10^4代
渐近稳定时的f_{c}=0.3226
渐近稳定后窗口均值近似正态分布
95%置信区间为[0.3220,0.3228]

around a constant. Also the experiments were repeated for lattice sizes from 20×20 to 400×400 and it was observed that asymptotic cooperation levels are almost independent of lattice size. These emergent stable cooperation levels independent of the initial configuration of the model are very interesting.

在20*20和400*400的网格上重复实验，发现f_{c}结果几乎与图大小不相关

The second experiment considered the mean-field interaction scenario for a population size of 2500 players so that the effect of spatial structure on cooperation lev-

实验2：不用有网格的RSS结构，采用更简单的MFA结构。人数为50*50方便类比。

playing model proposed in lebiere et al. [13] is directly used. A generation in this case consists of $N/2$ micro time steps, where N is the size of the population. In each micro time step, two randomly selected distinct players play a bilateral PD game.

30次重复实验（run）
每次实验有多代
每代有N/2个微小步，N为人数
每步随机选取2个个体进行双边的囚徒博弈
实验结果：
1. 同样渐近稳定
2. 渐近稳定后窗口均值同样近似正态
3. 95%置信区间为[0.2446,0.2448]
4. 渐近值同样与人数大小无关

the population. Also, this is in contrast with evolutionary PD where cooperation is not possible in mean-field interaction case. Comparison between cooperation lev-

与进化囚徒困境不同，这种基于记忆的MFA结构是可以支持合作的

case suggests that spatial structure can support higher levels of cooperation than that of well-mixed case in a population of memory-based players. However, further

对比表明：
RSS的空间结构相比MFA的混合均匀，支持更高水平的合作比例
但是接下来的实验表明也不尽然
RSS改用Moore邻居后渐近值减小为0.2196，比MFA还小

explored the effect of number of neighbors

实验3：接下来探究邻居数对渐近合作水平的影响
实验1的基础上
顺序选取[1,10]内的随机整数为单个个体周围的邻居个数
对每个个体，按照该邻居个数随机匹配邻居编号
结果：邻居数量>6，比MFA的混合均匀模式所支持的合作水平低

levels smaller than that of the well-mixed case. The other experiment explored the effect of the range of Moore neighborhood on the asymptotic cooperation level in

实验4：Moore邻居的范围的影响
实验1的基础上
结果：渐近合作水平随着邻居范围增大而减小
邻居数量>6，比MFA的混合均匀模式所支持的合作水平低

compared to the well-mixed case. Thus in a population of memory-based players spatial structure is beneficial for cooperative behavior only for smaller neighborhood sizes. Furthermore, it is interesting to note that for all these experiments, the asymptotic cooperation levels were observed to be almost independent of the size of the population.

总结论：
1.总的来说，更小的邻居数目支持更高水平的合作等级
2.人数几乎不影响渐近合作水平