بسم الله الرحمن الرحیم

یادگیری بندیت

جلسه ۳:

بندیت تصادفی با تعداد دسته متناهی

ترم بهار ۱۳۹۹ - ۱۴۰۰

الگوریتم «گردش سپس تعهد»

Explore Then Commit (ETC)

مسئله بندیت تصادفی

۱ـ اگر σ=1 نبود
۲- σ را می‌دانیم
۳- σها برابر نبودند

گاوسی با
σ=1

$\mathcal{E}^{k}_{\mathrm{SG}}(1)$

مسئله بندیت تصادفی

$$\mathcal{E}_{\mathrm{SG}}^{k}(1)$$

گاوسی با
σ=1

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۳ـ σها برابر نبودند

تعداد
دسته

تعداد دفعات
دسته i

$$R_n = \sum_{i=1}^{k} \Delta_i \mathbb{E}\left[T_i(n)\right]$$

$$\Delta_i = \mu^* - \mu_i$$

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انتخاب مرحله i

$$A_t = \begin{cases} (t \bmod k) + 1, & \text{if } t \leq mk; \\ \operatorname{argmax}_i \hat{\mu}_i(mk), & t > mk. \end{cases}$$

m مرحله بگرد

سپس تعهد

$$\hat{\mu}_i(t) = \frac{1}{T_i(t)} \sum_{s=1}^{t} \mathbb{I}\{A_s = i\} X_s$$

قضیه

$$\Delta_i = \mu^* - \mu_i$$

$$R_n \leq m \sum_{i=1}^{k} \Delta_i + (n - mk) \sum_{i=1}^{k} \Delta_i \exp\left(-\frac{m\Delta_i^2}{4}\right)$$

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$$R_n = \sum_{i=1}^{k} \Delta_i \mathbb{E}\left[T_i(n)\right]$$

$$\leq m + (n - mk)\mathbb{P}\left(\hat{\mu}_i(mk) \geq \max_{j \neq i} \hat{\mu}_j(mk)\right)$$

$$R_n \leq m \sum_{i=1}^{k} \Delta_i + (n - mk) \sum_{i=1}^{k} \Delta_i \exp\left(-\frac{m\Delta_i^2}{4}\right)$$

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$\sqrt{2/m}$–زیرگوسی

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$\sqrt{2/m}$-زیرگوسی

$$\leq \exp\left(-\frac{m\Delta_i^2}{4}\right)$$

حالت k=2:

$$R_n \leq m \sum_{i=1}^{k} \Delta_i + (n - mk) \sum_{i=1}^{k} \Delta_i \exp\left(-\frac{m\Delta_i^2}{4}\right)$$

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$$m = \max\left\{1, \left\lceil \frac{4}{\Delta^2} \log\left(\frac{n\Delta^2}{4}\right) \right\rceil \right\}$$

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$$\leq \min\left\{n\Delta, \frac{4}{\Delta} \log\left(\frac{n\Delta^2}{4}\right) + \frac{4}{\Delta}\right\}$$

حدودا

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حدودا

$$\leq \Delta + C\sqrt{n},$$

حالت k=2:

$$
\begin{aligned}
R_n &\le m\sum_{i=1}^{k}\Delta_i + (n-mk)\sum_{i=1}^{k}\Delta_i \exp\left(-\frac{m\Delta_i^2}{4}\right)\\
&\le m\Delta + n\Delta \exp\left(-\frac{m\Delta^2}{4}\right)
\end{aligned}
$$

$$m = \max\left\{1, \left\lceil \frac{4}{\Delta^2}\log\left(\frac{n\Delta^2}{4}\right)\right\rceil\right\}$$

$$\le \min\left\{n\Delta, \frac{4}{\Delta}\log\left(\frac{n\Delta^2}{4}\right) + \frac{4}{\Delta}\right\}$$

حدودا

$$
\begin{aligned}
&\le \Delta + C\sqrt{n},\\
&\le 1 + C\sqrt{n},
\end{aligned}
$$

برای Δ ≤ ۱

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$$\leq m\Delta + n\Delta\exp\left(-\frac{m\Delta^2}{4}\right)$$

$$m = \max\left\{1, \left\lceil \frac{4}{\Delta^2}\log\left(\frac{n\Delta^2}{4}\right)\right\rceil\right\}$$

$$\leq \min\left\{n\Delta, \frac{4}{\Delta}\log\left(\frac{n\Delta^2}{4}\right) + \frac{4}{\Delta}\right\}$$

حدودا

$$\leq \Delta + C\sqrt{n},$$

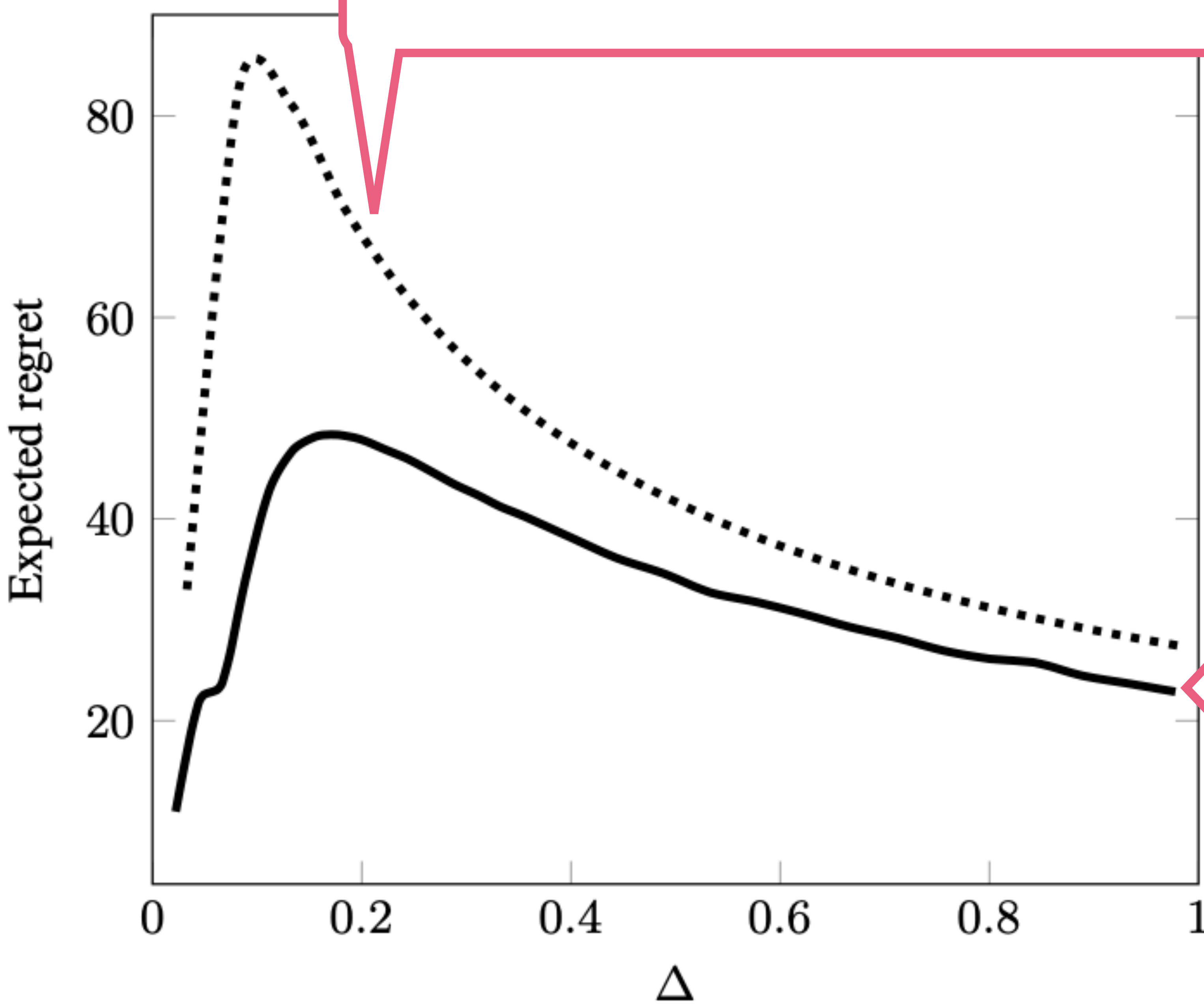
$$\leq 1 + C\sqrt{n},$$

برای Δ ≤ ۱

بدترین حالت،
بدون مسئله،
مستقل از مسئله،

بدون فاصله،

$$R_n \leq \min\left\{n\Delta,\ \Delta + \frac{4}{\Delta}\left(1 + \max\left\{0,\ \log\left(\frac{n\Delta^2}{4}\right)\right\}\right)\right\}$$



الگوریتم «گردش سپس تعهد» با

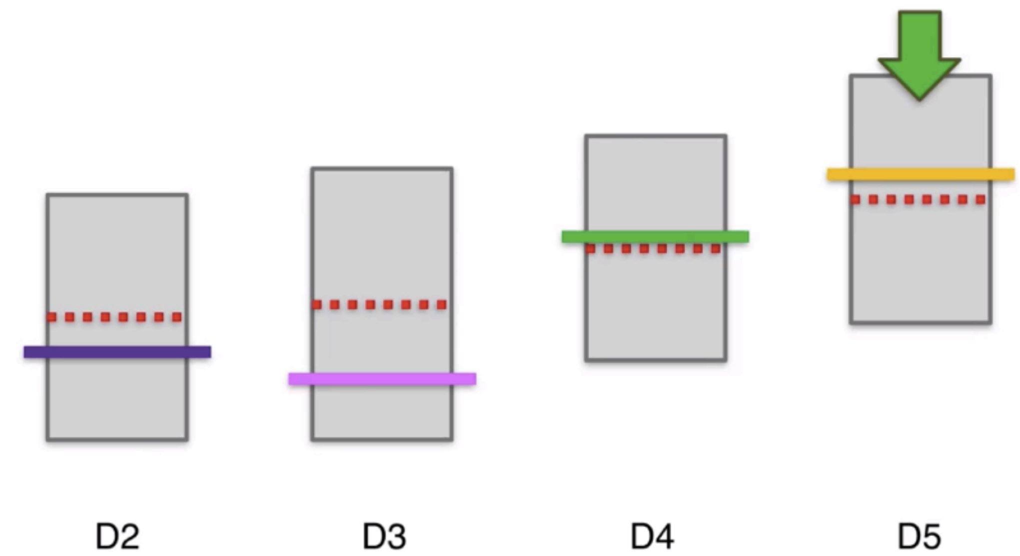
$$m = \max\left\{1,\ \left\lceil \frac{4}{\Delta^2} \log\left(\frac{n\Delta^2}{4}\right) \right\rceil\right\}$$

نسخه‌های الگوریتم «گردش سپس تعهد»

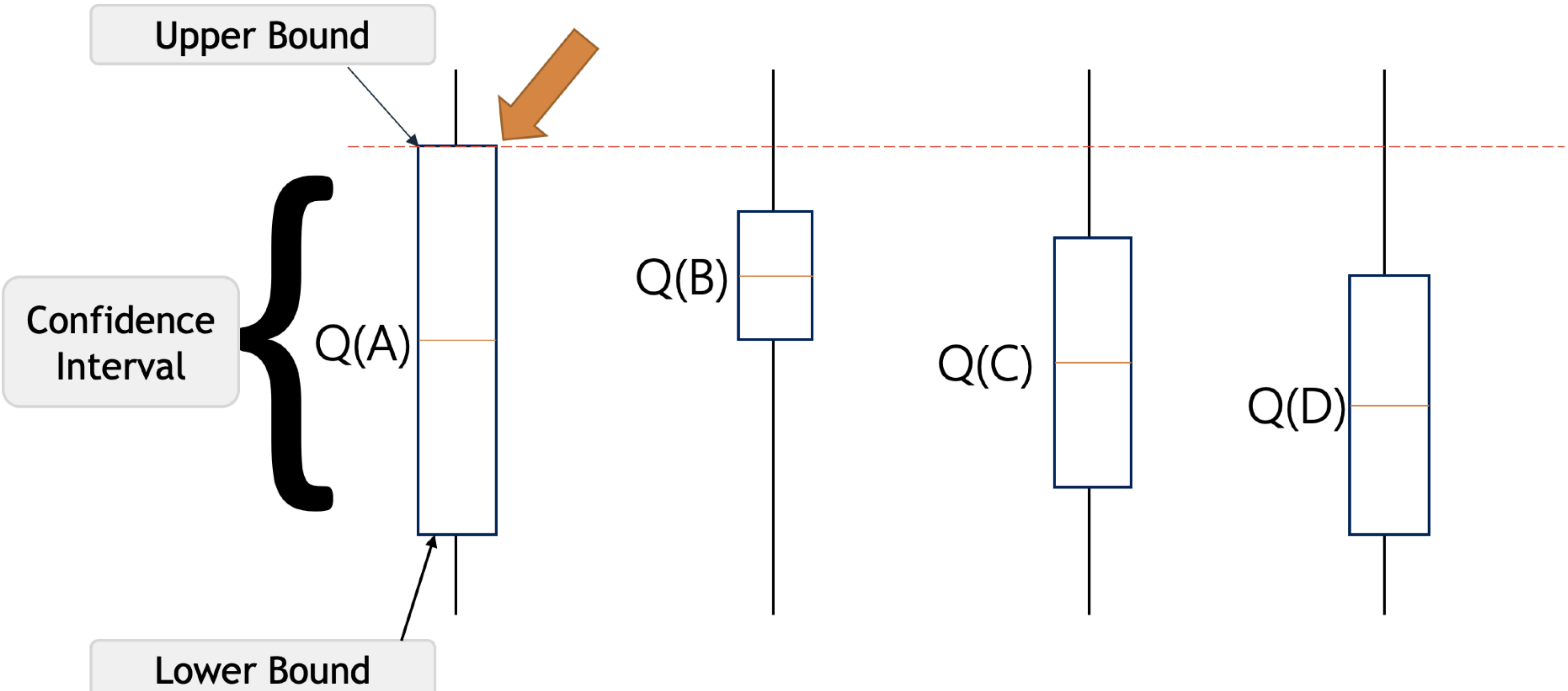
- اگر n را ندانیم:
  - فن دوبرابر کردن
- اگر Δ را ندانیم:
  - m مستقل از Δ، آنگاه $R_n(\nu) \leq (\Delta_\nu + C)n^{2/3}$
- وابسته به داده:
  - $$R_n(\nu) \leq \Delta_\nu + \frac{C \log n}{\Delta_\nu} \leq \Delta_\nu + C\sqrt{n \log(n)}$$

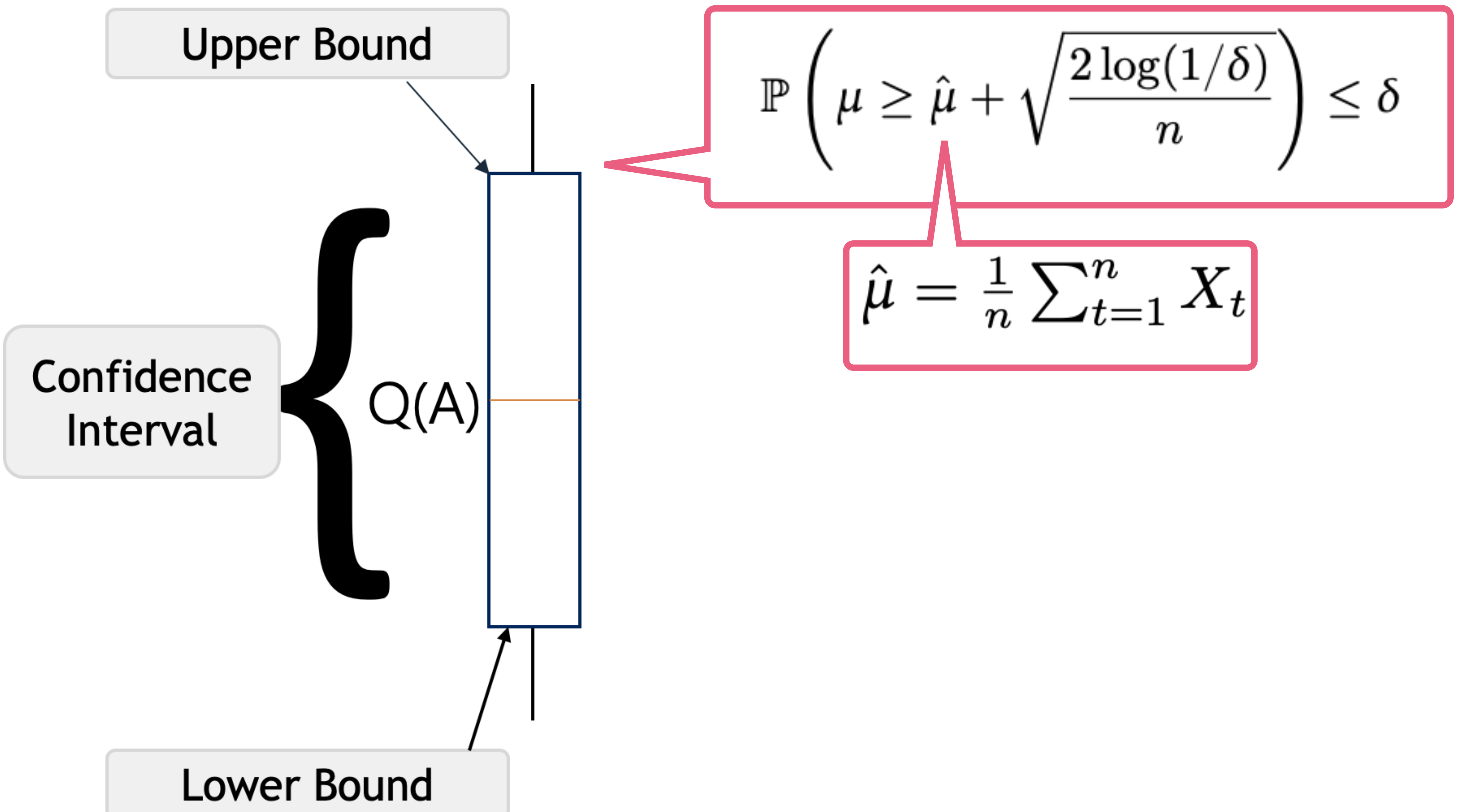
الگوریتم «کران بالای اطمینان»

Upper Confidence Bound (UCB)



ایده UCB





Upper Bound
Confidence Interval
Q(A)
Lower Bound
$\mathbb{P}\left(\mu \geq \hat{\mu} + \sqrt{\frac{2\log(1/\delta)}{n}}\right) \leq \delta$
$\hat{\mu} = \frac{1}{n}\sum_{t=1}^{n} X_t$

الگوریتم UCB(δ)

$$= \begin{cases} \infty & \text{if } T_i(t-1) = 0 \\ \hat{\mu}_i(t-1) + \sqrt{\frac{2\log(1/\delta)}{T_i(t-1)}} & \text{otherwise.} \end{cases}$$

Input k and δ

for $t \in 1, \ldots, n$ **do**

Choose action $A_t = \text{argmax}_i \, \text{UCB}_i(t-1, \delta)$

Observe reward X_t and update upper confidence bounds

end for

الگوریتم UCB(δ)

اندیس دسته i:

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:i اندیس دسته

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Observe reward X_t and update upper confidence bounds

end for

چرا کار می‌کند؟

برای الگوریتم UCB(1/n²)

$$\boxed{R_n \leq 3\sum_{i=1}^{k}\Delta_i + \sum_{i:\Delta_i>0}\frac{16\log(n)}{\Delta_i}.}$$

اثبات:

$$R_n = \sum_{i=1}^{k} \Delta_i \mathbb{E}\left[T_i(n)\right]$$

اثبات:

$$R_n = \sum_{i=1}^{k} \Delta_i \mathbb{E}\left[T_i(n)\right]$$

$$= \mathbb{E}\left[\mathbb{I}\left\{G_i\right\} T_i(n)\right] + \mathbb{E}\left[\mathbb{I}\left\{G_i^c\right\} T_i(n)\right] \leq u_i + \mathbb{P}\left(G_i^c\right) n$$

؟

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$$G_i = \left\{\mu_1 < \min_{t \in [n]} \mathrm{UCB}_1(t, \delta)\right\} \cap \left\{\hat{\mu}_{i u_i} + \sqrt{\frac{2}{u_i} \log\left(\frac{1}{\delta}\right)} < \mu_1\right\}$$

اثبات:

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$$\mathbb{P}\left(G_i^c\right)$$

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$$\leq n\delta.$$

$$\mathbb{P}\left(G_i^c\right)$$

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$$\mathbb{P}\left(G_i^c\right)$$

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$$\mathbb{P}\left(\hat{\mu}_{iu_i} - \mu_i \geq \Delta_i - \sqrt{\frac{2\log(1/\delta)}{u_i}}\right)$$

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$$\mathbb{P}\left(G_i^c\right)$$

$$\leq n\delta.$$

$$\mathbb{P}\left(\hat{\mu}_{iu_i} - \mu_i \geq \Delta_i - \sqrt{\frac{2\log(1/\delta)}{u_i}}\right)$$

$$\leq \mathbb{P}\left(\hat{\mu}_{iu_i} - \mu_i \geq c\Delta_i\right) \leq \exp\left(-\frac{u_i c^2 \Delta_i^2}{2}\right)$$

اثبات:

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$$\mathbb{P}\left(G_i^c\right)$$

$$\leq n\delta.$$

$$\mathbb{P}\left(\hat{\mu}_{iu_i} - \mu_i \geq \Delta_i - \sqrt{\frac{2\log(1/\delta)}{u_i}}\right)$$

$$\leq \mathbb{P}\left(\hat{\mu}_{iu_i} - \mu_i \geq c\Delta_i\right) \leq \exp\left(-\frac{u_i c^2 \Delta_i^2}{2}\right)$$

$$\Delta_i - \sqrt{\frac{2\log(1/\delta)}{u_i}} \geq c\Delta_i$$

$$R_n \leq 3 \sum_{i=1}^{k} \Delta_i + \sum_{i:\Delta_i > 0} \frac{16 \log(n)}{\Delta_i}.$$

اثبات:

$$R_n = \sum_{i=1}^{k} \Delta_i \mathbb{E}\left[T_i(n)\right]$$

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$$\mathbb{P}\left(G_i^c\right) \leq n\delta + \exp\left(-\frac{u_i c^2 \Delta_i^2}{2}\right)$$

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اثبات:

$$R_n = \sum_{i=1}^{k}\Delta_i\mathbb{E}\left[T_i(n)\right]$$

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$$\mathbb{P}\left(G_i^c\right) \leq n\delta + \exp\left(-\frac{u_ic^2\Delta_i^2}{2}\right)$$

$$\leq 3 + \frac{16\log(n)}{\Delta_i^2}.$$

برای

$$u_i = \left\lceil\frac{2\log(1/\delta)}{(1-c)^2\Delta_i^2}\right\rceil \quad \delta = 1/n^2 \quad c = 1/2,$$

$$\mathbb{P}\left(G_i^c\right) \leq n\delta + \exp\left(-\frac{u_i c^2 \Delta_i^2}{2}\right)$$

$$\mathbb{E}\left[T_i(n)\right] \leq u_i + n\left(n\delta + \exp\left(-\frac{u_i c^2 \Delta_i^2}{2}\right)\right)$$

$$\mathbb{E}[T_i(n)] \leq u_i + 1 + n^{1-2c^2/(1-c)^2} = \boxed{\left\lceil \frac{2\log(n^2)}{(1-c)^2\Delta_i^2} \right\rceil} + 1 + n^{1-2c^2/(1-c)^2}$$

$$\mathbb{E}\left[T_i(n)\right] \leq 3 + \frac{16\log(n)}{\Delta_i^2}$$

$$R_n \leq 3\sum_{i=1}^{k}\Delta_i + \sum_{i:\Delta_i>0}\frac{16\log(n)}{\Delta_i}.$$

$$R_n \leq 8\sqrt{nk\log(n)} + 3\sum_{i=1}^{k}\Delta_i$$

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$$R_n = \sum_{i=1}^{k}\Delta_i\mathbb{E}\left[T_i(n)\right] = \sum_{i:\Delta_i<\Delta}\Delta_i\mathbb{E}\left[T_i(n)\right] + \sum_{i:\Delta_i\geq\Delta}\Delta_i\mathbb{E}\left[T_i(n)\right]$$

$$R_n \leq 3\sum_{i=1}^{k}\Delta_i + \sum_{i:\Delta_i>0}\frac{16\log(n)}{\Delta_i}.$$

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$n\Delta$

$$R_n \leq 3 \sum_{i=1}^{k} \Delta_i + \sum_{i:\Delta_i > 0} \frac{16 \log(n)}{\Delta_i}.$$

$$R_n \leq 8\sqrt{nk \log(n)} + 3 \sum_{i=1}^{k} \Delta_i$$

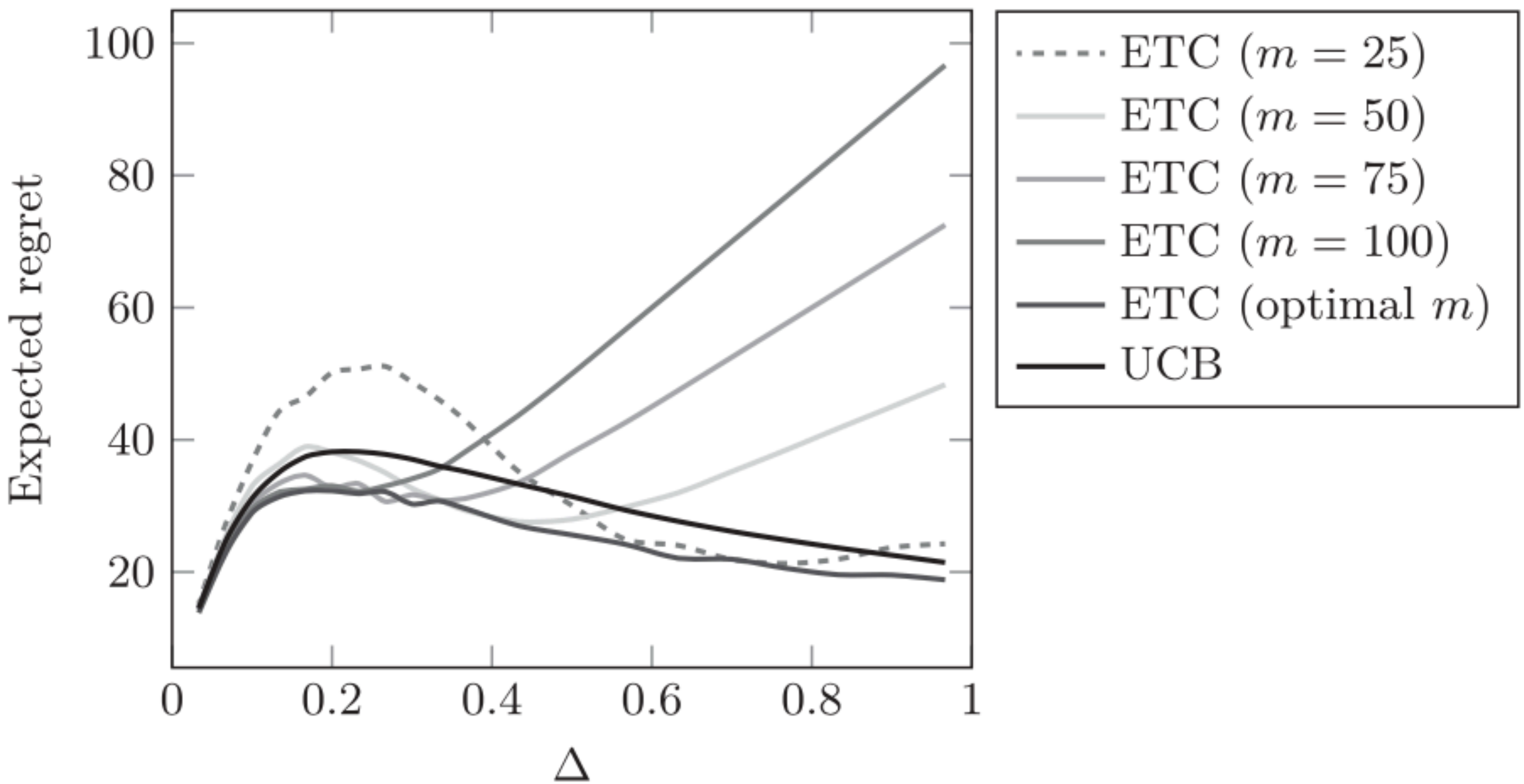
$$R_n = \sum_{i=1}^{k} \Delta_i \mathbb{E}\left[T_i(n)\right] = \sum_{i:\Delta_i < \Delta} \Delta_i \mathbb{E}\left[T_i(n)\right] + \sum_{i:\Delta_i \geq \Delta} \Delta_i \mathbb{E}\left[T_i(n)\right]$$

$$n\Delta$$

$$\frac{16k \log(n)}{\Delta} + 3 \sum_{i} \Delta_i$$

$$R_n \leq 8\sqrt{nk\log(n)} + 3\sum_{i=1}^{k}\Delta_i$$

کران پایین: $O(\sqrt{nk})$



Expected regret
100
80
60
40
20
0
0.2
0.4
0.6
0.8
1
Δ
ETC ($m = 25$)
ETC ($m = 50$)
ETC ($m = 75$)
ETC ($m = 100$)
ETC (optimal m)
UCB

پایان