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## Online Sparse Bandits

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# Online Sparse bandit

## What is a zero-sum Matrix Game (MG) ?

M = KxK matrix, coefficients in [0,1]  
 Player 1 chooses i in {1,2,3,...,K}  
 Player 2 chooses j in {1,2,3,...,K}  
 Player 1 gets reward Mij  
 Player 2 gets reward 1-Mij

## Is solving a MG hard ?

= polynomial time (by linear programming)  
 best known coef 3.5

## How to find approximate solutions ?

Grigoriadis & Khachiyan or Exp3 or Inf:  
 time  $O(K \log K / \epsilon^2)$  with proba  $\frac{1}{2}$   
 (Auer et al, Audibert et al, Grigoriadis et al)

## Sparse versions ?

Very often,  $(x^*, y^*)$  is very sparse; plenty of 0's.  
 How to benefit from this ?  
 Algo. in Flory et al.:

1. Approximate solving by t iterations of EXP3
2. Remove small components (keep only components  $\geq (\max(tx))^{(4/5)} / t$ )
3. Re-normalize  
 $\implies$  no proof

## We propose the following online version $\implies$ (EXP3 recalled below...)

**Algorithm 1** EXP3 algorithm for iteration  $t$  with  $K$  arms.

```

Initialise  $\forall i, p(i) = \frac{1}{K}, n(i) = 0, S(i) = 0; t = 0$ 
while  $t < T$  do
  Arm  $i$  is chosen with probability  $p(i)$ 
   $n(i) \leftarrow n(i) + 1$ 
  Receive reward  $r$ 
   $t \leftarrow t + 1$ 
   $S_i$  modified by the update formula  $S_i \leftarrow S_i + r/p(i)$  (and  $S_j$  for  $j \neq i$  is not modified).
   $\forall i, p(i) = 1/(K\sqrt{t}) + (1 - 1/\sqrt{t}) \times \exp(S_i/\sqrt{t}) / \sum_j \exp(S_j/\sqrt{t})$ 
end while
return  $n$ 
    
```

## What means "solving" a MG ?

Strategy x: probability distribution on {1,2,3,...,K}  
 Strategy y: probability distribution on {1,2,3,...,K}  
 Expected Reward:

$$R(x,y) = \sum_{i,j} M_{ij} x_i y_j$$

Nash equilibrium:

$$(x^*, y^*) = \text{Nash}$$

$\iff$  for all  $(x,y)$

$$R(x, y^*) \geq R(x^*, y^*) \geq R(x^*, y)$$

## Approximate solving ?

$(x^*, y^*)$   $\epsilon$ -approximate Nash equilibrium if for all  $(x,y), R(x, y^*) + \epsilon \geq R(x^*, y^*) \geq R(x^*, y) - \epsilon$

## So what ?

There is a *offline* solution (i.e. sparsity used at the end).  
 Can we use it online ?

**Algorithm 3** onEXP3, an online EXP3 algorithm with a cut solely based on  $T$ .

```

Initialise  $\forall i, p(i) = \frac{1}{K}, n(i) = 0, S(i) = 0; t = 0$ 
while  $t < T$  do
  Arm  $i$  is chosen with probability  $p(i)$ 
   $n(i) \leftarrow n(i) + 1$ 
   $t \leftarrow t + 1$ 
  Receive reward  $r$ 
   $S_i$  modified by the update formula  $S_i \leftarrow S_i + r/p(i)$ 
   $\forall i, p(i) = 1/(K\sqrt{t}) + (1 - 1/\sqrt{t}) \times \exp(S_i/\sqrt{t}) / \sum_j \exp(S_j/\sqrt{t})$ 
  if  $x_i > \lceil \frac{t}{K} \rceil$  and  $x_i < (b_1 \times T^\delta \times (\frac{t}{T})^\beta)$  then
    Remove arm  $i$ 
  end if
  if every arm has been pruned then
    Use plain EXP3
  end if
  Renormalize:  $p = p / \sum_i p(i)$ 
end while
Execute the truncation TEXP3 as presented in 2.3
return  $n$ 
    
```

## Conclusions ?

(i) it works (see numbers in paper)      (ii) theory missing      (iii) better (parameter-free ?) versions



$\iff$  application: Urban Rivals (free, you can test!)  
 Next application: Pokemon  $\implies$

