Technique 5: Randomized Rounding

One round of randomized rounding:
Pick set S_j uniformly at random with probability $1 - x_j$ (for all j).

Version A: Repeat rounds until you have a cover.

Version B: Repeat for s rounds. If you have a cover STOP.
Otherwise, repeat the whole algorithm.

Technique 5: Randomized Rounding

One round of randomized rounding:
Pick set S_j uniformly at random with probability $1 - x_j$ (for all j).

Version A: Repeat rounds until you have a cover.

Version B: Repeat for s rounds. If you have a cover STOP.
Otherwise, repeat the whole algorithm.

Technique 5: Randomized Rounding

One round of randomized rounding:
Pick set S_j uniformly at random with probability $1 - x_j$ (for all j).

Version A: Repeat rounds until you have a cover.

Version B: Repeat for s rounds. If you have a cover STOP.
Otherwise, repeat the whole algorithm.

Probability that $u \in U$ is not covered (in one round):

$$\Pr[u \text{ not covered in one round}]$$

Probability that $u \in U$ is not covered (in one round):

$$\begin{aligned}\Pr[u \text{ not covered in one round}] \\ = \prod_{j: u \in S_j} (1 - x_j)\end{aligned}$$

Probability that $u \in U$ is not covered (in one round):

$$\begin{aligned}\Pr[u \text{ not covered in one round}] \\ &= \prod_{j:u\in S_j}(1-x_j) \le \prod_{j:u\in S_j} e^{-x_j}\end{aligned}$$

Probability that $u \in U$ is not covered (in one round):

$$\begin{aligned}
&\Pr[u \text{ not covered in one round}] \\
&\qquad = \prod_{j:u\in S_j} (1 - x_j) \le \prod_{j:u\in S_j} e^{-x_j} \\
&\qquad = e^{-\sum_{j:u\in S_j} x_j}
\end{aligned}$$

Probability that $u \in U$ is not covered (in one round):

$$\begin{aligned}
&\Pr[u \text{ not covered in one round}] \\
&\qquad = \prod_{j:u\in S_j} (1-x_j) \le \prod_{j:u\in S_j} e^{-x_j} \\
&\qquad = e^{-\sum_{j:u\in S_j} x_j} \le e^{-1} \enspace .
\end{aligned}$$

Probability that $u \in U$ is not covered (in one round):

$$\begin{aligned}
&\Pr[u \text{ not covered in one round}] \\
&\qquad = \prod_{j:u\in S_j}(1-x_j) \le \prod_{j:u\in S_j} e^{-x_j} \\
&\qquad = e^{-\sum_{j:u\in S_j} x_j} \le e^{-1} \enspace .
\end{aligned}$$

Probability that $u \in U$ is not covered (after ℓ rounds):

$$\Pr[u \text{ not covered after } \ell \text{ round}] \le \frac{1}{e^{\ell}} \enspace .$$

$\Pr[\exists u \in U$ not covered after ℓ round$]$

$$\Pr[\exists u \in U \text{ not covered after } \ell \text{ round}]$$
$$= \Pr[u_1 \text{ not covered} \vee u_2 \text{ not covered} \vee \ldots \vee u_n \text{ not covered}]$$

$$
\begin{aligned}
&\Pr[\exists u \in U \text{ not covered after } \ell \text{ round}] \\
&\quad = \Pr[u_1 \text{ not covered} \vee u_2 \text{ not covered} \vee \ldots \vee u_n \text{ not covered}] \\
&\quad \le \sum_i \Pr[u_i \text{ not covered after } \ell \text{ rounds}]
\end{aligned}
$$

$$\begin{aligned}
&\Pr[\exists u \in U \text{ not covered after } \ell \text{ round}] \\
&\qquad = \Pr[u_1 \text{ not covered} \vee u_2 \text{ not covered} \vee \ldots \vee u_n \text{ not covered}] \\
&\qquad \le \sum_i \Pr[u_i \text{ not covered after } \ell \text{ rounds}] \le ne^{-\ell} \enspace .
\end{aligned}$$

$$
\begin{aligned}
&\Pr[\exists u \in U \text{ not covered after } \ell \text{ round}] \\
&\quad = \Pr[u_1 \text{ not covered} \vee u_2 \text{ not covered} \vee \ldots \vee u_n \text{ not covered}] \\
&\quad \le \sum_i \Pr[u_i \text{ not covered after } \ell \text{ rounds}] \le ne^{-\ell}\enspace .
\end{aligned}
$$

Lemma 5

With high probability $\mathcal{O}(\log n)$ *rounds suffice.*

$$
\begin{aligned}
&\Pr[\exists u \in U \text{ not covered after } \ell \text{ round}] \\
&\qquad = \Pr[u_1 \text{ not covered} \vee u_2 \text{ not covered} \vee \ldots \vee u_n \text{ not covered}] \\
&\qquad \le \sum_i \Pr[u_i \text{ not covered after } \ell \text{ rounds}] \le ne^{-\ell} \enspace .
\end{aligned}
$$

Lemma 5

With high probability $\mathcal{O}(\log n)$ rounds suffice.

With high probability:

For any constant α the number of rounds is at most $\mathcal{O}(\log n)$ with probability at least $1 - n^{-\alpha}$.

Proof: We have

$$\Pr[\#\text{rounds} \geq (\alpha+1)\ln n] \leq ne^{-(\alpha+1)\ln n} = n^{-\alpha} \enspace .$$

Expected Cost

- Version A.
  Repeat for $s = (\alpha + 1) \ln n$ rounds. If you don't have a cover simply take all sets.

Expected Cost

- Version A.
  Repeat for $s = (\alpha + 1)\ln n$ rounds. If you don't have a cover simply take all sets.

  $E[\text{cost}]$

Expected Cost

- Version A.
  Repeat for $s = (\alpha + 1)\ln n$ rounds. If you don't have a cover simply take all sets.

$$E[\text{cost}] \le (\alpha+1)\ln n \cdot \text{cost}(LP) + (\sum_j w_j)n^{-\alpha}$$

Expected Cost

- Version A.
  Repeat for $s = (\alpha + 1)\ln n$ rounds. If you don't have a cover simply take all sets.

$$E[\text{cost}] \le (\alpha+1)\ln n \cdot \text{cost}(LP) + (\sum_j w_j)n^{-\alpha} = \mathcal{O}(\ln n)\cdot \text{OPT}$$

Expected Cost

- Version A.

  Repeat for $s = (\alpha + 1)\ln n$ rounds. If you don't have a cover simply take all sets.

$$E[\text{cost}] \le (\alpha+1)\ln n \cdot \text{cost}(LP) + (\sum_j w_j)n^{-\alpha} = \mathcal{O}(\ln n) \cdot \text{OPT}$$

  If the weights are polynomially bounded (smallest weight is 1), sufficiently large α and OPT at least 1.

Expected Cost

- Version B.
  Repeat for $s = (\alpha + 1) \ln n$ rounds. If you don't have a cover simply repeat the whole process.

$$E[\text{cost}] =$$

Expected Cost

- Version B.
  Repeat for $s = (\alpha + 1)\ln n$ rounds. If you don't have a cover simply repeat the whole process.

$$E[\text{cost}] = \Pr[\text{success}] \cdot E[\text{cost} \mid \text{success}]$$
$$\qquad + \Pr[\text{no success}] \cdot E[\text{cost} \mid \text{no success}]$$

Expected Cost

- Version B.
  Repeat for $s = (\alpha + 1) \ln n$ rounds. If you don't have a cover simply repeat the whole process.

$$\begin{aligned} E[\text{cost}] &= \Pr[\text{success}] \cdot E[\text{cost} \mid \text{success}] \\ &\quad + \Pr[\text{no success}] \cdot E[\text{cost} \mid \text{no success}] \end{aligned}$$

This means

$E[\text{cost} \mid \text{success}]$

Expected Cost

- Version B.
  Repeat for $s = (\alpha + 1)\ln n$ rounds. If you don't have a cover simply repeat the whole process.

$$E[\text{cost}] = \Pr[\text{success}] \cdot E[\text{cost} \mid \text{success}] + \Pr[\text{no success}] \cdot E[\text{cost} \mid \text{no success}]$$

This means

$$E[\text{cost} \mid \text{success}] = \frac{1}{\Pr[\text{sucess}]}\Big(E[\text{cost}] - \Pr[\text{no success}] \cdot E[\text{cost} \mid \text{no success}]\Big)$$

Expected Cost

- Version B.
  Repeat for $s = (\alpha + 1)\ln n$ rounds. If you don't have a cover simply repeat the whole process.

$$\begin{aligned} E[\text{cost}] = {} & \Pr[\text{success}] \cdot E[\text{cost} \mid \text{success}] \\ & + \Pr[\text{no success}] \cdot E[\text{cost} \mid \text{no success}] \end{aligned}$$

This means

$E[\text{cost} \mid \text{success}]$

$$\begin{aligned} &= \frac{1}{\Pr[\text{sucess}]}\Big(E[\text{cost}] - \Pr[\text{no success}] \cdot E[\text{cost} \mid \text{no success}]\Big) \\ &\le \frac{1}{\Pr[\text{sucess}]} E[\text{cost}] \le \frac{1}{1 - n^{-\alpha}} (\alpha + 1)\ln n \cdot \text{cost}(LP) \end{aligned}$$

Expected Cost

- Version B.
  Repeat for $s = (\alpha + 1)\ln n$ rounds. If you don't have a cover simply repeat the whole process.

$$
\begin{aligned}
E[\text{cost}] = \Pr[\text{success}] \cdot E[\text{cost} \mid \text{success}] \\
+ \Pr[\text{no success}] \cdot E[\text{cost} \mid \text{no success}]
\end{aligned}
$$

This means

$$
\begin{aligned}
&E[\text{cost} \mid \text{success}] \\
&\quad = \frac{1}{\Pr[\text{sucess}]}\Big(E[\text{cost}] - \Pr[\text{no success}] \cdot E[\text{cost} \mid \text{no success}]\Big) \\
&\quad \le \frac{1}{\Pr[\text{sucess}]} E[\text{cost}] \le \frac{1}{1 - n^{-\alpha}} (\alpha + 1)\ln n \cdot \text{cost}(LP) \\
&\quad \le 2(\alpha + 1)\ln n \cdot \text{OPT}
\end{aligned}
$$

Expected Cost

- Version B.
  Repeat for $s = (\alpha + 1)\ln n$ rounds. If you don't have a cover simply repeat the whole process.

$$
\begin{aligned}
E[\text{cost}] = \Pr[\text{success}] \cdot E[\text{cost} \mid \text{success}] \\
+ \Pr[\text{no success}] \cdot E[\text{cost} \mid \text{no success}]
\end{aligned}
$$

This means

$E[\text{cost} \mid \text{success}]$

$$
\begin{aligned}
&= \frac{1}{\Pr[\text{sucess}]}\Big(E[\text{cost}] - \Pr[\text{no success}] \cdot E[\text{cost} \mid \text{no success}]\Big) \\
&\leq \frac{1}{\Pr[\text{sucess}]} E[\text{cost}] \leq \frac{1}{1 - n^{-\alpha}} (\alpha + 1)\ln n \cdot \text{cost}(LP) \\
&\leq 2(\alpha + 1)\ln n \cdot \text{OPT}
\end{aligned}
$$

for $n \geq 2$ and $\alpha \geq 1$.

Randomized rounding gives an $\mathcal{O}(\log n)$ approximation. The running time is polynomial with high probability.

Theorem 6 (without proof)

There is no approximation algorithm for set cover with approximation guarantee better than $\frac{1}{2}\log n$ unless NP has quasi-polynomial time algorithms (algorithms with running time $2^{\mathrm{poly}(\log n)}$).

Randomized rounding gives an $\mathcal{O}(\log n)$ approximation. The running time is polynomial with high probability.

Theorem 6 (without proof)

There is no approximation algorithm for set cover with approximation guarantee better than $\frac{1}{2}\log n$ unless NP has quasi-polynomial time algorithms (algorithms with running time $2^{\mathrm{poly}(\log n)}$).

Techniques:

- Deterministic Rounding
- Rounding of the Dual
- Primal Dual
- Greedy
- Randomized Rounding
- Local Search
- Rounding the Data + Dynamic Programming