



Online Sparse Bandits

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Online Sparse bandit

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

$M = K \times K$ matrix, coefficients in $[0,1]$
Player 1 chooses i in $\{1,2,3,\dots,K\}$
Player 2 chooses j in $\{1,2,3,\dots,K\}$
Player 1 gets reward M_{ij}
Player 2 gets reward $1 - M_{ij}$

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
==> no proof

We propose the following online version ==> (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 $\{1,2,3,\dots,K\}$
Strategy y : probability distribution on $\{1,2,3,\dots,K\}$
Expected Reward:

$$R(x,y) =$$

$$E M_{ij} \mid (i,j) \sim x,y$$

Nash equilibrium:

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

\Leftrightarrow for all (x,y)

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

Approximate solving ?

(x^*, y^*) ϵ -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



\Leftarrow application: Urban Rivals
(free, you can test!)
Next application: Pokemon ==>

