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Topics from Competitive Game Theory

*坂口 実 (Minoru Sakaguchi)

Some of the recent works by the present author are given in the two parts $\boxed{A}$ and $\boxed{B}$. A lot of interesting open problems are mentioned.

$\boxed{A}$ 2- AND 3- PLAYER GAMES OF SCORE SHOWDOWN

1. 3-Player Games of Score Showdown. Let X_{ij} $(i=1,2,3;j=1,2)$ be the j-th r.v. observed by Player i. Assume that $\{X_{ij}\}$ are i.i.d. with $U_{[0,1]}$ distribution. Each player i first observes $X_{i1}=x_{i1}$ and chooses A/R. If A(R) is chosen, the x_{i1} is accepted (rejected and the second r,v X_{i2} is observed). Player i's score is

$$S_i(X_{i1},X_{i2})=\begin{cases}X_{i1}\\ \varphi(X_{i1},X_{i2})\end{cases}, \text{ if } X_{i1}=x_{i1} \text{ is } \begin{cases}\text{accepted.}\\ \text{rejected \& } X_{i2} \text{ is observed.}\end{cases}$$

We consider the cases

$$\varphi(X_{i1},X_{i2})=X_{i2},\ X_{i2}I(X_{i2}\geqq X_{i1}),\ (X_{i1}+X_{i2})I(X_{i1}+X_{i2}\geqq 1),\ \tfrac{1}{2}(X_{i1}+X_{i2})$$

(Keep-or-Exchange, Risky-Exchange, Showcase-Showdown,CompetingAverage,resp)

Player who gets the highest score is the winner. Each player wants Pr(he wins)→max

Also we consider the two versions of the games;

Simultanious-move version —— Players' choices are made indep. and are not known to his rivals.

Sequential- move version —— Players move sequentially, i.e.,I at first, II at second,and III at third. After I's move, II and III are informed of $X_{11}=x_1$ and I's choice of A/R. After II's move, III is informed of $X_{21}=x_2$ and II's choice of A/R. All players are intelligent, and each player should prepare for that any subsequent player must employ their optimal strategies.

In the present article, we use Γ= game, C=common, EQ=equilibrium, S=strategy, V= value, D= draw. Players 1,2,3 are sometimes written by I,II, III, resp.

2. Solutions to the Games, It is shown that games of $\Gamma^{(2)}$SS and $\Gamma^{(2)}$RE have the same solution (REF[3]) Some other results are given below (Ref[1,2,3])

• Solution to $\Gamma^{(2)}$KE (simult.-move): CEQS is "Choose A(R) if his first observ.is $>(<)$ $a^* = \frac{1}{2}(\sqrt{5}-1) \doteqdot 0.618$, i.e., a unique root in $(0,1)$ of the equation $a^2+a=1$." CEQV$=\frac{1}{2}$. In $\Gamma^{(3)}$KE, the a^*, the equation and CEQV change to $a^* \doteqdot 0.691$, $2a^4 = 1-a+a^2-a^3$ and $\frac{1}{3}$ resp.

• Solution to $\Gamma^{(2)}$RE (simult.-move).; CEQS is "Choose A(R), if his first observ. is $>(<)$ $a^* \doteqdot 0.544$, i.e., a unique root in $(0,1)$ of the equation $a^3+a^2+a=1$." $P(D) = \frac{1}{4}a^{*4} \doteqdot 0.022$, $P(W_1) = P(W_2) = \frac{1}{2}(1-P(D)) \doteqdot 0.489$. In $\Gamma^{(3)}$RE, a^*, the equation and the other result change to $a^* \doteqdot 0.656$, $2a^4+a^5 = 1-a+a^2-a^3$, $P(D) = \frac{1}{8}a^{*6} \doteqdot 0.010$, $P(W_1) = P(W_2) = P(W_3) = \frac{1}{3}(1-P(D)) \doteqdot 0.330$.

• Solution to $\Gamma^{(2)}$RE (seq.-move); I's opt.str. is "Choose A (R) $X_{11} = x_1$, if $x_1 >(<) x_0$ where x_0 ($\doteqdot 0.570$) is a unique root in $(\sqrt{2}-1, 1)$ of $\bar{x}^4 = 2x(1-3x^2)$." II's opt.str. is

"Choose A(R) $X_{21} = x_2$ if $x_2 >(<) \begin{cases} x_1 \\ y_0(x_1) \end{cases}$, in state $\begin{cases} (x_2 \mid x_1, A) \\ (x_2 \mid x_1, R) \end{cases}$,
where $y_0(x_1) \equiv (\sqrt{2}-1)I(x_1 \leqq \sqrt{2}-1) + (\bar{x}_1^2/(2x_1))I(x_1 > \sqrt{2}-1)$." We obtain $P(D)$, $P(W_1)$, $P(W_2) \doteqdot 0.011, 0.477, 0.512$, resp.

• Solution to $\Gamma^{(2)}$CA (seq.-move): I's opt. str. is "Choose A(R) $X_{11} = x_1$ if $x_1 > (<) x_0$, where x_0 ($\doteqdot 0.549$) is a unique root in $(\frac{1}{2}, 1)$ of $7/(2x) - 4\sqrt{2x} = 6-(15/2)x+x^2$." II's opt. str. is "Choose A(R) $X_{21} = x_2$ if $x_2 >(<) \begin{cases} x_1 \\ y_0(x_1) \end{cases}$, in state $\begin{cases} (x_2 \mid x_1, A) \\ (x_2 \mid x_1, R) \end{cases}$,

where $y_0(x_1) \equiv (\sqrt{2\bar{x}_1} - \bar{x}_1)I(x_1 < \frac{1}{2}) + (\sqrt{2x_1} - x_1)I(x_1 \geqq \frac{1}{2})$. We obtain $P(W_1) = 1-P(W_2) \doteqdot 0.490$.

• Solution to $\Gamma^{(3)}$KE (seq.-move): It is too complicate to write here. We found that $P(W_1), P(W_2), P(W_3) \doteqdot 0.32309, 0.33270, 0.34421$, resp. The sum is 1.

3. Information Types in 2-Player Games. We consider the two information types, under which players decide their choices of A/R.

I^{11-11} means that I chooses $X_{11} = x_1$, II chooses $X_{21} = x_2$ and each player informs of his observed value to his opponent.

I^{10-11} means that I observes $X_{11} = x_1$, II observes $X_{21} = x_2$ and I informs his x_1 to II, and II doesn't inform his x_2 to I.

It is clear that I^{10-01} is the information type discussed in Section 2.

Some results are given as follows (Ref[4]).

• Solution to $\Gamma^{(2)}$RE under I^{11-11} ; In state $x_1 - x_2$ there exists a unique saddle point at R-A, R-R, A-R, if $x_1 \vee x_2 \vee (\sqrt{2}-1) = x_2, \sqrt{2}-1, x_1$, resp.

We obtain $P(D)=\frac{1}{4}(\sqrt{2}-1)^4 \fallingdotseq 0.007$, $P(W_1)=P(W_2)=\frac{1}{2}(1-P(D)) \fallingdotseq 0.496$.

• Solution to $\Gamma^{(2)}$KE under $I^{(0-1)}$: I's opt. str. is "Choose A (R) $X_{i1}=x_1$, if $x_1 >(<)\ a^*=\sqrt{3/8} \fallingdotseq 0.6124$." II's opt. str.in state $x_1 - x_2$ is given by

Condition	II's opt. Choice
$x_1 < a^*$	$A(R)$, if $x_2 >(<) 1/2$
$a^* < x_1 < x_2$	A
$x_1 > a^* \vee x_2$	R

We obtain $P(W_1) = 1 - P(W_2) = \frac{1}{3} + \frac{1}{4}a^* \fallingdotseq 0.4864$.

4. 2-Player game of Continue-or-Stop. Player i observes ($X_{i1}, X_{i2}, \cdots X_{in}$), sequentially one-by-one, and facing each X_{ij} chooses Cont/Stop. If Stop is chosen X_{ij} is accepted by player i and his play ends. If Cont. is chosen, X_{ij} is rejected and the next $X_{i,j+1}$ is observed and the game continues. Assume that $\{X_{ij}\}$ are i.i.d. with $U_{[0,1]}$ distribution. Score is

$$S_i(X_{i1},\cdots,X_{in})=\begin{cases} X_{i1} \\ X_{i,j+1} \end{cases}, \text{ if } \begin{cases} \text{stop at } X_{i1} \\ X_{i1}, X_{i2}, \cdots, X_{ij} \text{ are rejected and stop at } X_{i,j+1} \end{cases}$$

Consider the situation where player i has $n-1$ decision thresholds $(1 >) a_{i1} > a_{i2} > \cdots > a_{i,n-1}$ (>0), so that i chooses Stop (Cont.) if $X_{ij} >(<)\ a_{ij}$. Player who gets the higher score than his opponent is the winner. Each player aims Pr (he wins) → max.

• Solution when n = 3 (Ref[5]); The common optimal thresholds are $(b_1^0, b_2^0) \fallingdotseq (0.743, 0.657)$, where (b_1^0, b_2^0) is a unique root in $(0,1)^2$ of

$$\begin{cases} b_2^2 + b_2 - (b_1^{-1} - 1 + b_1) = 0 \\ b_1^2 + (1+b_2)^{-1} b_1 - 1 = 0 \end{cases}$$

$P(W_1)=P(W_2)=\frac{1}{2}$.

5. Remark. There are many open problems of interest around the topic— games of score showdown. Three among them are given below.

(1). Let (X_{ij}, Y_{ij}), $i=1,2$, $j=1,2$, are i.i.d. with joint p.d.f.

$$f(x,y)=1+\gamma(1-2x)(1-2y), \quad \forall (x,y)\in[0,1]^2,$$

with $|\gamma| \le 1$. In the game $\Gamma^{(2)}$KE (simult.-move), the score is

$$S_i(X_{i1}Y_{i1}, X_{i2}Y_{i2})=\begin{cases} (X_{i1}, Y_{i1}) \\ (X_{i2}, Y_{i2}) \end{cases}, \text{ if } (X_{i1}, Y_{i1}) \text{ is } \begin{cases} \text{accepted} \\ \text{rejected} \end{cases}.$$

Define that (x, y) is higher than [lower than, intermediate to] (x', y'), if $(x, y) \gtrsim$ [$<$, otherwise] (x', y'). Player with score (x, y) gets 1 [$-1, 0$]. Solve this zero-sum game.

(2). Sequential-move games $\Gamma^{(3)}RE$ and $\Gamma^{(3)}CA$ remain unsolved.

(3). 3-player games under various information types are of interest. $\Gamma^{(3)}KE$, $\Gamma^{(3)}RE$ and $\Gamma^{(3)}CA$, under $I^{111\text{-}111\text{-}111}$, $I^{100\text{-}110\text{-}111}$, $I^{110\text{-}011\text{-}101}$, etc. remain unsolved. The last one $I^{110\text{-}011\text{-}101}$, for example, means that each player observes his own $X_{i1} = x_{i1}$ and, in addition, I knows x_{21}, II knows x_{31} and III knows x_{11}.

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$\boxed{B}$ MULTISTAGE OPTIMAL STOPPING GAMES

1. Each Player has his Priority. Player I, II, and III observe $X_1, X_2, \cdots, X_n$ with i.i.d. $U_{[0,1]}$ distribution sequentially one-by-one. They have their previously given priorities $\langle p_1, p_2, p_3 \rangle$. Facing X_j each player chooses R/A, independently of his rivals.

If only one player chooses A, he gets X_j with his priority, dropping out from the game thereafter, and the remaining two players continue their two-player game with the "revised" priorities. If two players choose A, one player selected according to the "revised" priorities gets X_j, drops out from the game thereafter, and the remaining two players continue their 2-player game with the "revised" priorities. If the choices are A-A-A player i gets X_j with prob. p_i dropping out from the game, and the remaining two players continue their 2-player game with the revised" priorities. If the choices are R-R-R then X_j is rejected, the next X_{j+1} is observed and the subsequent 3-player game continues. Each player aims to maximize the ENV he can get (N in ENV means net, i.e. no-observation-cost and no-discounting).

Let W_n (V_n) be CEQV, for 3-player (2-player) equal-priority game. Then the Opt. Eq. is

$$(W_n, W_n, W_n) = E\left[\text{eq. val. } M_n(X)\right] \qquad (n \geq 1, \ W_0 = V_0 = 0)$$

$$M_n(x)=\begin{cases}\xrightarrow{\text{R by III}} M_{n,R}(x)= \begin{array}{c|c|c} & \text{R by II} & \text{A by II} \\ \hline \text{R by I} & W,\ W,\ W & V,\ x,\ V \\ \text{A by I} & x,\ V,\ V & \frac{1}{2}(x+V),\ \frac{1}{2}(x+V),\ V \end{array} \\[2ex] \xrightarrow{\text{A by III}} M_{n,A}(x)= \begin{array}{|c|c|} \hline V,\ V,\ x & V,\ \frac{1}{2}(x+V),\ \frac{1}{2}(x+V), \\ \hline \frac{1}{2}(x+V),\ V,\ \frac{1}{2}(x+V), & \frac{1}{3}(x+2V),\ \frac{1}{3}(x+2V),\ \frac{1}{3}(x+2V), \\ \hline \end{array}\end{cases}$$

$[\overline{W}(\overline{V})$ is $W_{n-1}(V_{n-1})]$

$$(V_n,\ V_n)=E\left\{\text{val.}\ \begin{array}{c|cc|cc} & \text{R} & & \text{A} & \\ \hline \text{R} & V_{n-1}, & V_{n-1} & U_{n-1}, & x \\ \text{A} & x, & U_{n-1} & \frac{1}{2}(x+U_{n-1}) & \frac{1}{2}(x+U_{n-1}) \end{array}\right\}$$

where $U_n=\frac{1}{2}(1+U_{n-1}^2)$, $(n\geq 1,\ U_0=0)$.

Common opt. str. for each player is derived, and CEQV is computed as

$U_n = 1/2,\ 0.7417\ \ 0.8364,\ 0.8791,$ for $n=1,4,8,12$, resp.

$V_n = 1/4,\ 0.6468,\ 0.7782,\ 0.8361,$ ibid

$W_n = 1/6\ \ 0.5506,\ 0.7196,\ 0.7936$ ibid

The cases $\langle p_1,\ p_2\rangle=\langle 1,0\rangle$ and $\langle p_1,\ p_2,\ p_3\rangle=\langle \frac{1}{2},\ \frac{1}{2},0\rangle, \langle 1,0,0\rangle$ are also solved (Ref[1~4])

Player with low priority stands at disadvantage, since he remains late in the game, and faces less offers.

The cases where player's aim is Pr. (he gets a r.v. better than opponent) ⟶ max. are solved in Ref[1, 2]. In the 2-player No-Information case, for example, let us

Define state (i,y) to mean that (1) both players remain in the game, and (2) players currently face the r.v. $Y_i = y$. Let $V(i,y)$ be the value of the game in state (i,y), for the n-problem. Note that n is fixed throughout, players should choose A-A in state (n,y) and hence draw of the game cannot occur.

Then t he Opt. Eq. in state (i,y) is

$$V(i,y)=\text{val.}\left\{\begin{array}{c} \\ \text{R} \\ \text{A}\end{array}\begin{array}{cc} \text{R} & \text{A} \\ \hline \mu_{i+1} & 1-g(i,y) \\ g(i,y) & (p-\bar{p})g(i,y)+\bar{p}\end{array}\right]$$

$1\leq i\leq n-1,\quad V(n,y)=p\in[1/2,1],\ \forall y\in\{1,2,\ldots,n\}.$

where $\mu_{i+1}=(i+1)^{-1}\sum_{y'=1}^{i+1}V(i+1,y')$, and

$$g(i,y)=\Pr\{i\text{-th has absolute rank } y, \text{ in state } (i,y)\}$$
$$=\prod_{j=i}^{n}\left(1-\frac{y}{i+j}\right)=\binom{i}{y}\binom{n}{y}=(i)_y\,(n)_y$$

The solution is: Opt. str. pair in state (i, y) is
R-R, R-A, A-A, if $0<g(i,y)<\bar{\mu}_{i+1}$, $\bar{\mu}_{i+1}<g(i,y)<\frac{1}{2}$, $\frac{1}{2}<g(i,y)<1$, resp.

The winning prob. for $n=10$ are computed downward in i until reaching $\mu_1 = V(1,1)$. We obtain

$$Pr.(\text{I wins}) \doteqdot 0.578,\ 0.619,\ \text{for } p=3/4,\ 1,\ \text{resp.}$$

3. Commitee's Selection   I and II observe (X_j, Y_j) $j = 1, \cdots, n$, i.i.d.with $U_{[0,1]} \times U_{[0,1]}$ distribution sequentially one-by-one, and each player chooses R/A. X_j (Y_j) is I's (II's) evaluation of j-th applicant's ability (Ref.[9]). The Opt. Eq. is

$$(u_n, v_n) = E[\text{eq.val}\, M_n(X,Y)], \quad M_n(x,y) = \begin{array}{c|cc} & R & A \\ \hline R & u_{n-1}, v_{n-1} & pu_{n-1}+\bar{p}x,\ pv_{n-1}+\bar{p}y \\ A & px+\bar{p}u_{n-1},\ py+\bar{p}v_{n-1} & x, y \end{array}$$

The solution is : In state $(X_j = x, Y_j = y)$,

I chooses A (R), if $x \geqslant (<)\ u_{n-1}$, indep. of y,
II chooses A (R), if $y \geqslant (<)\ v_{n-1}$, indep. of x,

where

$$u_n = \frac{1}{2}\{pu_{n-1}^2 + \bar{p}(2u_{n-1}-1)v_{n-1} + 1\}, \quad v_n = \text{same with } p \to \bar{p} \text{ and } u \leftrightarrow v.$$

It is shown that $u_n \uparrow u_\infty$, $v_n \uparrow v_\infty$, and (u_∞, v_∞) is a unique root in $(0,1)^2$ of

$$u = \frac{\sqrt{1-\bar{p}v}}{\sqrt{1-\bar{p}v}+\sqrt{\bar{p}\bar{v}}}, \qquad v = \frac{\sqrt{1-pu}}{\sqrt{1-pu}+\sqrt{p\bar{u}}}$$

Convergence is quick:

$u_{10} =$	0.6592,	0.6867,	0.7530,	0.8611,	for $p = 0.5, 0.6, 0.8, 1.0$, resp.
$v_{10} =$	0.6592,	0.6331,	0.5788,	1/2,	ibid
$u_\infty =$	2/3,	0.6946,	0.7663,	1,	ibid.
$v_\infty =$	2/3,	0.6408,	0.5899,	1/2,	ibid

Various interesting open problems arise. ① If X_j (Y_j) is the ability of management (foreign language), then X_j and Y_j are not independent. ② The case where players aim ENV of $(X_j \mid Y_j \geqslant a) \longrightarrow$ max, (Ref.[11]). ③ 3-player game where (X_j, Y_j, Z_j) is observed.

3. High-Hand-Wins Poker.

We first consider a simple n-round poker. Each of two players I and II receives a hand x and y, respectively, in $[0,1]$, according to a uniform distribution, and chooses one of two alternatives Reject or Accept. If choice-pair is R–R, the game proceeds to the next round and both players are dealt new hands x and y. If the choice-pair is A–A showdown occurs and the game ends with I's reward $sgn(x-y)$. If players choose different choices, then arbitration comes in, and forces them to take the same choices as I's (II's) with probability p ($\bar{p}$). This zero-sum game is played in n-rounds, and player I(II) aims to maximize(minimize) the expected reward to I.

Let $\phi_n(x)(\psi_n(y))$ be the probability that player I (II) chooses A on the hand x (y). Also let v_n be the value (for I) of the n-round game. Then we have

$$v_n = \max_{\phi_n(\cdot)} \min_{\psi_n(\cdot)} E_{x,y}[(\bar{\phi}_n(x), \phi_n(x)) M_n(x,y) (\bar{\psi}_n(y), \psi_n(y))^T]$$

where

$$M_n(x,y) = \begin{array}{c c} & \begin{array}{cc} R & A \end{array} \\ \begin{array}{c} R \\ A \end{array} & \begin{pmatrix} v_{n-1} & \bar{p}sgn(x-y) + pv_{n-1} \\ psgn(x-y) + \bar{p}v_{n-1} & sgn(x-y) \end{pmatrix} \end{array}$$

The solution is

$$\phi_n^*(x) = I(x > a_n), \quad \psi_n^*(y) = I(y > \bar{a}_n), \quad v_n = 2a_{n+1} - 1$$

where $\{a_n\}$ is determined by $a_{n+1} = a_n + \frac{1}{2}(p\bar{a}_n^2 - \bar{p}\, a_n^2)$ $(n \geq 1,\ a_1 = \frac{1}{2})$.

We obtain $a_n \uparrow a_\infty = \sqrt{p}/(\sqrt{p} + \sqrt{\bar{p}})$, $v_n \uparrow 2a_\infty - 1 = (\sqrt{p} - \sqrt{\bar{p}})/(\sqrt{p} + \sqrt{\bar{p}})$.

The bilateral-move version, when $p = 1/2$ has an interesting solution. Let w_n be the value of the n-stage game. $w_n < 0$, since I must move first and inevitably gives some information about his true hand. We find that $w_n \downarrow w_\infty = -(1-\sqrt{g})/(1+\sqrt{g}) \doteqdot -0.1197$ where $g = \frac{1}{2}(\sqrt{5}-1) \doteqdot 0.618$, the golden bisection number.
Also we find that disadvantage disappears when $p = 0.6$, i.e. $w_n = 0, \forall n \geq 1$. (Ref.[10]).

3-player High-Hand-Wins poker, under simple-majority rule and with bet $B \geq 0$, is also an interesting open problem.

4. Odd-Man-Wins and Odd-Man-Out.

In the three-player two-choice games there often appear Odd-Man and Even-Men. What is the reasonable partition among players of each X_j ?

Let v_n (w_n) be CEQV of n-stage Odd-Man-Wins (Odd-Man-Out). Then the payoff matrices $M_n(X)$ are

		R by III	A by III
R by I	R by II	$v_{n-1}, v_{n-1}, v_{n-1}$	$0, \quad 0, \quad x$
	A by II	$0, \quad x, \quad 0$	$x, \quad 0, \quad 0$
A by I	R by II	$x, \quad 0, \quad 0$	$0, \quad x, \quad 0$
	A by II	$0, \quad 0, \quad x$	$x/3, \quad x/3, \quad x/3$

$n \geqq 1, \ v_1 = \frac{1}{6}$,

		R by III	A by III
R by I	R by II	$w_{n-1}, w_{n-1}, w_{n-1}$	$x/2, \quad x/2, \quad 0$
	A by II	$x/2, \quad 0, \quad x/2$	$0, \quad x/2, \quad x/2$
A by I	R by II	$0, \quad x/2, \quad x/2$	$x/2, \quad 0, \quad x/2$
	A by II	$x/2, \quad x/2, \quad 0$	$x/3, \quad x/3, \quad x/3$

$n \geqq 1, \ w_1 = \frac{1}{6}$,

for Odd-Man-Wins, Odd-Man-Out, resp.

Each player must think about : (1) He wants to become the odd-man (an even-man), when the game is Odd-Man-Wins (Odd-Man-Out), especially when he faces a very large X_j, and (2) Since X_j is a random variable, he can expect a larger one may come up in the future.

It is shown that (Ref.[6]), $v_n \uparrow v_\infty \doteqdot 0.205$ and $w_n \downarrow w_\infty \doteqdot 0.160$. So,multi-stage play yields each player a merit of size $v_\infty - \frac{1}{6} \doteqdot 0.039$ and a demerit of size $\frac{1}{6} - w_\infty \doteqdot 0.0064$.

The extension to the many-player two-choice simple-majority games is an interesting open problem.

The case where the odd-man has priority p, and the even-men has priority $\bar{p}/2$ is solved in Ref.[7]. When p = $1/3$, CEQV = $\frac{1}{3}\mu_n$, where $\{\mu_n\}$ is the Moser's sequence. When p = 0 (1), the game reduces to Odd-Man-Out (Odd-Man-Wins).

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In some of these, names of co-author(s) are omitted.

* 3-26-4 Midorigaoka, Toyonaka, Osaka, 560-0002 Japan.
Fax: +81-6-6856-2314 E-mail: minorus@tcct.zaq.ne.jp