Improving Community-Participated Patrol for Anti-Poaching






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Anti-Poaching

- Security Games
  - A framework in game theory for optimizing resource allocation to protect valuable targets against adversarial threats.
- Anti-poaching
  - resources: rangers
  - targets: wildlife populations
  - adversaries: poachers

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  - resources: rangers and **community members**
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RACPP

- Resources Allocation of Community Participated Patrol

- Two types of patrol resources
  - Professional rangers
    - distribute efforts among multiple targets
  - Community members (villagers)
    - patrol a single target (less flexible)

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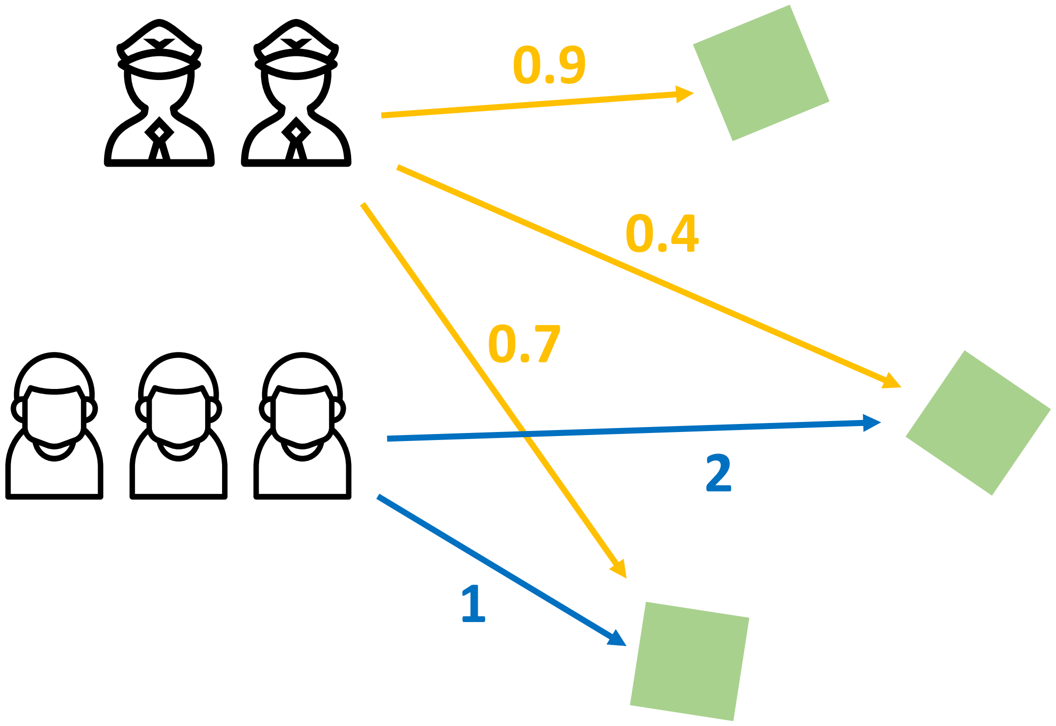

RACPP

- Resources Allocation of Community Participated Patrol

- n targets
- Rewards and penalties
  - If target i is successfully defended
    - defenders receive reward R_i^{d}
    - the attacker receives penalty P_i^{a}
  - Otherwise
    - defenders receive penalty P_i^{d}
    - the attacker receives reward R_i^{a}
- Expected utility of defenders and the attacker
- Goal
  - maximize the defenders' expected utility by adjusting defensive strategy

Mixed-Integer Linear Program Solution

- Stackelberg game
  - Defenders distribute resources
  - An attacker observes the distribution and attacks the target that maximizes his expected utility

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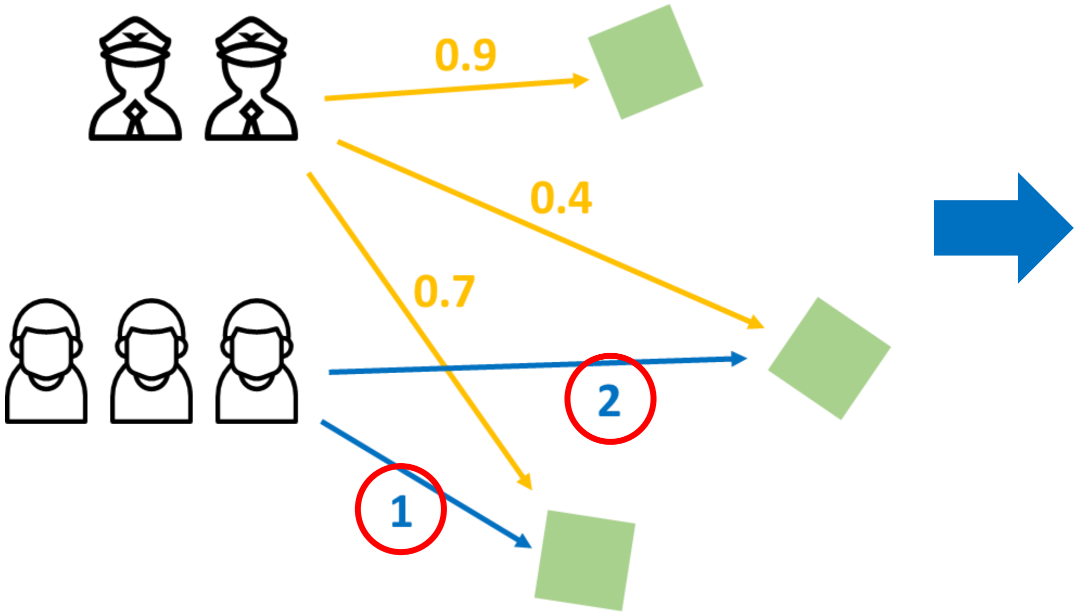

MILP

Mixed-Integer Linear Program Solution

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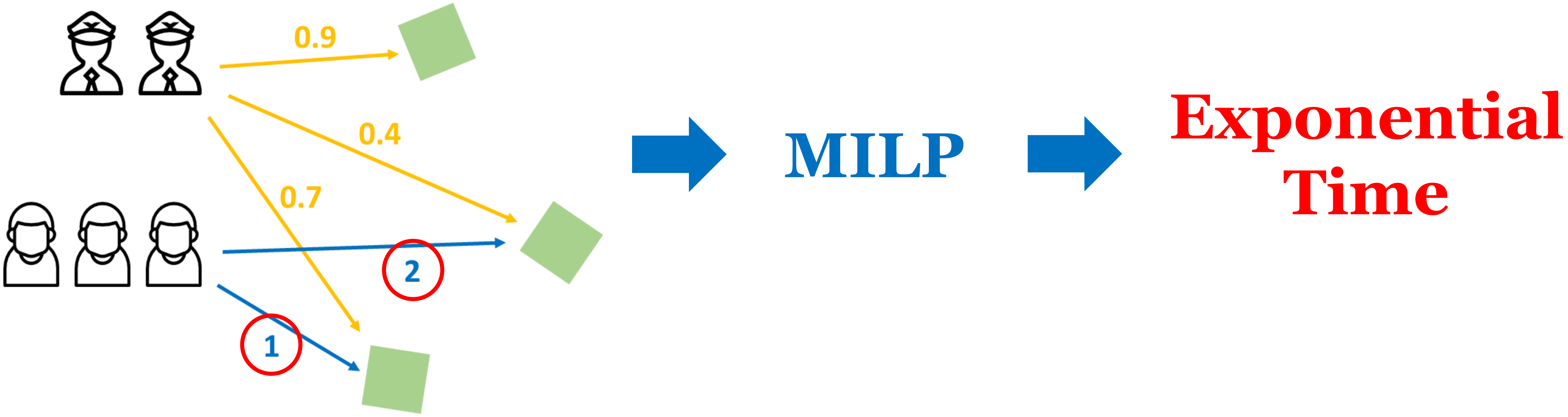
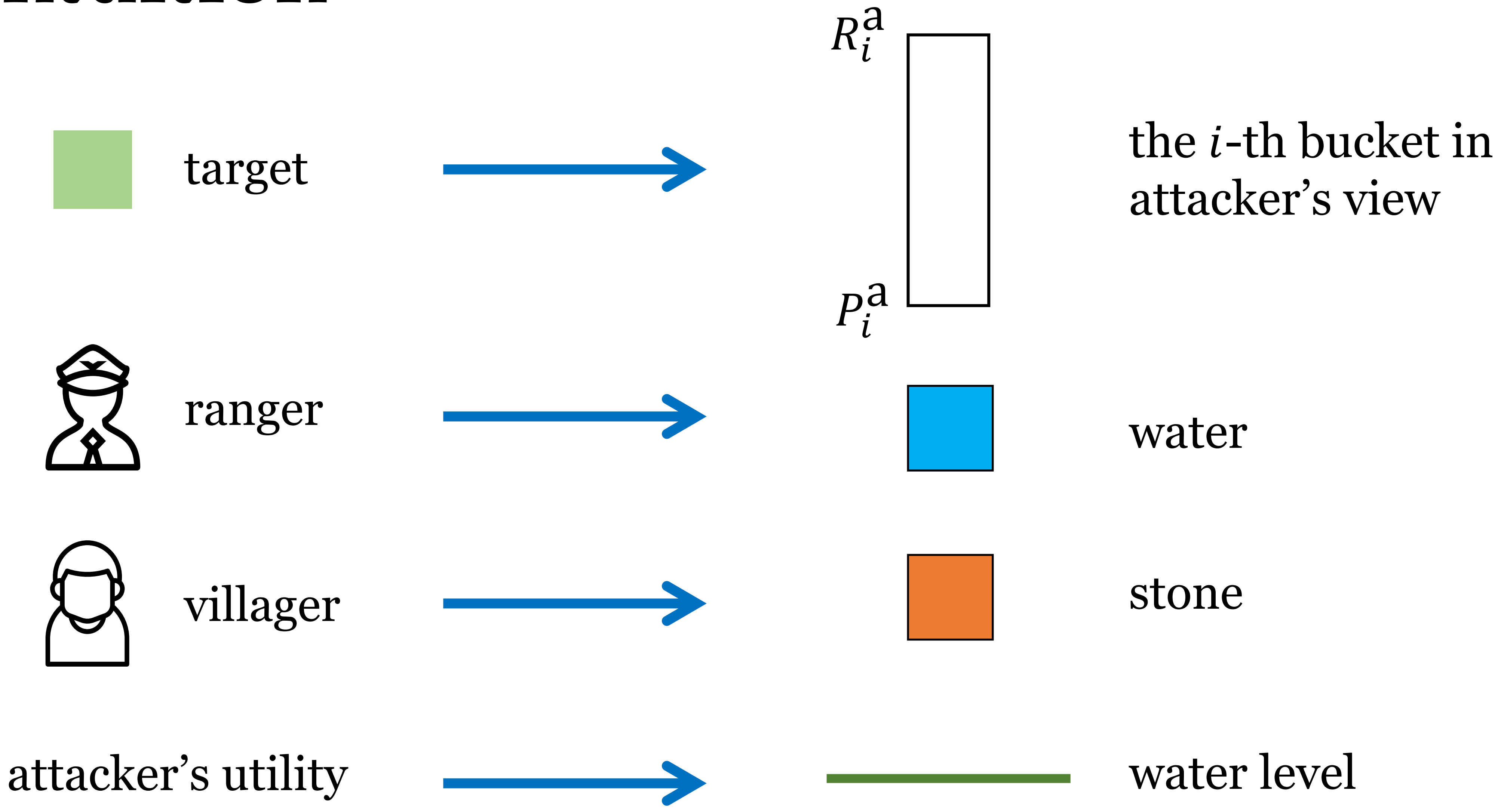
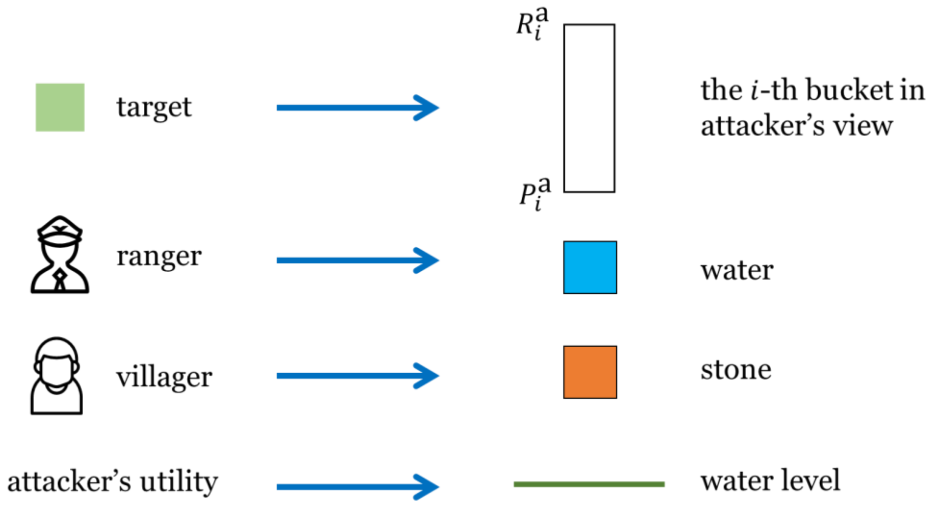


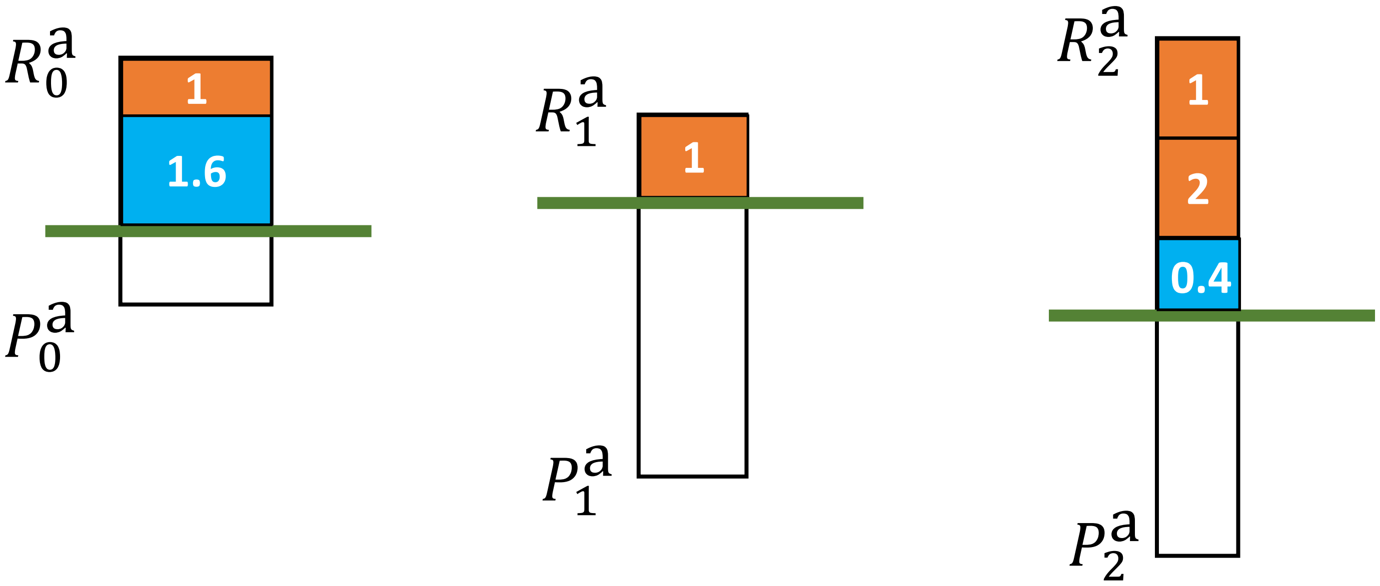
Intuition


R_i^{a}
P_i^{a}
target
the i-th bucket in attacker's view
ranger
water
villager
stone
attacker's utility
water level

Intuition



- Stone: thrown into the bucket as a whole
- Water: poured into the bucket at will
- Attacker attacks the bucket i^* with the highest water level
- Goal: Adjust resources to lower the water level of bucket i^*



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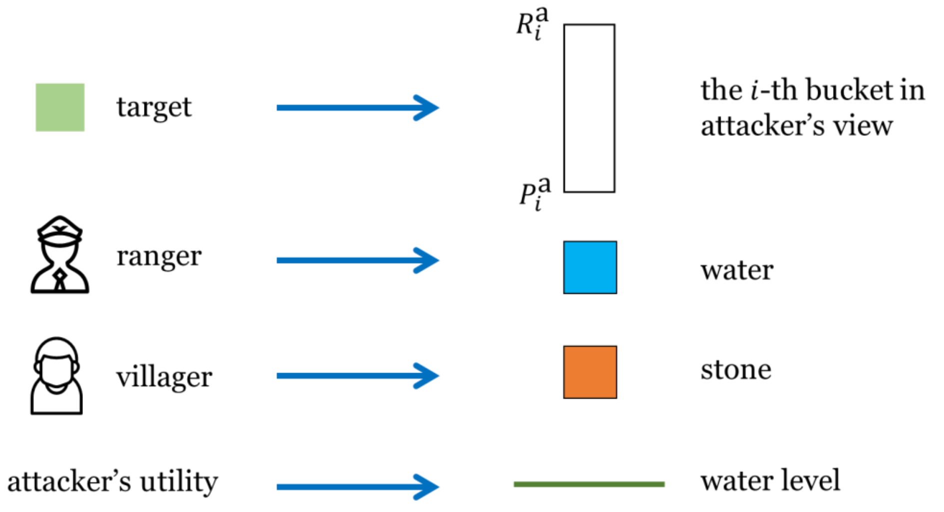

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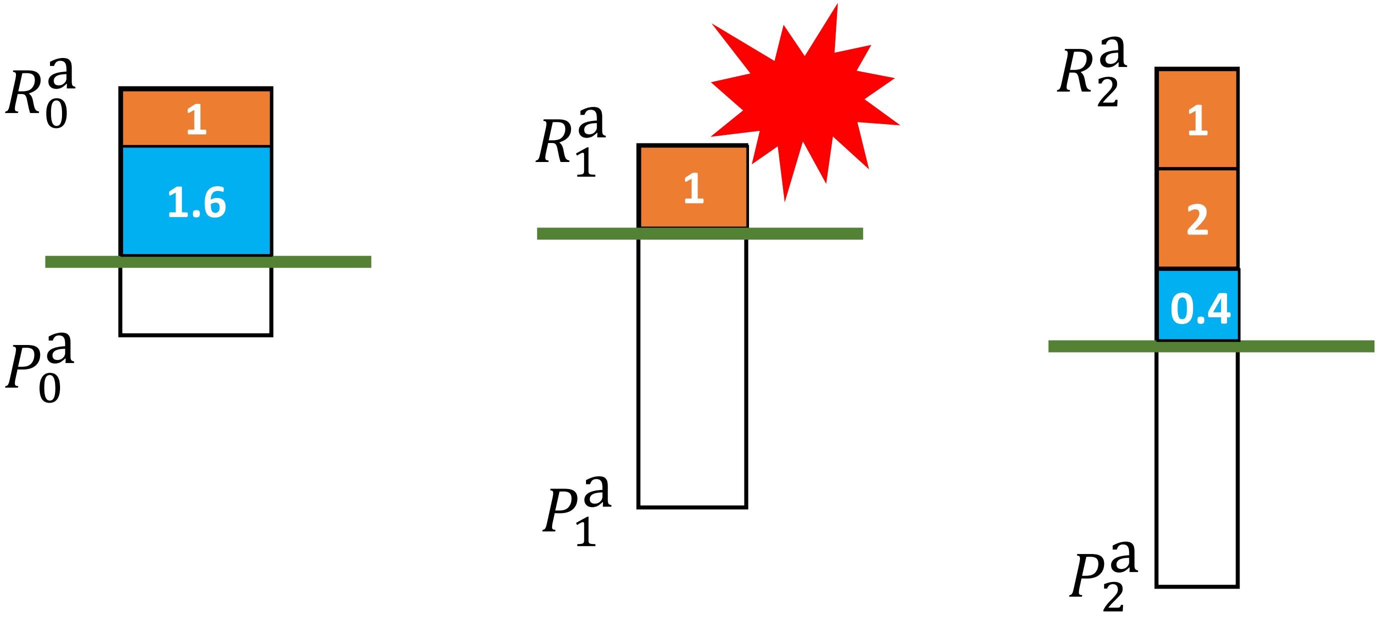
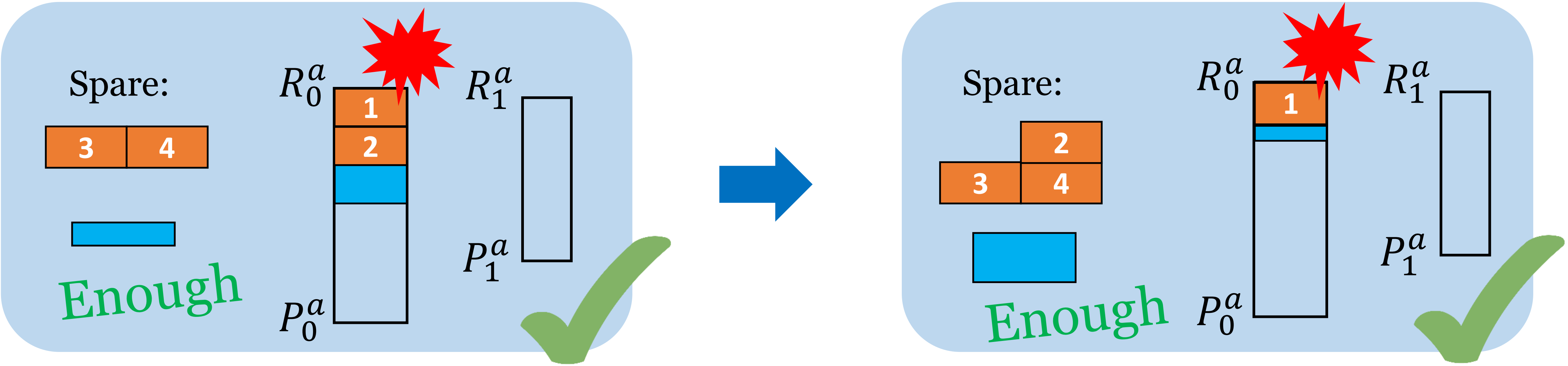


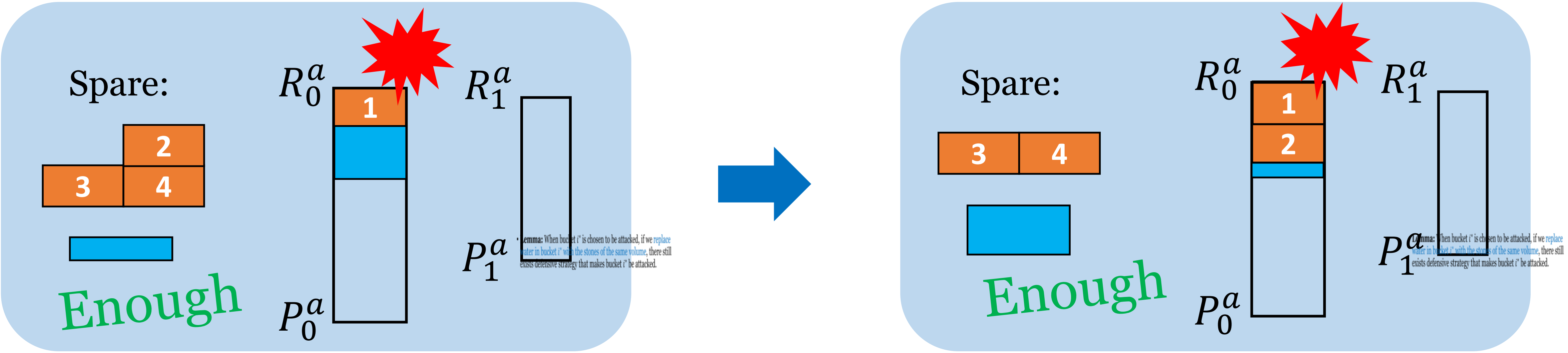
Monotonicity

- **Lemma:** When bucket i^* is chosen to be attacked, if we put fewer stones and less water in bucket i^*, there still exists defensive strategy that makes bucket i^* be attacked.



Monotonicity

- **Lemma:** When bucket i^* is chosen to be attacked, if we replace water in bucket i^* with the stones of the same volume, there still exists defensive strategy that makes bucket i^* be attacked.



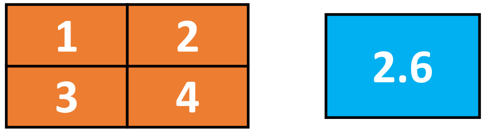
Two-Dimensional Binary Search

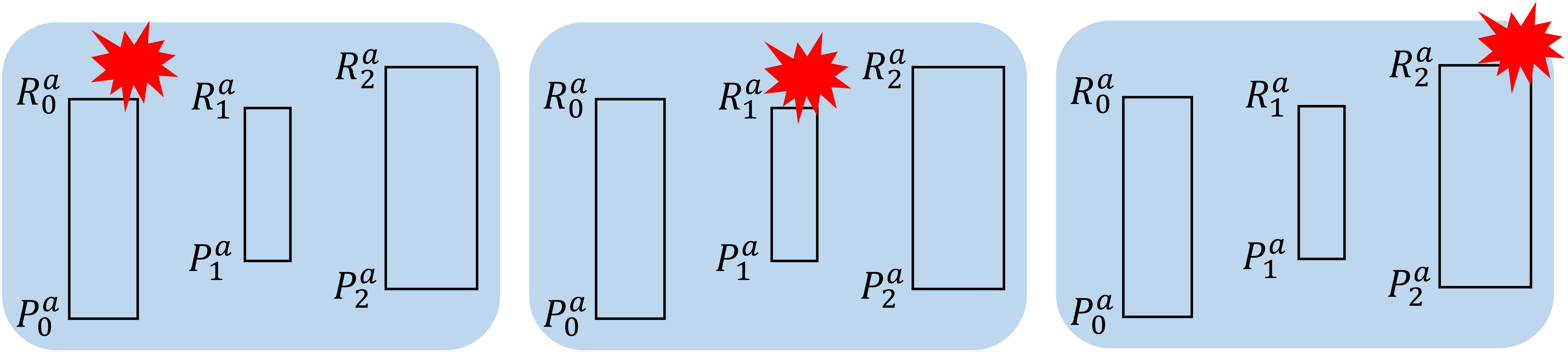
- Polynomial approximate algorithm
  - Accuracy: any desired ε
  - Complexity: $O(n^2 \log \frac{M}{\varepsilon})$
    - M is the maximum absolute reward or penalty

Two-Dimensional Binary Search

1. Iterate over all buckets as the attacked bucket i^*
   - As the one with the highest water level

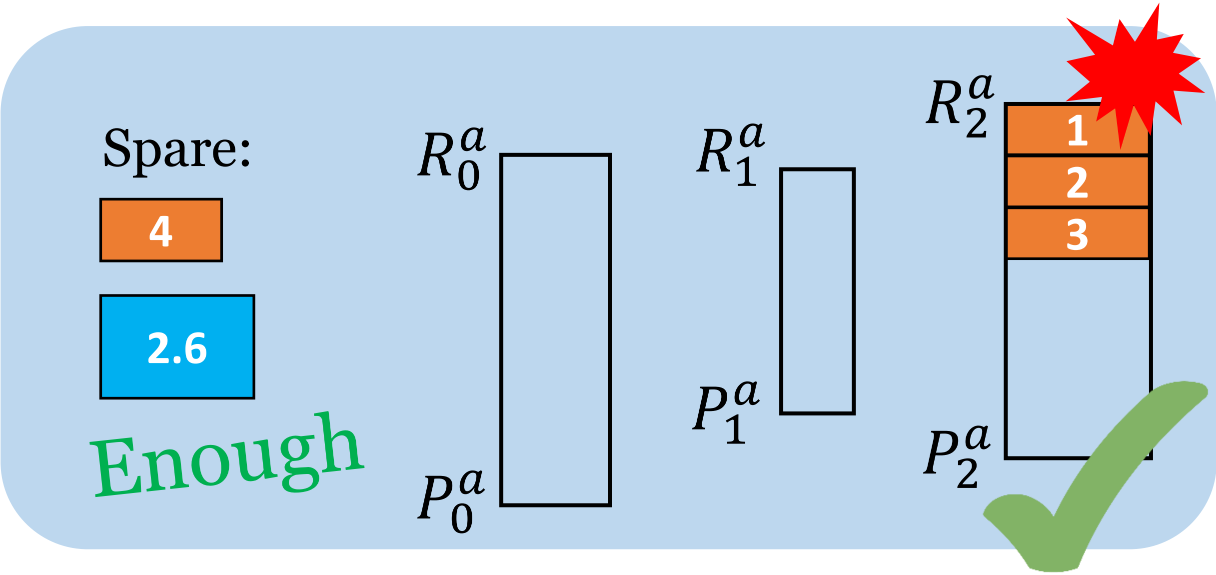
Resources:

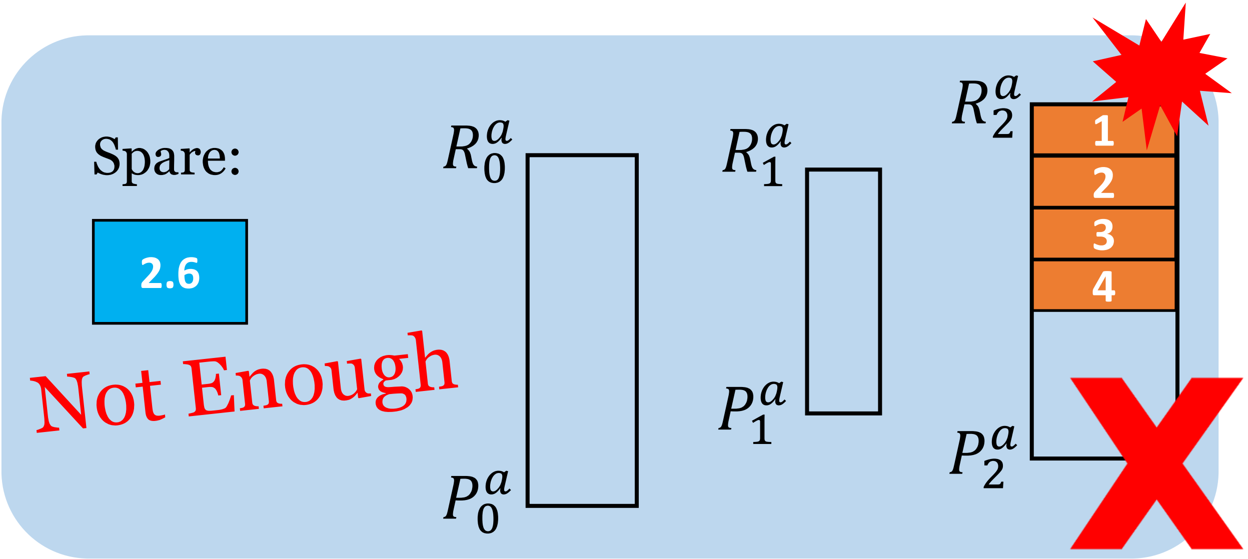




Two-Dimensional Binary Search

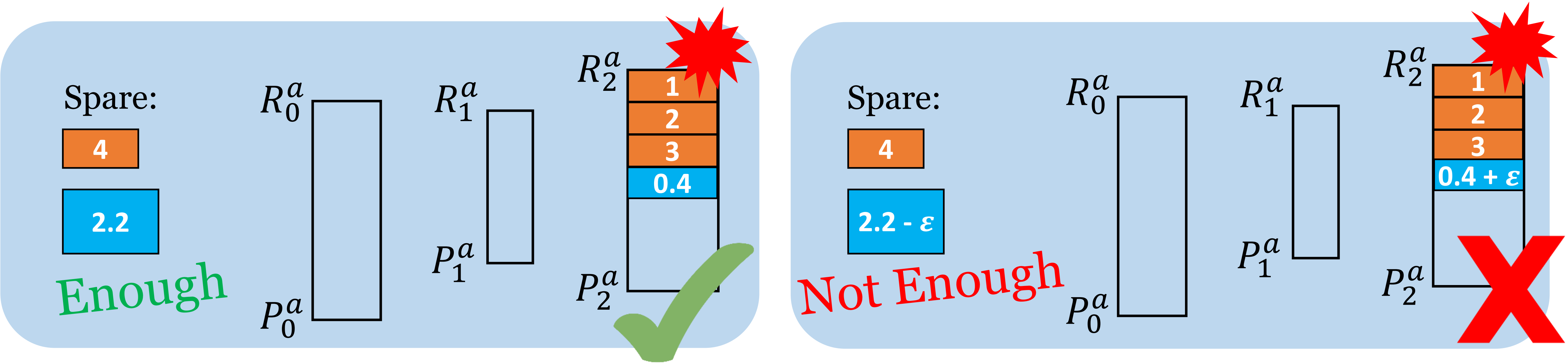
1. Iterate over all buckets as the attacked bucket i^*
2. Binary search on the max number of stones thrown into i^*
   - With enough spare resources for a defensive strategy to allow attacking bucket i^*





Two-Dimensional Binary Search

1. Iterate over all buckets as the attacked bucket i^*
2. Binary search on the max number of stones thrown into i^*
3. Binary search on the amount of water poured into i^*
   - To the desired accuracy ε
   - With enough spare resources for a defensive strategy to allow attacking bucket i^*



Two-Dimensional Binary Search

1. Iterate over all buckets as the attacked bucket i^*
   - As the one with the highest water level
2. Binary search on the max number of stones thrown into i^*
   - With enough spare resources for a defensive strategy to allow attacking bucket i^*
3. Binary search on the amount of water poured into i^*
   - To the desired accuracy ε
   - With enough spare resources for a defensive strategy to allow attacking bucket i^*

Complexity: $O(n^2 \log \frac{M}{\varepsilon})$

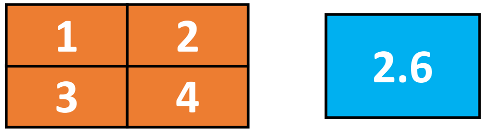
Hybrid Waterfilling

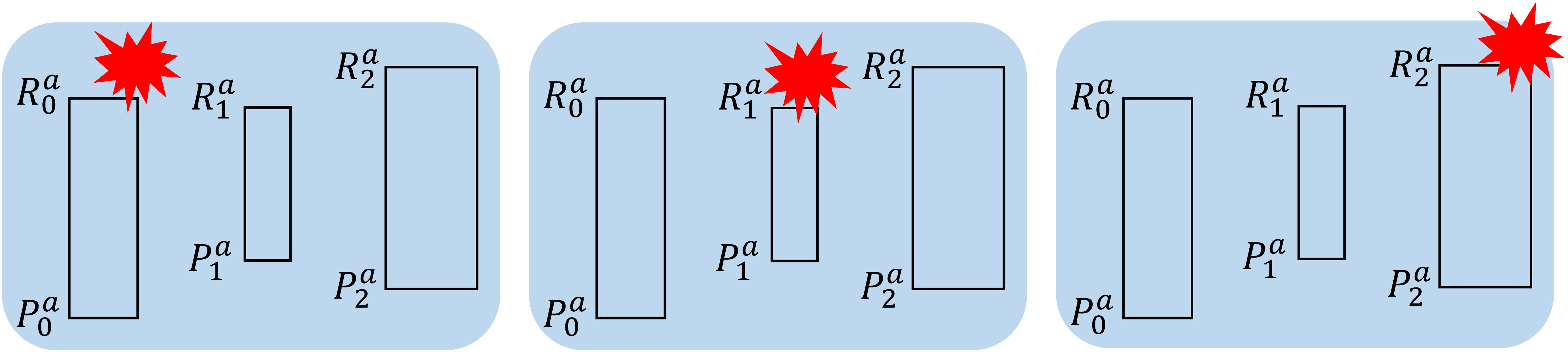
- Polynomial exact algorithm
  - Accuracy: precise
  - Complexity: $O(n^4 \log n)$

Hybrid Waterfilling

1. Iterate over all buckets as the attacked bucket i^*
    - As the one with the highest water level

Resources:





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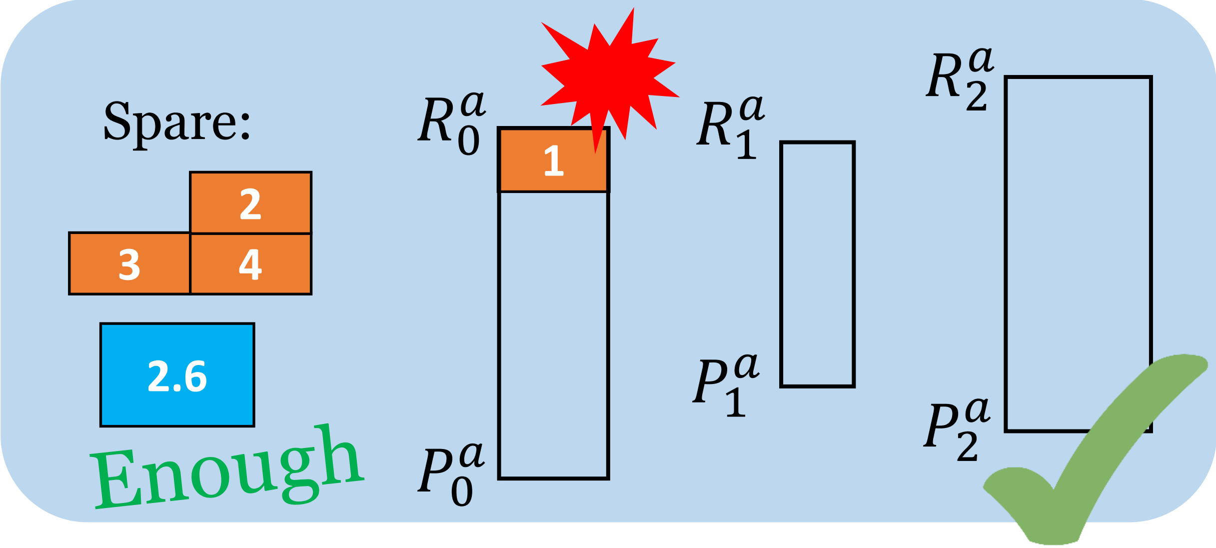
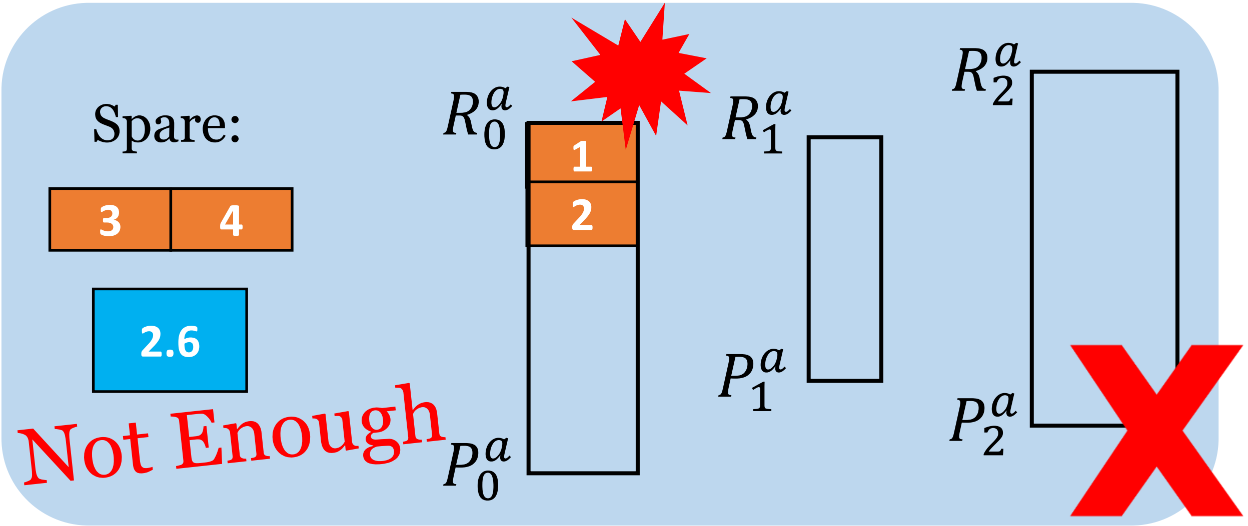
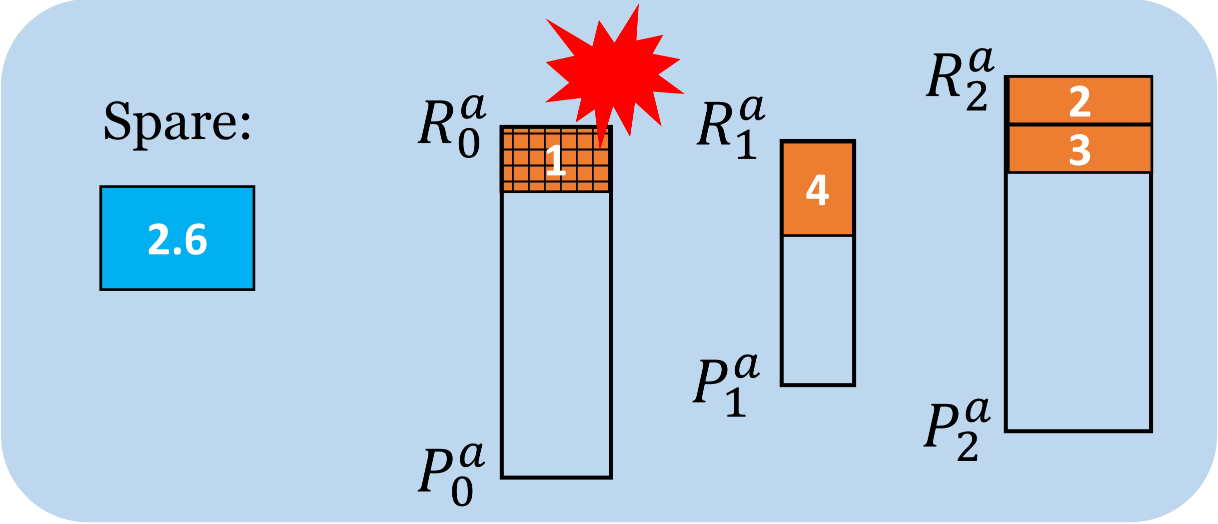




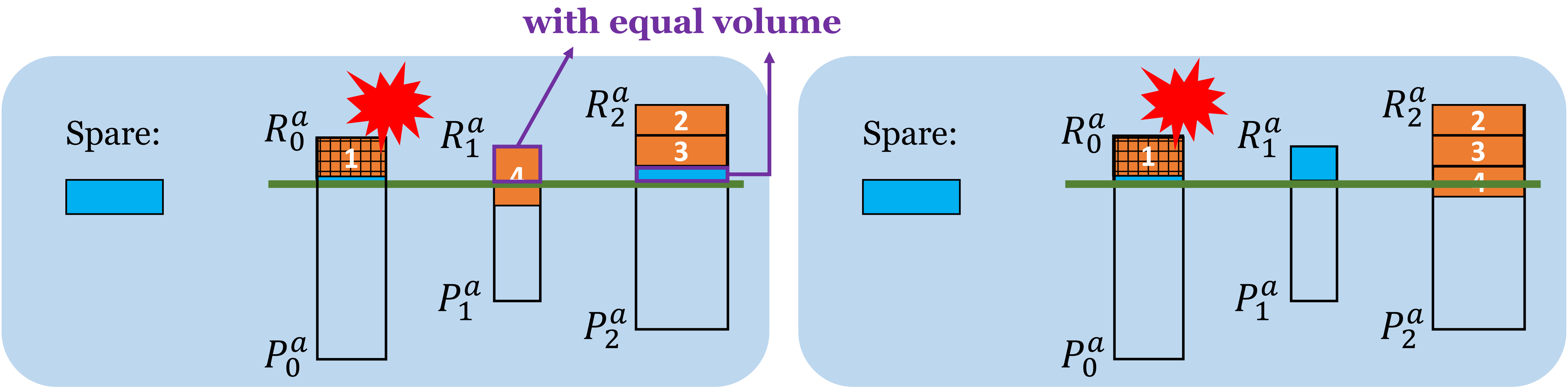
Hybrid Waterfilling

1. Iterate over all buckets as the attacked bucket i^*
2. Binary search on the max number of stones thrown into i^*
3. Greedy for spare stones
    - Throw into the bucket with the highest water level except bucket i^*



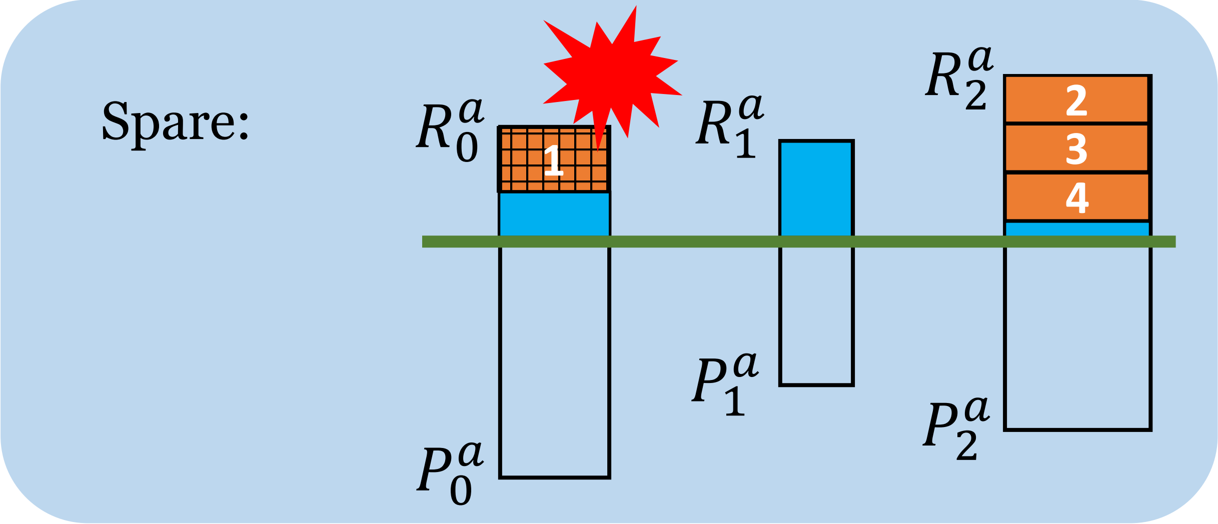
Hybrid Waterfilling

1. Iterate over all buckets as the attacked bucket i^*
2. Binary search on the max number of stones thrown into i^*
3. Greedy for spare stones
4. Waterfilling to a critical point and trigger a swap



Hybrid Waterfilling

1. Iterate over all buckets as the attacked bucket i^*
2. Binary search on the max number of stones thrown into i^*
3. Greedy for spare stones
4. Waterfilling to a critical point and trigger a swap
5. Finish Waterfilling



Hybrid Waterfilling

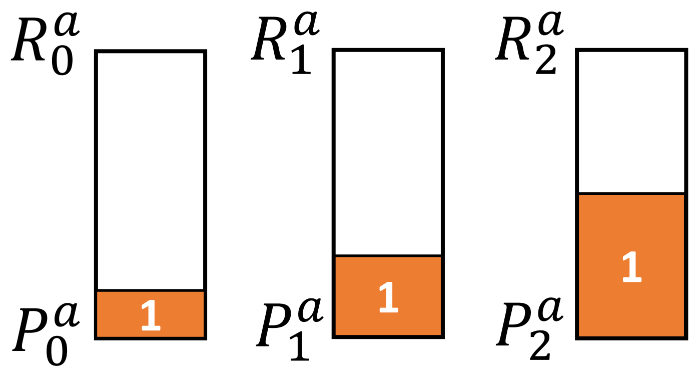
1. Iterate over all buckets as the attacked bucket i^*
   - As the one with the highest water level
2. Binary search on the max number of stones thrown into i^*
   - With enough spare resources for a defensive strategy to allow attacking bucket i^*
3. Greedy for spare stones
   - Throw into the bucket with the highest water level except bucket i^*
4. Waterfilling to a critical point and trigger a swap
   - With equal volume
5. Finish Waterfilling

Complexity: $O(n^4 \log n)$

Extensions for Practical Constraints

RACPP with Target-Specific Effectiveness

A stone has different volumes in each bucket



Adapted TDBS with unchanged complexity

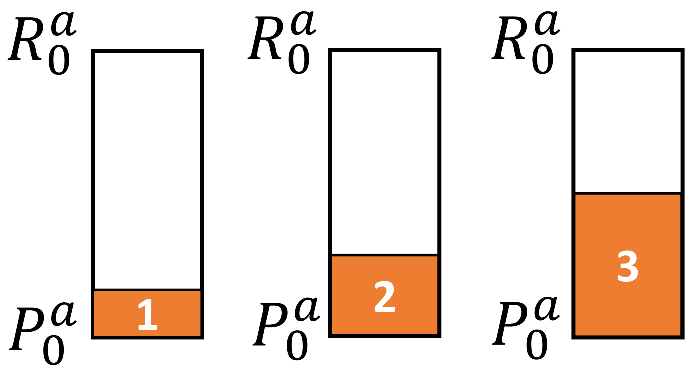
Complexity: $O(n^2 \log \frac{M}{\varepsilon})$

Extensions for Practical Constraints

RACPP with Villager-Specific Effectiveness

→

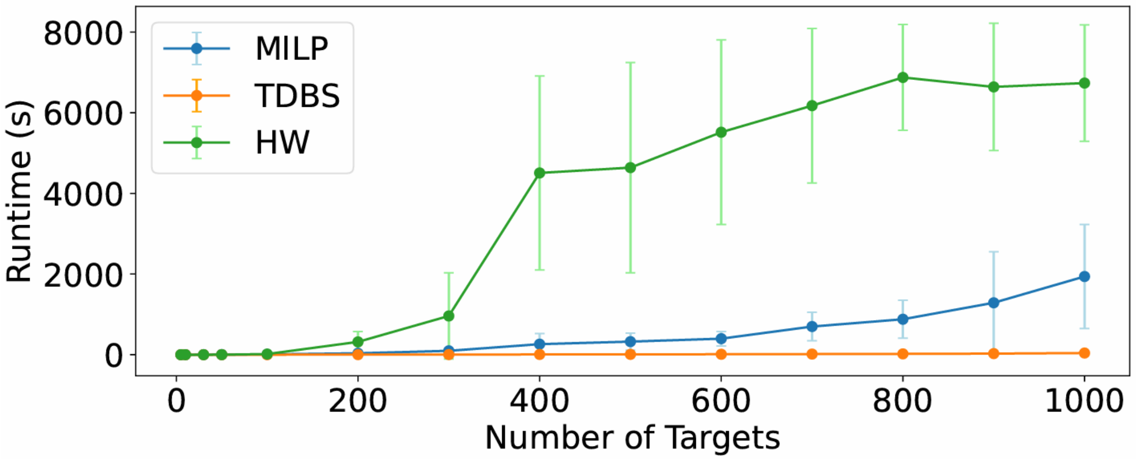
Stones have different volumes

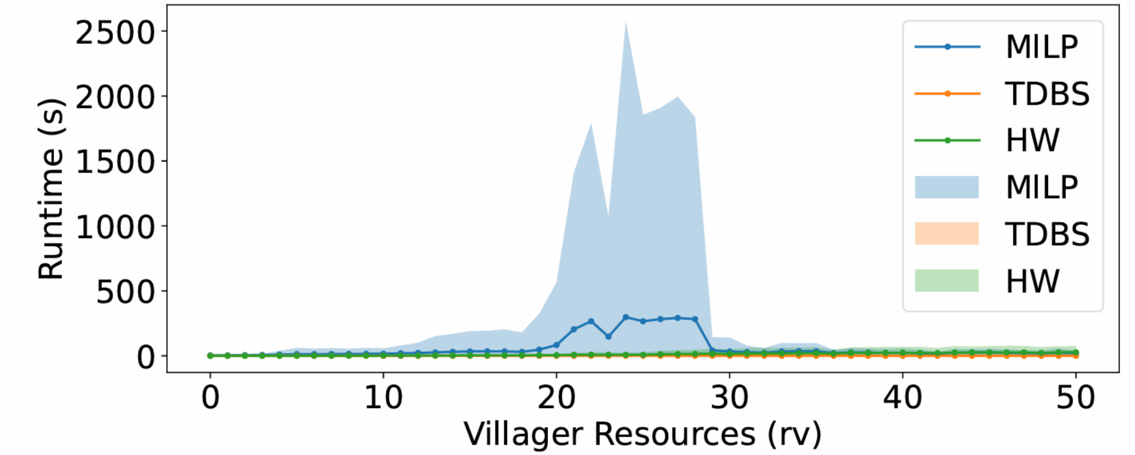


⇒

NP-Hard

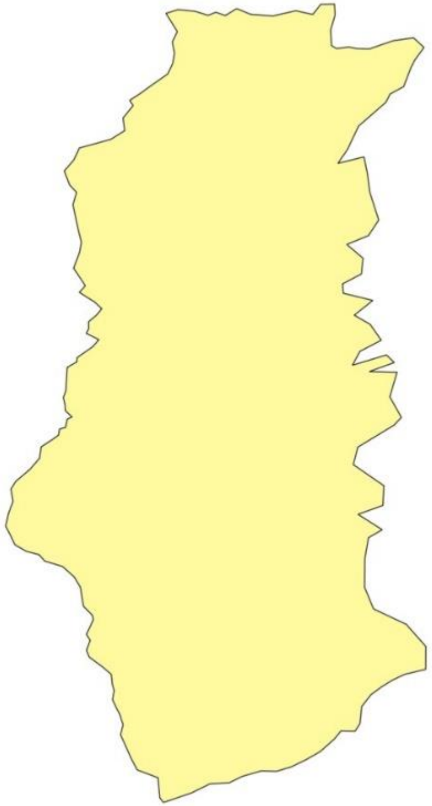
Experiments





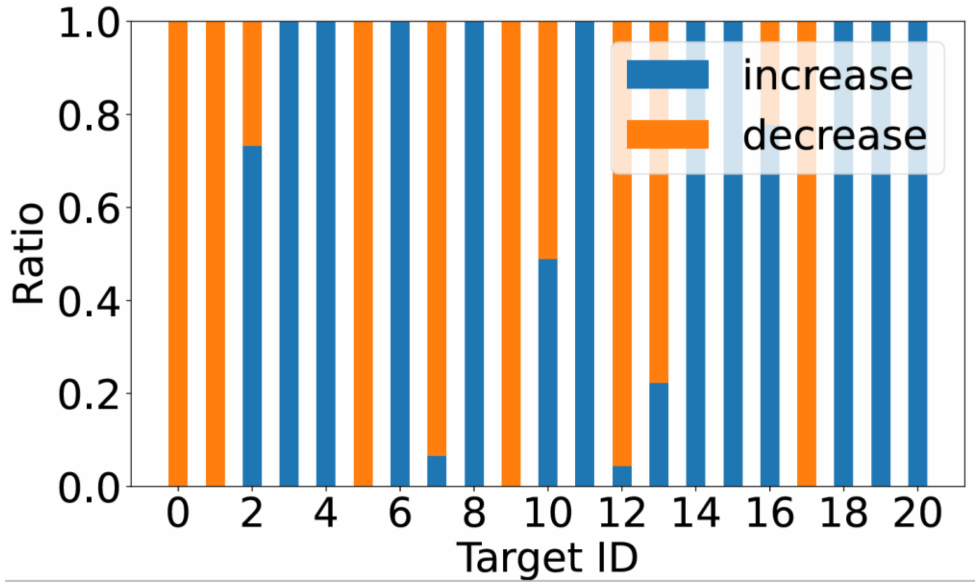
- TDBS
  - significantly faster
  - accurate enough for practical applications
- TDBS and HW
  - more stable

Case Study on Anti-poaching

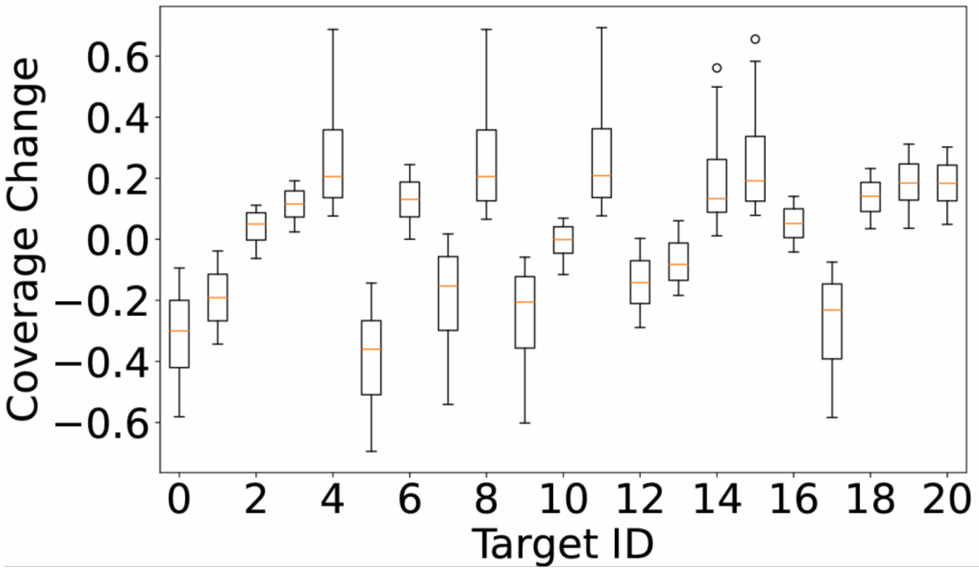


- A protected area in Northeast China
  - Home to the Manchurian tiger
  - 21 2km×2km regions
  - Defended by rangers and villagers

Case Study on Anti-poaching



Ratio of advice to increase or decrease resources on each target

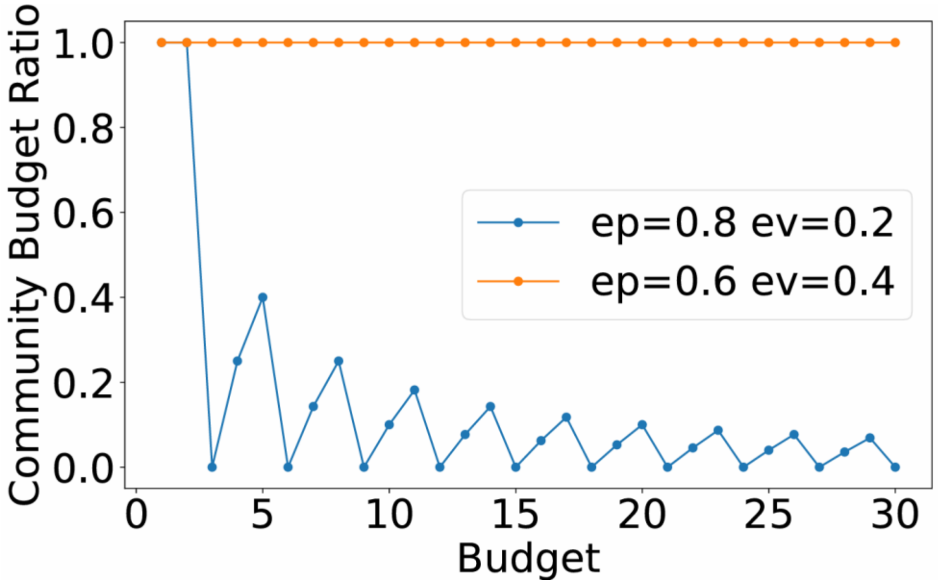


Distribution of coverage change on each target

Defenders' utility ↑ 25.9% To 152.6%

Average: 83.1%

Case Study on Anti-poaching



Cost ratio **V.S.** Effectiveness ratio

Preference for rangers or villagers

Our Contributions

- We propose a novel game-theoretic model for community-participated patrol

- We introduce two algorithms
  - A polynomial approximate algorithm: Two-Dimensional Binary Search
  - A polynomial exact algorithm: Hybrid Waterfilling

- We conduct a detailed case study
  - On a protected tiger habitat in Northeast China